STRESS AND DEFLECTION ANALYSIS OF REGULAR, TELESCOPING AND TIE ROD CYLINDERS

By

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NOMENCLATURE

A_b	bore area of the cylinder tube
A_b'	bore area of the cylinder minus rod cross sectional area
A_c	cross sectional area of the cylinder wall
A_t	total cross sectional area of the tie rods
e_c and e_r	eccentricities of loading at cylinder and rod supports, respectively
E_i	modulus of elasticity of the ith tube material
E_t	modulus of elasticity of tie rods material
f_c and f_r	friction coefficient times the radius of the support pin at the cylinder and rod supports, respectively
F_b^p and F_f^p	lateral force at the piston head backside and frontside metal-to-metal contact points, respectively
F_b^r and F_f^r	lateral force at the stuffing box inside and outside metal-to-metal contact points, respectively
F_{bot}	final force in bottom tie rods in deflected cylinder
F_c	final axial force on the cylinder wall
F_{cc}	final axial force on cap side cylinder part in an intermediately supported cylinder
F_{cr}	final axial force on head side cylinder part in an intermediately supported cylinder
F_i	force in tie rods equal to force on the cylinder wall, before pressurizing the cylinder
F_i^p	lateral force on the ith piston bearing
F_i^r	lateral force on the ith rod bearing
F_t	final force in the tie rods in straight pressurized cylinder
F_{top}	final force in top tie rods in deflected cylinder

I_i	moment of inertia of the ith tube
K_c and K_r	stiffnesses of the rotational springs at the cylinder and rod pin supports, respectively
K_i^p	stiffness of the ith piston bearing in compression
K_i^r	stiffness of the ith rod bearing in compression
ℓ_c	length of the modeled cylinder part
ℓ_i	distance of the ith step point from the cylinder support
ℓ_p	overhanging length of the cylinder part from the cylinder support
ℓ_r	length of the modeled rod part
L	distance between the supports
L_c	length of the cylinder tube
L_{cc}	overhanging length of cylinder tube in intermediately supported cylinders
L_{cp}	pressurized length of the cylinder during forward stroking
L'_{cp}	pressurized length of the cylinder during backward stroking
L_{cr}	length of the cylinder tube part within supports in intermediately supported cylinders
L_t	length of tie rods between the tie rod nuts
M	number of piston bearings and seals on the piston head
M_G	bending moment at the sliding connection
M_p	moment at the cylinder support due to overhanging cylinder part's self weight
M_t	tie rod moment on the cylinder part
N	number of rod bearings and seals in the stuffing box
p	fluid pressure on the cap side
p'	fluid pressure on the head side
p_s	separation pressure
P	axial compressive load on cylinder during a forward stroke

P'	axial tensile load on cylinder during a backward stroke
PCL	radial clearance between piston head and cylinder tube
R'_c and R'_r	lateral reactions due to self weights of the system at the cylinder and rod supports, respectively
RCL	radial clearance between rod and stuffing box
w_i	weight per unit length of the ith tube
W_i	total concentrated weight at the ith step point
δ_b^p	displacement of the piston head backside edge
δ_b^r	displacement of the stuffing box inside edge
δ_c	change in length of the cylinder tube due to pressurization of the cylinder
δ_f^p	displacement of the piston head frontside edge
δ_f^r	displacement of the stuffing box outside edge
δ_t	change in length of the tie rods due to pressurization of the cylinder
δ_{tm}	change in length of the tie rods due to bending of the cylinder
θ_c	slope of the cylinder at the cylinder support
θ_g	slope of the cylinder at the step point
θ_i	crookedness angle at the ith sliding connection
θ_r	slope of the rod at the rod support
μ_c	Poisson's ratio for the cylinder material

CHAPTER I

INTRODUCTION

Fluid power cylinders have found a wide application in practice in all branches of industry. The primary functions of fluid power cylinders in industrial application are to move or position loads or mechanisms. A cylinder will properly perform these functions only if the stresses and deflections to which it is subjected remain within tolerable limits. In addition to physical sizes, stroke and operating pressure, the design of a cylinder must be based on the same principles of stress analysis as any other structural member.

To date empirical formulae have been used for establishing loading limits. The factors of safety incorporated into such formulae are subjective in nature and have resulted generally in overly conservative ratings for static loading.

Historically, all attempts at developing structural analysis techniques for statically loaded cylinders have considered them as long columns, and buckling loads were calculated by using classical buckling theory. A regular cylinder was, at best, treated as a stepped column with constant crookedness angle at the sliding connection (1). Analyses for telescoping cylinders have been developed (2)(3) for computing the critical load by treating them as stepped column having a finite number of steps with rigid connections. As yet a bending analysis of tie rod cylinders has not been made.

Presented herein are the methods of analyses for regular, telescoping and tie rod cylinders which permit the determination of stress and deflection at any point in the system under any particular loading, and hence, permit the determination of the critical load for a cylinder assembly by iterating with different loads and comparing the maximum stresses and deflections with limiting values.

The analyses include the influences of: the crookedness angle at the sliding connection; the eccentricity of loading at both supports; the friction effects at both supports; self weights of the system; stop tube effects; and overhanging cylinder part effects in the case of internally mounted cylinders. The analyses apply to regular, telescoping, and tie rod cylinders with: pinned, fixed, or elastically restrained supports; solid rod or hollow rod with or without fluid pressure in it; any number of piston and rod bearings and seals; and any number of tie rods.

Three separate computer programs have been written for the analytical procedures developed for the three major types of cylinders, mainly to determine the critical load for the system and to determine the maximum stresses and deflections in the system at any operating pressure. The programs can be further used to make parametric studies and to develop design aids.

CHAPTER II

CYLINDERS--GENERAL

General information on fluid power cylinders is presented in this chapter. This general information on types of cylinders, parts of cylinders, cylinder sealing, and cylinder mounts, was obtained from several cylinder manufacturer's catalogs, design handbooks, and specifications.

Fluid power cylinders are linear actuators which are used in industrial applications to move or position loads or mechanisms. Cylinders can be categorized into two types on the basis of the kind of fluid used--"pneumatic," where air is the fluid; or "hydraulic," where oil is the fluid. The same design concepts are used for both types except that pneumatic cylinders are usually designed for much lower pressures.

The higher the fluid pressure which can be used in a cylinder, the more compact and more efficient the hydraulic system is likely to be. However, there is an upper limit at which the stresses in the material involved in accommodating the internal pressure start to outweigh the advantages to be gained. This is in the range of 5,000 to 6,000 psi (350-420 kg/cm^2), although higher pressures still may well be utilized in large cylinders for press work. Normally, however, 3,000 psi (210 kg/cm^2) is the maximum for normal working, and 2,000 psi (140 kg/cm^2) is a more usual maximum for industrial hydraulics.

In the case of pneumatic cylinders, the maximum pressure available from a compressed air supply is of the order of 90 to 100 psi (6.3 to

7.0 kg/cm^2). Compressed air is seldom produced and worked at higher pressures, except for specialized applications, because of the practical difficulties involved both in compressing and utilizing an essentially "elastic" fluid at high compression ratios.

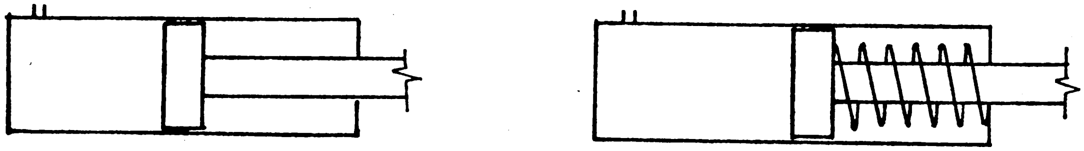
Some of the factors favoring pneumatics are: low initial cost; low operating costs; high reliability, high operating speeds; simplicity of control; operation in hazardous ambients; operation at high temperatures; and cleanliness of operation. Some of the factors favoring hydraulics are: high output forces; high rigidity of system; good synchronization possible; extremely high power amplification; working components self-lubricated by fluid; and low noise levels.

Types of Cylinders

Cylinders can be categorized into different groups in many ways. For example: depending on the type of fluid used--pneumatic cylinders and hydraulic cylinders; depending on whether the piston is acted on by fluid pressure on one side or both sides--single acting cylinders and double acting cylinders; depending on their structural shape and application--roundline series or regular cylinders, squareline cylinders or tie rod cylinders, telescoping cylinders, differential cylinders, multipiston cylinders, tandem and duplex cylinders, locking cylinders, rotating cylinders, etc. Brief descriptions of the most commonly used cylinders are given in the following sections.

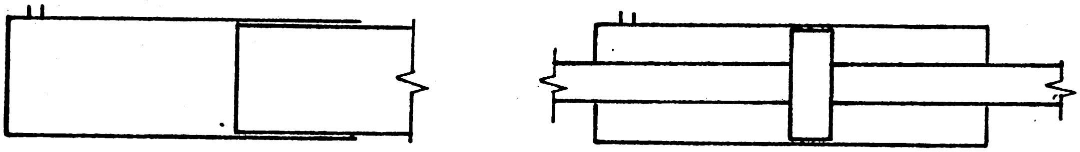
Single Acting Cylinders

These are the simplest type of cylinders (Figure 1). Fluid pressure is applied to one side only of the piston to produce the power



Force Return Type

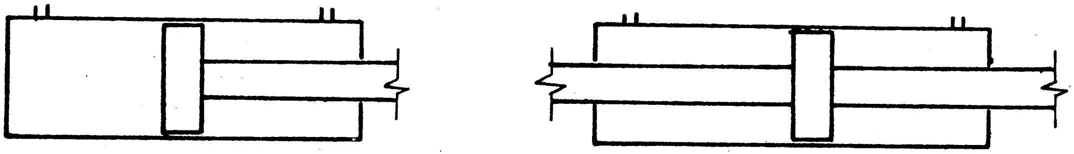
Spring Return Type



Ram Type

Through-Rod Type

Figure 1. Single Acting Cylinders



Single Rod Type

Double Rod Type

Figure 2. Double Acting Cylinders

stroke, or outward stroke. Return action on release of the fluid pressure is by means of a spring or some external force or by gravity, in the case of a vertical cylinder. Depending on the type of return action, these cylinders are generally classified as: gravity return cylinders, force return cylinders, and spring return cylinders. Two lesser used variations on the single acting cylinder are the plunger type (ram type), and the through-rod type. In the former case the conventional piston and rod assembly is replaced by a plunger, the action remaining the same. The through-rod configuration is unusual for a single acting cylinder, but may be employed where greater mechanical rigidity is required.

Double Acting Cylinders

This type of cylinder is by far the most common, and can be used in nearly all types of applications (Figure 2). With a double acting cylinder, ports are provided at each end so that the piston can be acted on by fluid pressure on both sides, alternately, to extend and retract the rod. The single rod configuration is the more usual, although the through-rod form may be adopted for greater rigidity or where exactly equal forces are required on both the outward and inward stroke.

Two other familiar types in single and double acting cylinders are: one piece cylinders and threaded head cylinders. One piece cylinders are compact and simple, but unlike other types, they cannot be repaired when damaged or worn. Threaded head cylinders can be disassembled for repair by unthreading either or both ends from the cylinder body.

Tie Rod Cylinders

The oldest and most common type made is typically used in industrial jobs (Figure 3). The cylinder body is held together by four or more tie rods that extend the full length of the body and pass through the end caps or mounting plate. This type performs any of the functions that the above two types perform.

Telescoping Cylinders

This type of cylinder, also known as a co-axial cylinder, is often used where a relatively long stroke is required in relation to the retracted length of the cylinder (Figure 4). These are manufactured as either single acting or double acting. The disadvantages with this type of cylinder are that the operating speeds, both when extending and retracting, vary over the total stroke. Force output is highest at the beginning, when full piston area is used, and lowest at the end of the stroke, when only the area of the final stage can be used to transmit force.

Differential Cylinders

The differential cylinder is used where differential outputs are required. Figure 5 shows a three volume, double acting differential cylinder. There are three modes of operation--inward and outward stroking of the piston and main hollow rod unit, and independent extension via pressurization of the third volume. The same principles can be applied to give a larger number of modes of operation.

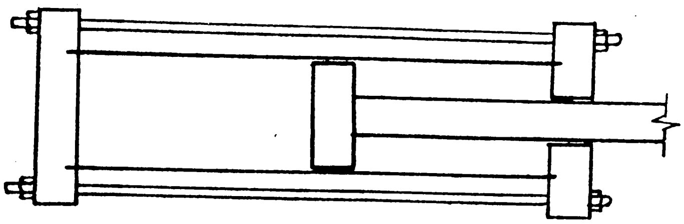


Figure 3. Tie Rod Cylinder

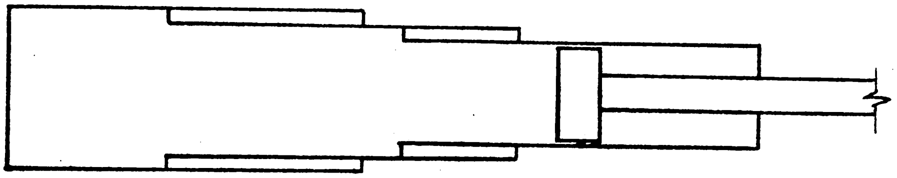


Figure 4. Telescoping Cylinder

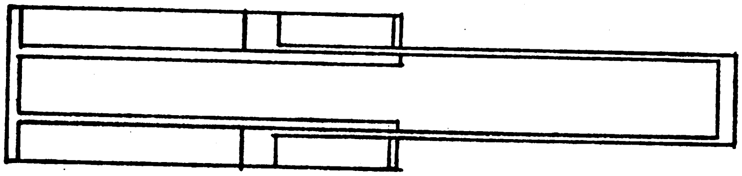


Figure 5. Differential Cylinder

Tandem and Duplex Cylinders

Tandem cylinders comprise single or double acting cylinders mounted in line in a common construction. There are numerous possible arrangements, capable of providing separate movements, and because of this, tandem cylinders are sometimes called multi-position cylinders. The simplest and most common type is a two cylinder combination giving a three position movement (Figure 6). In the case of duplex cylinders the cylinders are physically separated, but their pistons are mounted on a common rod (Figure 7).

Multi-Piston Cylinders

Multi-piston cylinders provide specialized motion by moving two or more pistons simultaneously. The positional cylinder shown (Figure 8) provides three rod positions: one step, two steps, or full retract.

Parts of Cylinders

Figures 9, 10 and 11 show all the important parts of regular, telescoping and tie rod cylinders, respectively. Descriptions of the major components are given in the following paragraphs.

Cylinder Tube

The cylinder tube is usually hard drawn tubing, although cast tubes and welded tubes are also in use. Common materials used in medium duty and heavy duty cylinders are hard drawn brass or steel tubes, aluminum, brass, bronze, iron or steel castings, or welded steel tubes. A high bore finish and excellent geometric and material properties increase the durability and efficiency of the cylinder and increase the life of

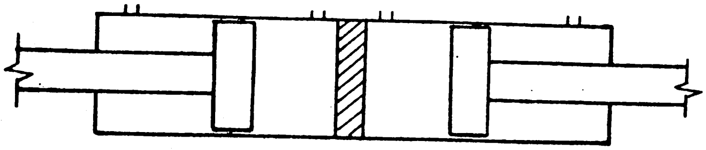


Figure 6. Tandem Cylinder

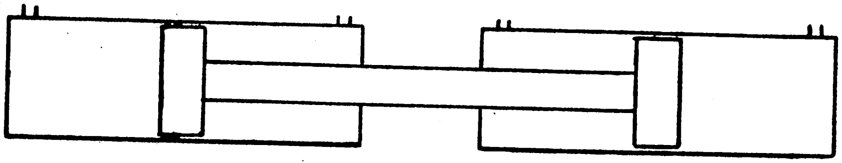


Figure 7. Duplex Cylinder

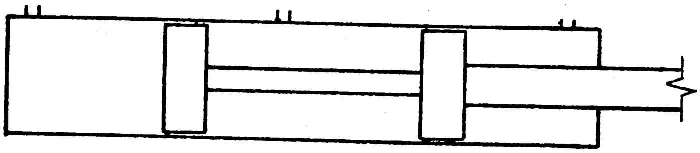
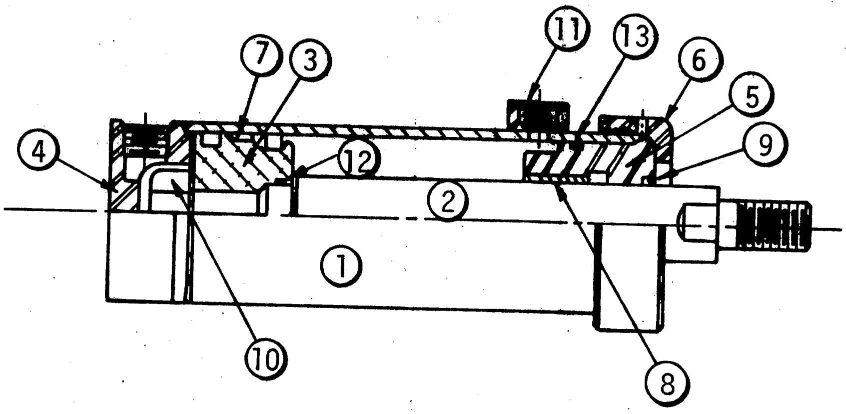


Figure 8. Multipiston Cylinder



① Tube

② Rod

③ Piston

④ Cap end

⑤ Head

⑥ Head retaining design

⑦ Piston bearings and seals

⑧ Rod bearings and seals

⑨ Rod scraper and/or wiper

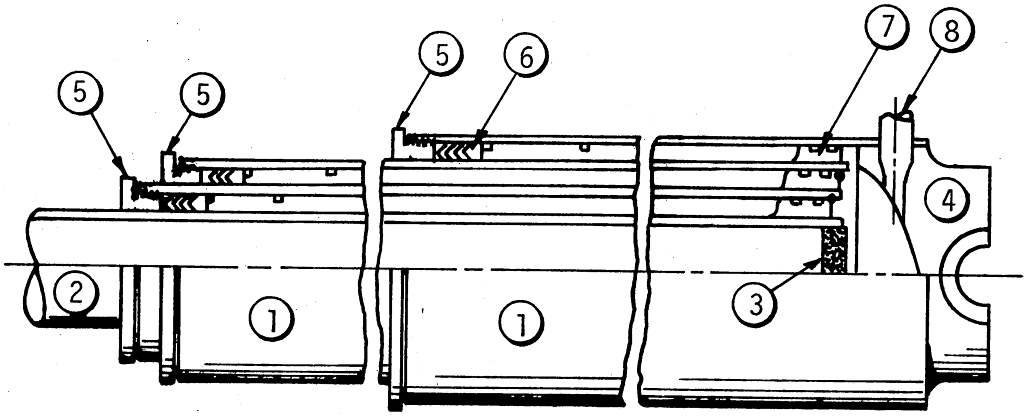
⑩ Piston nut

⑪ Ports

⑫ Piston seal "O" ring

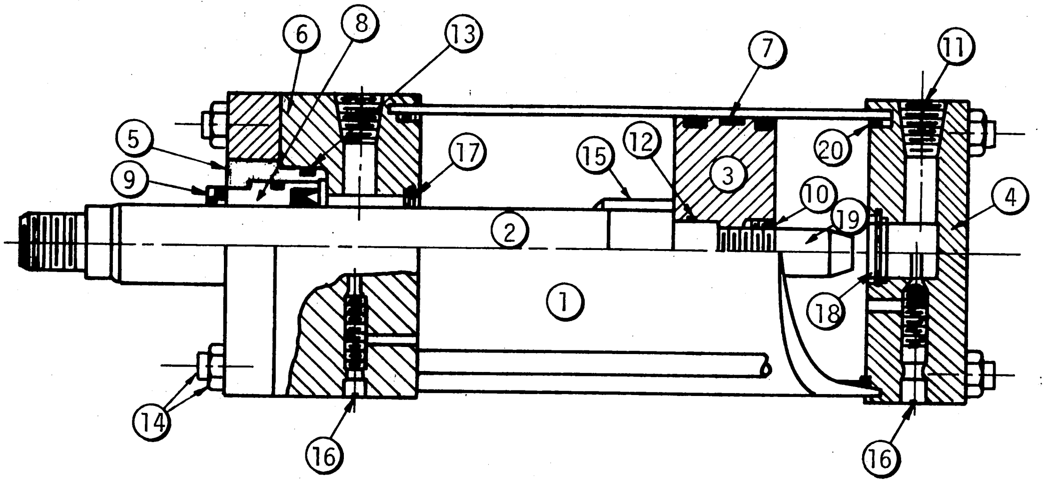
⑬ Rod bearing "O" ring

Figure 9. Parts of a Regular Cylinder



① Tubes
② Rod (or tube)
③ Piston (just a metal cap)
④ Cap end
⑤ Gland nuts (act as bearings)
⑥ V-rings (seals)
⑦ Bearings and seals
⑧ Port

Figure 10. Parts of a Telescoping Cylinder



① Tube

② Rod

③ Piston

④ Cap end

⑤ Rod bearing cartridge

⑥ Head

⑦ Piston bearings and seals

⑧ Rod bearings and seals

⑨ Rod scraper and/or wiper

⑩ Pilot fitting or self-locking nut

⑪ Ports

⑫ Piston seal "0" ring

⑬ Rod bearing "0" ring

⑭ Tie rod and nuts

⑮ Cushion sleeve of stop tube in long cylinders

⑯ Needle valve or ball check valve

⑰ Head cushion

⑱ Cap cushion

⑲ Cushion spear

⑳ Tube seals

Figure 11. Parts of a Tie Rod Cylinder

bearings and seals. A honed finish, which is common in medium to high pressure cylinders, is capable of producing a surface finish of 10-15 microinches (400-600 microns). The bore surface may be protected by nickel or chromium plating.

Piston Rods

Piston rods are normally of hardened steel, ground and polished, or chrome plated and polished. A very smooth rod finish is desirable as this reduces wear on the rod bearings and seals. Since the diameter of the rod can be relatively large, a hollow rod may be preferred in some cases. Wiper seals only or wiper seals together with metal scrapers are generally used to provide protection against dirt or solid contaminants clinging to the rod surface being drawn back into the rod bearing.

Piston

The piston is generally constructed of cast iron or high grade alloy iron or steel, but light weight cylinders may use heat treated aluminum alloy. The piston is usually of one-piece construction, but may be of two-piece or three-piece construction for certain types of seals. The piston may be attached to the rod by a nut or nuts, threaded in place on the end of the rod, or welded to the rod.

End Covers

Cap and head ends are usually made of aluminum stock, brass stock, bronze stock, or aluminum, brass, iron or steel castings. They do not present any particular problem in design or material construction, since no limitation is imposed on their thicknesses. The main problem is the method of fastening them in place to provide a tight, high pressure seal. Popular types of covers are threaded, welding, or shear bar types (full 360° internal locking key type), and finally tie rod construction. Probably the most positive fitting of all for high pressure operation, is tie rod construction. The end covers are usually square in shape, with holes drilled in each corner through which high tensile steel tie rods are fitted and bolted. The cover can seal on a gasket, or be plug fitted to accommodate an O-ring seal.

Stop Tube

The function of a stop tube (Figure 11) is to limit the minimum distance between the piston and rod bearing when the piston rod is in its fully extended position. This increase in spacing serves to reduce bearing loads and, at the same time, to increase the structural rigidity of the assembly to prevent excessive deflection and jack-knifing.

Rod Bearing Cartridge

The externally removable cartridge (Figure 11) is a steel shell containing a floating metal rod scraper, rod bearing, multiple vee chevron packings with a male adapter, and all spring loaded. In case of wear or damage of bearings and packings, the cartridge can be easily threaded out and replaced with a new or rebuilt cartridge.

Cylinder Sealing

Hydraulic seals are used in many different operating conditions. The ideal would, of course, be one type of seal for all pressures, temperatures, surfaces, and fluids. The ranges of use of most types are, however, very limited. For this reason the differences between the various types of seals are great. In the following paragraphs a summary of different types of seals is presented.

All seals can be described as falling into three basic categories:

1. Positive interference seals--which are designed to be larger than the seal housing, such that they have built-in interference which ensures an immediate seal at low pressures.

2. Pressure energized seals--which require a housing which permits rapid access of fluid pressure to the sealing lips to ensure successful operation. These have a low friction value at low pressures while friction values at high pressures may be higher than with positive interference seals.

3. Housing preloaded seals--which differ from positive interference seals in that they need to have light tension applied endwise to effect the initial sealing. As pressure increases, the seal lip load becomes greater against the static and dynamic faces, as with other seals.

Seals are also classified as dynamic seals and static seals. Dynamic seals between a moving and a static surface are used on the rim of the piston and inside the rod opening in the cylinder head. These are also known as packings. The most common types of dynamic seals are lip seals, U-seals, and V-rings, often stacked together into a chevron configuration. Static seals are used at many points between two static surfaces, for example, piston to rod, cylinder to end cap, cylinder to head, etc. O-rings are the most common type of static seals.

Lip seals which include flange, cup, U-cup, U-ring, and V-ring are made of impregnated leather or synthetic rubber, with or without fabric reinforcement. The most common fabrics are cotton duck, asbestos, and nylon. V-rings are installed in sets, each set consisting of a number of V-rings and male and female adapter rings. The female adapter supports the entire set when the set is under pressure and the male adapter acts as a guide and spacer. Both types of adapters are usually made from metal, hard homogeneous rubber, leather, phenolics, or fabric reinforced rubber.

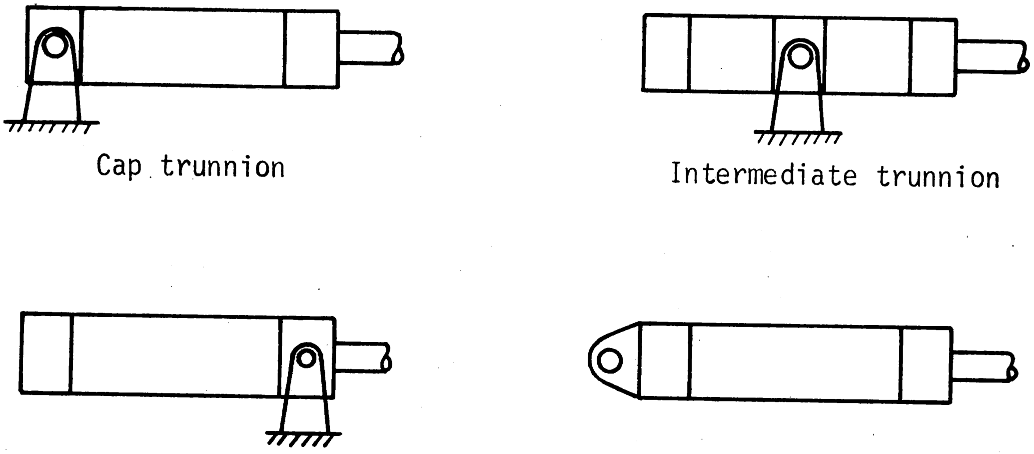
Squeeze type seals include D-rings, delta rings, T-rings, square-rings, X-rings, and O-rings. O-rings used as rod seals or piston seals, must be used in conjunction with backup rings. The main function of a backup ring is to reduce the clearance gap around a rod or piston so that extrusion of the O-ring is prevented. Backup rings are usually made of thin metal, bakelite, leather, or teflon.

Piston seals and rod seals are dynamic seals. Prevention of leakage is their main purpose. On the other hand, low static and dynamic friction is important so that maximum cylinder power and smooth piston movement can be obtained. They must be long wearing and tough. They must have resistance to rolling, extrusion, and have good shape retention.

Cylinder Mounts

A wide variety of mounts are available for pneumatic and hydraulic cylinders. Each type of mount has its own specific application. They can be grouped broadly as "floating" or "rigid" mounts with numerous variations on individual attachments.

A floating mount anchors the cylinder at one point only with freedom to move in one plane. The common forms of floating mounts are Cap, Intermediate or Head trunnion and Clevis mounts (Figure 12 (a)). These are also referred to as pivoted centerline mountings. For fully



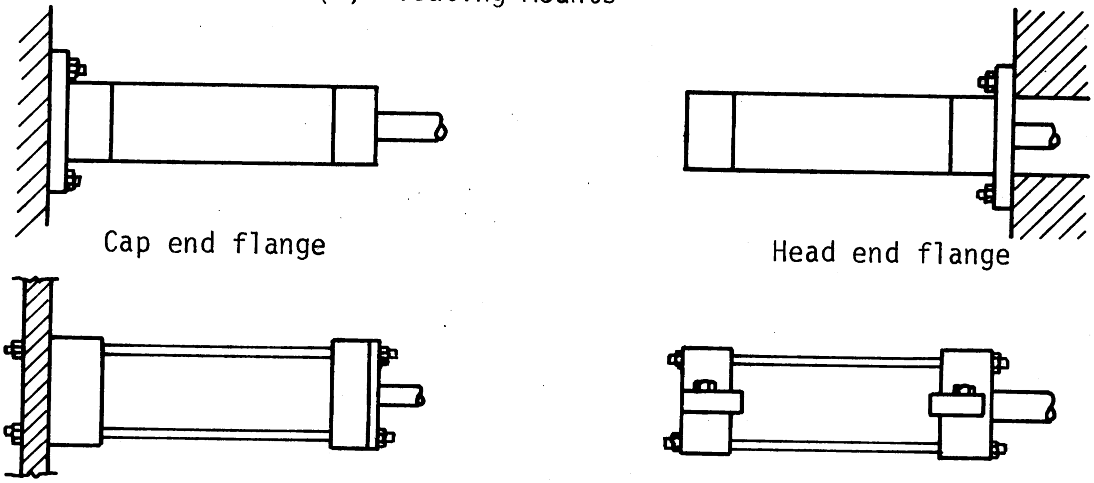
Cap trunnion

Intermediate trunnion

Head trunnion

Clevis

(a) Floating Mounts



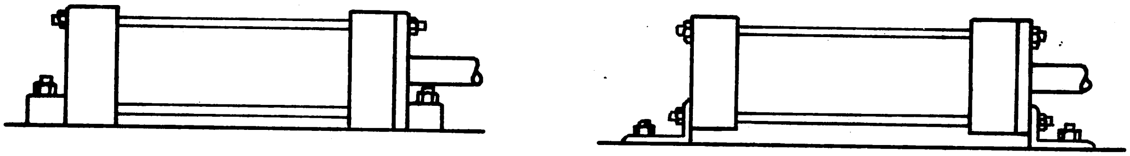
Cap end flange

Head end flange

Tie rod

Centerline lugs

(b) Fixed Centerline Mounts



Side end lug

Side end angle

(c) Fixed Noncenterline Mounts

Figure 12. Common Types of Cylinder Mounts

floating mounting, ball and socket or universal joint type mounts fitted to the rear end cover, can be used.

Rigid mounts support the cylinder rigidly at the point of support and may be single or double mounts. These can be sub-divided into fixed centerline mountings and fixed noncenterline mountings. Some forms of fixed centerline mounts are--cap and flange, head and flange, tie rod mount, and centerline lugs (Figure 12 (b)). Some forms or fixed non-centerline mounts (foot mounts) are--side end lug, side end angle, integral key, and flush (Figure 12 (c)). All of the above may be used in combination, for example: flange and foot.

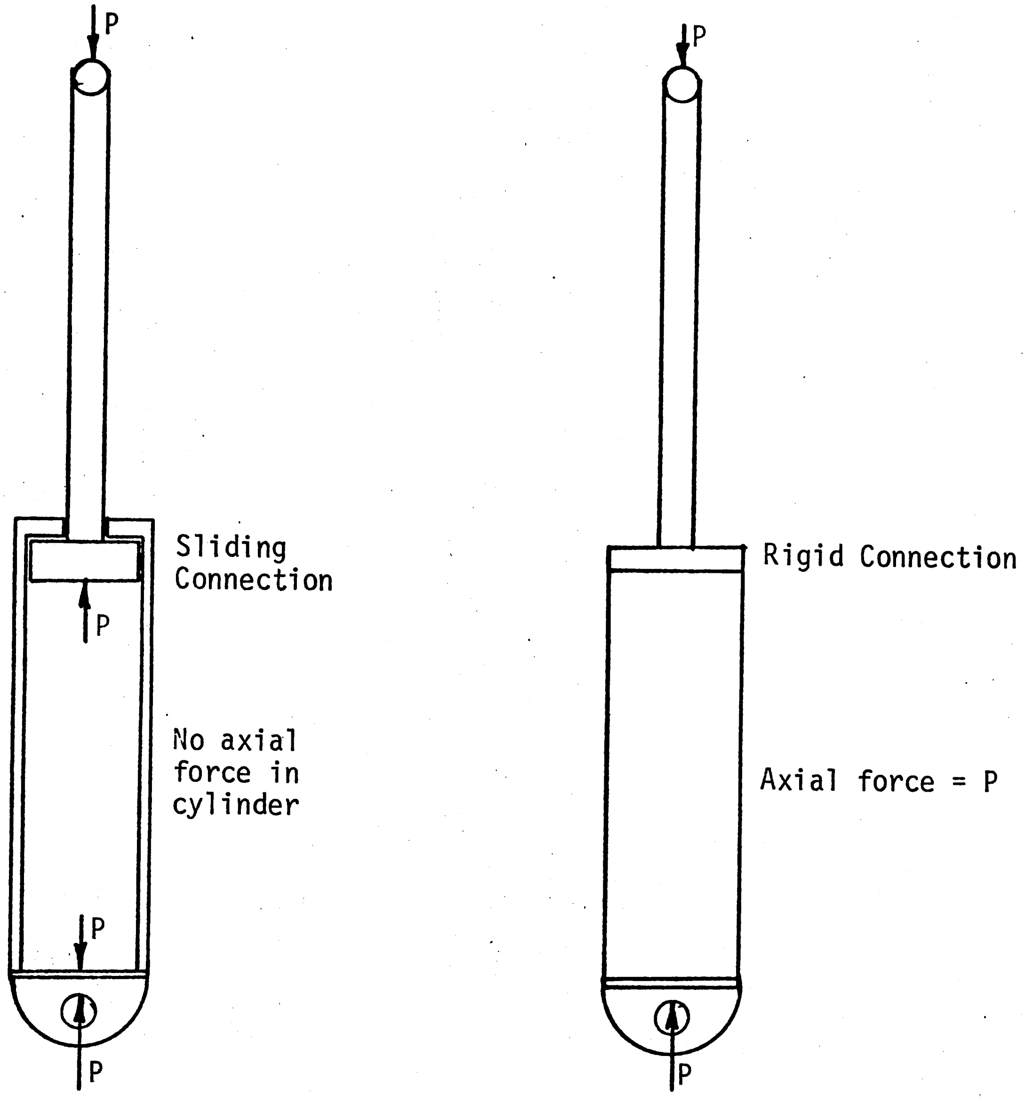
CHAPTER III

REVIEW AND DISCUSSION OF EARLIER ANALYSES

Early analytical investigations of cylinders use Euler's buckling analysis for columns. Initially, only the rod portion was analyzed as an axially loaded, slender column (1). For short and intermediate length columns, numerous empirical formulas, each with certain limitations, were developed.

In the slender column analysis of the rod portion, the cylinder was considered as a sealed tube with internal fluid pressure. Because the cylinder is usually much stiffer than the rod and it was misinterpreted that the cylinder would not buckle, only the rod portion was considered in the analysis. However, tubes sealed at both ends will have a stabilizing axial load in the wall due to internal pressure that is exactly equal to the destabilizing compression load carried by the fluid. In cylinders one end is sealed rigidly and the other end is sealed by means of a sliding connection. Due to the presence of the sliding connection there will not be stabilizing axial load in the wall of the cylinder. Hence, the cylinder must also be included in the analysis for buckling. When it was felt necessary to include both cylinder and rod in the analysis, the system was treated as a stepped, continuous column (Figure 13).

A transcendental equation describing buckling of an ideal stepped column was developed (4) (5) along the same lines as for Euler's simple



Long Real Cylinder

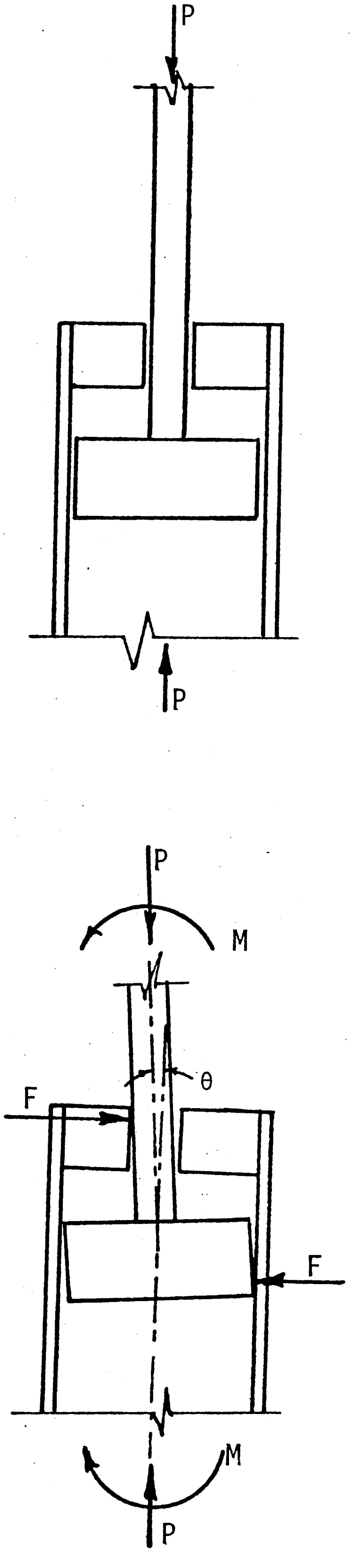
Equivalent Stepped Column

Figure 13. Stepped Column Representation

column. With the use of this equation, charts for computing the critical buckling loads of stepped columns with a rigid connnection at the step were developed (6).

Although the stress distribution in the stepped column is not the same as the actual cylinder stress distribution, it turns out to be fortuitously correct for buckling analysis, since buckling is mainly due to bending moments. If either axial load or internal fluid pressure causes any bending, it is found that the bending moment distribution is the same for both cases, and lateral elastic buckling is primarily dependent on bending moment (7). Hence, for only buckling analysis, the internal pressure in the cylinder can be replaced by axial load on the walls of the cylinder. This axial load, which is equal to pressure times cross sectional area of the cylinder bore, is the same as the load on the rod. It should be noted that this analysis cannot be used to determine stress failure of the cylinder, since the stress distribution in the cylinder due to internal pressure is completely different from that due to axial load.

A real cylinder differs from a stepped column mainly in the following aspects. The axial load is transmitted over part of the length of the column by fluid pressure. The two parts are not rigidly joined, but have a sliding contact between them. When the cylinder is straight there is no force transferred at the sliding connection, but when the cylinder is deflected lateral forces perpendicular to the axis of the cylinder are developed at the interface. These forces transfer moments across the interface and develop a crookedness angle between the two parts (Figure 14).



Straight cylinder
No force transfer at interface
Zero crookedness angle

Deflected cylinder
Moment transfer at interface
Crookedness angle develops

Figure 14. Crookedness Angle

The presence of the crookedness angle reduces the stiffness of the system and hence the load carrying capacity decreases. Several analyses were developed to account for crookedness angle at the sliding connection between the cylinder and rod (8) (1) (9). In one of the procedures (1) a constant crookedness angle determined from empirical data was assumed; in another (9) a small eccentricity in loading was assumed to account for the crookedness angle.

A more rigorous analysis (8) was made which includes the effects of self weights and crookedness angle, but the cylinder part was treated as an infinitely stiff member which restricts the application to a particular type of cylinder.

The critical load is the smallest when the distance between the cylinder support and piston rod support is at its maximum. In general, only this case needs to be investigated. However, if the force developed by the assembly decreases inherently as the length between supoorts increases, investigations must be made for several combinations of load and length. When the cylinder is not fully extended, the central overlapping part consisting of the rod inside the cylinder may be reasonably long compared to the cylinder tube and rod portions on either side of it. In such a case it is required to consider two steps in the system resulting in three parts with different bending stiffnesses. With certain approximations, equations for moments and stresses in these three spans were developed (10) for this particular type of cylinder.

For buckling analysis, a telescoping cylinder can be treated as a stepped column with more than one step. A few procedures have been developed (2) (3) for computing the critical load of a column having a finite number of steps with rigid connections.

It should be noted that in all the methods of analysis no direct solution is possible and the critical load is obtained by iteration. Stepped column analyses apply only for long, and to some moderately long, cylinders. Cylinders which are fairly short usually fail by yielding (material failure) due to combined direct and bending stresses, since the real cylinder is neither ideal nor perfectly axially loaded.

Little work has been done towards the analyses of cylinders with tie rods. Equations for hoop and axial stresses in a straight cylinder mounted at the head were developed (11), but as yet bending analyses of tie rod cylinders have not been made.

CHAPTER IV

DEVELOPMENT OF ANALYSIS

Types of Failure

Failure types are categorized as primary failures and secondary failures.

Primary failures are structural failures of the main components (cylinder, rod and tie rods), which mainly depend on length, yield stress and stiffness of the members. Primary failures in cylinders can occur due to: excessive axial stress as in short columns; excessive hoop stress due to internal hydraulic pressure; buckling, as in long columns; or a combination of axial, bending and hoop stresses resulting in excessive of material capacity. Where the cylinder part is very stiff compared to the rod, the rod can fail individually by excessive stress or buckling, depending on its length. If a tie rod cylinder bends excessively, some tie rods may lose tension resulting in fluid leakage or others may yield in tension.

Secondary failures are due to stress concentrations at threads, piping connections, welds, bolt holes, etc., due to failure of nonstructural components such as bearings and seals, or due to failure of secondary structural elements such as support pins. These failures are mainly due to the configuration and strength characteristics of the individual elements and local effects such as wear and tear, fatigue and stress concentrations.

The analysis developed herein is concerned only with primary failures. Once the capacity of the system against primary failure has been determined, the secondary components can always be proportioned suitably to avoid secondary types of failures.

Factors Influencing Primary Failure

Failure occurs when any type of stress at any point in the system reaches a prescribed limit. In the following paragraphs the factors that influence the magnitude of stresses in the system are discussed.

The main factor contributing to any kind of stress at any point is the axial load. In the rod it produces direct axial stresses and hoop stresses if the rod is hollow and pressurized, and in the cylinder it results in hoop stresses due to hydraulic pressure. Axial load also interacts with deflections to develop bending stresses in both rod and cylinder portions.

Eccentricity of loading, eccentricity of supports, and self weights develop bending moments in the system and, hence, bending stresses.

The cylinder support location and type of support, either fixed or pinned, determines the effective length of the system. As the cylinder support is moved toward the rod end, the distance between pins decreases which in turn increases the load carrying capacity. On the other hand, in the case of an inclined or horizontal cylinder with an intermediate cylinder support, the overhanging portion beyond the cylinder support produces a constant moment at the cylinder pin which will induce moments and stresses in the system.

The crookedness angle at the sliding connection causes the system deflections to increase and, hence, increases the bending moments and bending stresses.

Stop tubes reduce the contact forces at the cylinder/rod interface by increasing the lever arm of the moment carried by the sliding connections. Stop tubes also reduce the crookedness angle and hence reduce deflections, moments and stresses. It is to be noted that as the stop tube length increases, the extended length of the cylinder also increases which in turn reduces the load carrying capacity of the cylinder. The stresses resulting from each of the above may be additive or subtractive.

Friction moments at nonrotating support pins tend to stabilize the system. However, rotation of the support pins occurs in mechanisms where a rotating crank is pinned to the rod end, in which case friction moments may be either stabilizing or destablizing depending on the direction of rotation of the pins.

All of the above mentioned factors are included in the analysis described later. There are numerous other factors which may influence the stresses in the system. However, these factors cannot be treated mathematically and can only be accounted for by increasing the factor of safety applied to the system.

Problem Definition

Methods of analysis to determine the capacity of the system and to determine deflections and stresses in the system at any other loading for regular, telescoping and tie rod cylinders are presented here. The effects taken into consideration in the analyses are: selfweight of the system; loading eccentricities at both ends; variation in crookedness angle due to the elasticity of the bearings; friction moments at supports; general support conditions--pinned, fixed or elastically restrained; cylinder support location anywhere along the cylinder length; inclination of the cylinder; and solid rod or hollow rod with or without internal pressure.

Assumptions and Limitations

The assumptions and limitations on the above effects used in the development of the analyses are described below:

1. All materials are linearly elastic, isotropic and homogeneous.
2. Deflections are small compared to the total length of the system.
3. Ordinary bending analysis is applicable.
4. The system is perfectly straight before loading.
5. The axes of the cylinder and rod portions are colinear before loading.
6. The rod is fully extended but the piston head is not in contact with the stuffing box.
7. The length of the sliding connection is small compared to the total length of the cylinder. In telescoping cylinders, the ratio of length of each sliding connection to the total length of its neighboring tubes is small.
8. The system can be treated as piecewise prismatic with a change in cross section occurring at each sliding connection.
9. The portion of the rod within the sliding connection region remains straight.
10. Bearings and seals at the sliding connections can be replaced by linear springs in the plane of bending.
11. There is no axial force transfer through friction in either piston head or stuffing box bearings.

12. All applied forces and moments act in one of the principal planes of the system and produce bending in that plane only.

13. All support pins are perpendicular to the plane of bending.

14. Cylinder support anywhere along the cylinder length however the sliding connection must be between the cylinder and rod supports.

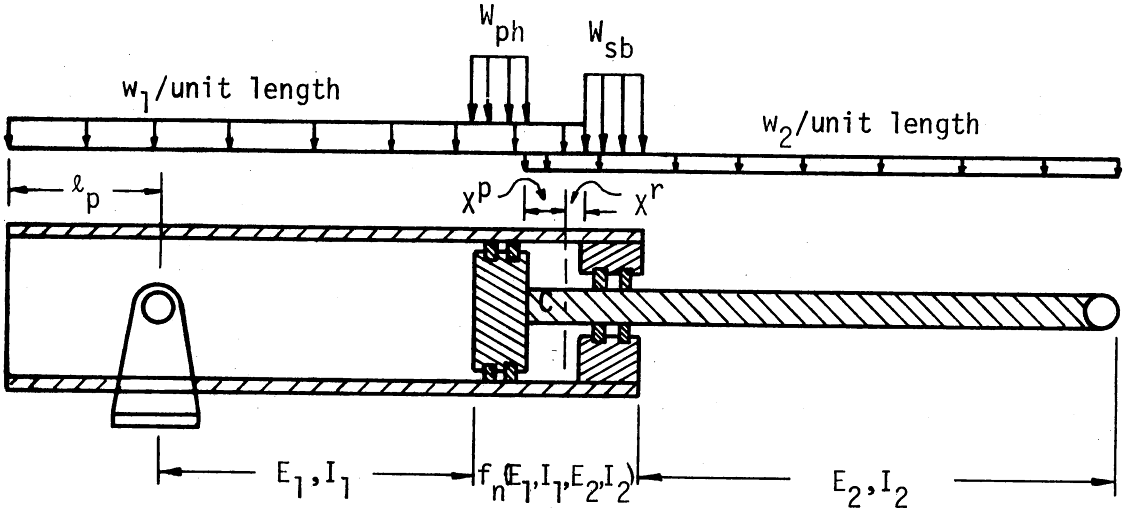
15. The end blocks (cap and head) of a cylinder with tie rods remain perpendicular to the cylinder axis at the cylinder ends before and after loading.

16. All tie rods are pretensioned to the same level before external load is applied to the system.

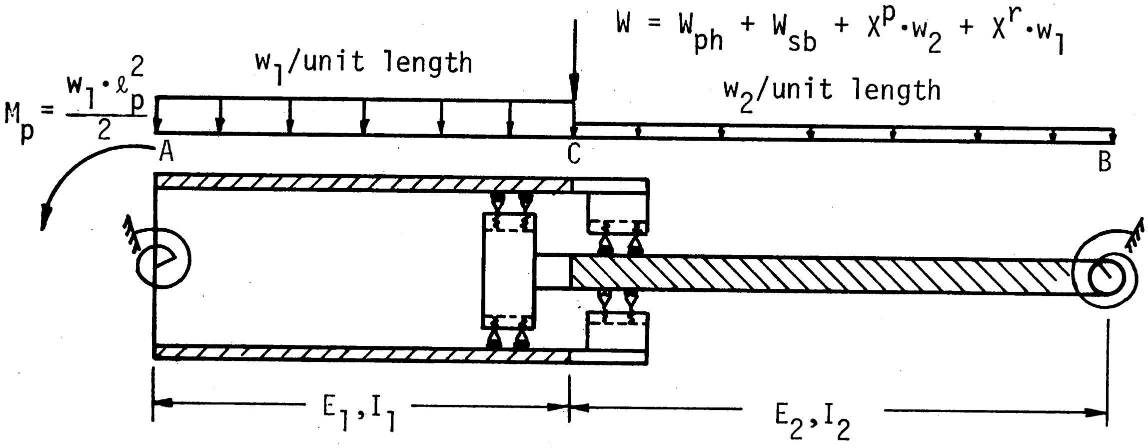
Analytical Model

The assumptions discussed above permit the real structure to be modeled as shown in Figure 15. The two parts of the model, AC and CB (Figure 15 (b)), have stiffnesses equal to the cylinder and rod stiffnesses, respectively. The step point, C, is the point at which the cylinder axis and the rod axis meet when the system is deflected due to loads. Parts AC and CB are loaded uniformly with cylinder and rod weights per unit length, respectively. The weight of the sliding connection is applied as a concentrated load at the step point C, as shown in Figure 15. For an intermediate cylinder support condition, the moment due to weight of the overhanging part is applied at the cylinder support.

Rotational springs at the supports can represent pinned, fixed, or elastic end restraint conditions, depending on their stiffnesses. The bearings and seals at the sliding connection are replaced by linear springs.



(a) Real System



(b) Modeling of Real System

Figure 15. Analytical Model

Method of Analysis

A real fluid power cylinder may be considered as a beam-column with flexible joints at each sliding connection. As indicated earlier, the flexible joint develops a crookedness angle, the magnitude of which depends on the bending moment at the sliding connection. In this analysis a differential equation for deflections is written for each part and solved using boundary conditions that deflections and slopes are continuous at each sliding connection. The number of unknown constants in the solution of differential equations and the number of available boundary conditions are equal, and hence the unknown constants can be determined.

The moment equations and the slope compatibility condition equation at each sliding connection involve the crookedness angle term which is an unknown. Hence, the complete solution will be in terms of the unknown crookedness angle.

To determine the crookedness angle and the deflected equilibrium position, the following method is used. An initial value of the crookedness angle is determined (a small value is assumed in the case of vertical cylinders) from the moment at the sliding connection due to selfweight. This value of corrkedness angle and the applied load are used to estimate the deflections of the system. Using this estimate of deflections a new bending moment at the sliding connection is determined along with the corresponding value of the crookedness angle. The process is repeated until constant values of crookedness angle are obtained on successive iterations. This process converges to an error in the crookedness angle of less than half a percent of the total angle within 3 to

5 iterations.

The analysis for tie rod cylinders is similar to that for regular cylinders with the addition of a moment term for the cylinder part due to deformation of the tie rods. The magnitude of the tie rod moment depends on the deflected shape of the cylinder and is always opposite in direction to the bending moment in the cylinder. Hence, the tie rod moment reduces bending moments in the cylinder and reduces deflections. The tie rod moment term is evaluated by the following method. First, the deflections of the cylinder are determined with the tie rod moment equal to zero and the tie rod moment corresponding to this deflected shape is calculated. A fraction of this moment is applied to the system and the analysis is repeated. Again, the tie rod moment is determined and a fraction of this is added to the previous applied moment. This process is repeated until applied and calculated moments agree. It should be noted that at every step of this process, determination of the crookedness angle also requires iteration.

From the above discussion it is clear that two distinctly different parts of the analysis are linked by the iteration procedure. These two parts are: determination of the crookedness angle for a particular moment at the sliding connection, and determination of deflections in the system.

Although the crookedness angle analysis is the same for regular, telescoping and tie rod cylinders, the deflection analysis differs for each type. The following four chapters deal with these four types of analysis, namely: determination of the crookedness angle; deflection analysis for regular cylinders; deflection analysis for telescoping cylinders; deflection analysis for tie rod cylinders.

CHAPTER V

DETERMINATION OF CROOKEDNESS ANGLE

The sliding connection at the cylinder/rod interface in a fluid power cylinder introduces an angular deflection at the interface which increases with increasing applied load. To account for this angular distortion in the deflection and stress analysis of the cylinder, the relationship between crookedness angle and moment at the sliding connection must be determined. As indicated in Chapter II, the bearings and seals may appear in a variety of configurations and materials. Because of differences in design, assembly, and materials used in the sliding connection components, no completely general relationship is possible. The following procedure is used to develop the relationship between the moment and the crookedness angle at the sliding connection. It is sufficiently general that, with adjustments in the stiffnesses, it can be used for the analysis of a wide variation of configurations of the bearings and seals.

As the cylinder deflections increase with loading, the lateral loads on the bearings and seals increase. The compression in the bearings and seals, and hence, the angular deflection is directly proportional to the lateral loads. This linear variation of crookedness angle with the moment at the sliding connection is valid as long as no contact point (contact of rims of piston head or stuffing box with the cylinder wall or rod, respectively) is developed at the sliding connection. Depending on the configuration of the sliding connection (clearance between piston head and cylinder wall; clearance between stuffing box and rod; piston head and stuffing box lengths; and overlap length of cylinder and rod), as the crookedness angle increases, a contact point can occur. This contact point introduces a kinematic constraint and also a part of the lateral load develops at that point. Hence, when a contact point occurs there exists a different relationship between moment and crookedness angle. The increase in crookedness angle terminates when two kinematic constraints develop due to the occurrence of two contact points.

It can be seen from the above discussion that for low values of moments at the sliding connection there exists a direct relation between the moment and the crookedness angle. However, as the moment increases, a contact may occur either at the front edge of the piston head or at the outside edge of the stuffing box at which time the moment-crookedness angle relation changes. As the moment continues to increase, a second contact point occurs after which the crookedness angle remains constant. Depending on the configuration of the sliding connection, these pairs of contact points may be in three different combinations, such as: the front and back edges of the piston head; the outside and inside edges of the stuffing box; or the front edge of the piston head and the outside edge of the stuffing box. The equations for the moment-crookedness angle relationship for these six different cases and the equations for the lateral forces on the bearings and seals and on the contact points are developed in the following sections for a general sliding connection with any number of bearings and seals.

The line diagram (Figure 16) shows the crookedness angle between the cylinder axis and the rod axis, and the deformations of piston bearings

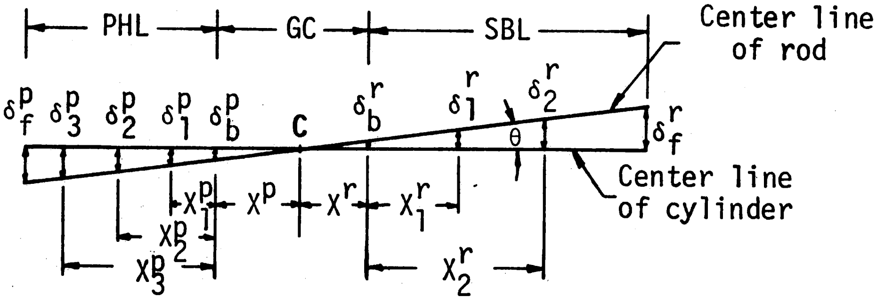


Figure 16. Deformations of Bearings and Seals

and rod bearings. From the free body diagram,

$$\theta = \frac{\delta_1^p}{X^p + X_1^p} = \frac{\delta_2^p}{X^p + X_2^p} = \cdot\ \cdot\ \cdot = \frac{\delta_M^p}{X^p + X_M^p}$$

$$= \frac{\delta_1^r}{X^r + X_1^r} = \frac{\delta_2^r}{X^r + X_2^r} = \cdot\ \cdot\ \cdot = \frac{\delta_N^r}{X^r + X_N^r} \tag{5.1}$$

where

δ_i^p,i = 1 to M are the deformations in the piston head bearings;

δ_i^r,i = 1 to N are the deformations in the rod bearings;

X_i^p,i = 1 to M are the distances of the piston head bearings from the piston head backface (see Figure 17);

X_i^r,i = 1 to N are the distances of the rod bearings from the stuffing box innerface (see Figure 17);

X^p is the distance of the piston head backface from step point C; and

X^r is the distance of the stuffing box innerface from step point C.

The bearings and seals are modeled as linear springs, hence

$$\delta_i^p = \frac{F_i^p}{K_i^p}\ ; \quad i = 1 \text{ to } M$$

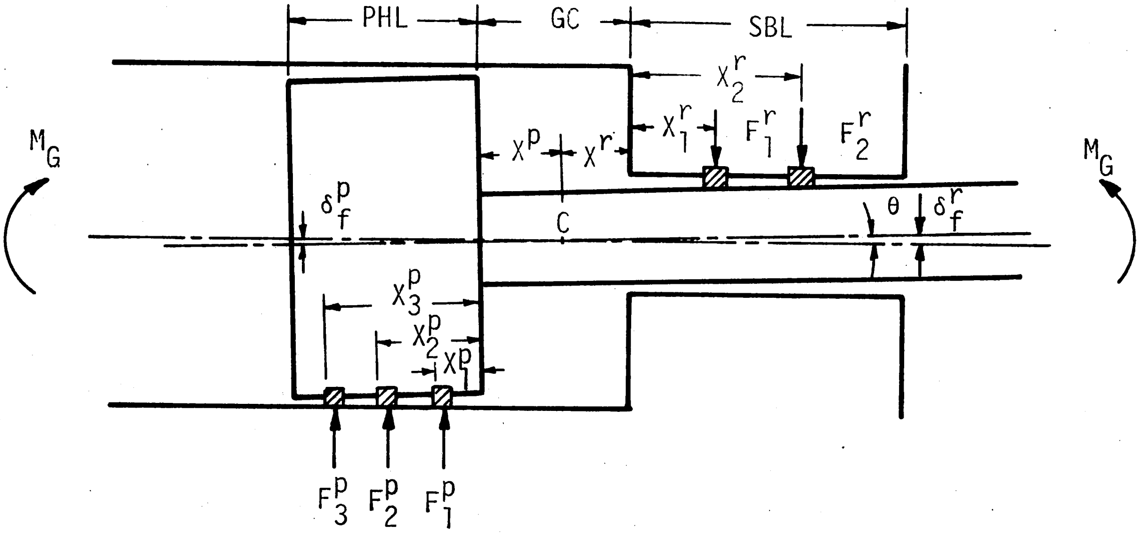


Figure 17. No Metal-to-Metal Contact

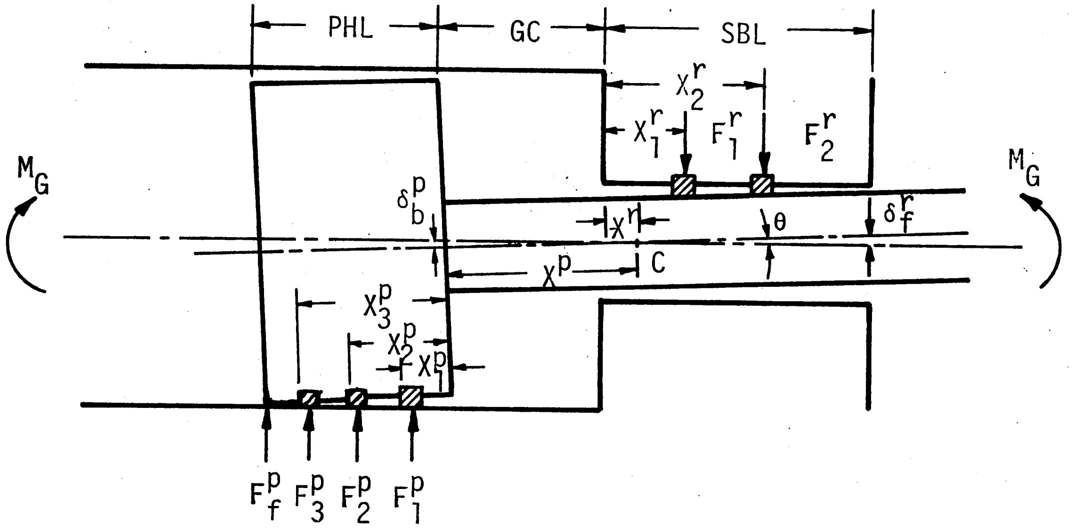


Figure 18. Contact at Piston Head Front Edge

and

$$\delta_i^r = \frac{F_i^r}{K_i^r} \; ; \quad i = 1 \text{ to } N \tag{5.2}$$

where

F_i^p and F_i^r are the lateral forces on the piston bearings and rod bearings, respectively; and

K_i^p and K_i^r are the stiffnesses of the piston bearings and rod bearings, respectively, which are modeled as linear springs.

Equations (5.1) and (5.2) are combined to obtain

$$\begin{aligned} \theta &= \frac{F_1^p}{K_i^p \cdot (X^p + X_1^p)} = \frac{F_2^p}{K_2^p \cdot (X^p + X_2^p)} = \; . \; . \; . \; = \frac{F_M^p}{K_M^p \cdot (X^p + X_M^p)} \\ &= \frac{F_1^r}{K_1^r \cdot (X^r + X_1^r)} = \frac{F_2^r}{K_2^r \cdot (X^r + X_2^r)} = \; . \; . \; . \; = \frac{F_N^r}{K_N^r \cdot (X^r + X_N^r)} \end{aligned} \tag{5.3}$$

in which X^r and X^p are related by

$$X^r = GC - X^p \tag{5.4}$$

where GC = gland clearance (see Figure 17).

Absence of Kinematic Constraints

The moment across the sliding connection develops lateral forces on only the bearings and seals. Figure 17 shows the crookedness angle and the corresponding forces on the bearings and seals. Summation of vertical forces gives,

$$\sum_{i=1}^{M} F_i^p = \sum_{i=1}^{N} F_i^r \; . \tag{5.5}$$

These forces are expressed in terms of θ using Equation (5.3) to obtain

$$\sum_{i=1}^{M} K_i^p \cdot X_i^p + X^p \cdot \sum_{i=1}^{M} \overset{?}{\boxed{X_i^p}} = \sum_{i=1}^{N} K_i^r \cdot X_i^r + GC \cdot \sum_{i=1}^{N} K_i^r - X^p \cdot \sum_{i=1}^{N} K_i^r$$

which may be solved for X^p

$$X^p = \frac{\sum_{i=1}^{N} K_i^r \cdot X_i^r + GC \cdot \sum_{i=1}^{N} K_i^r - \sum_{i=1}^{M} K_i^p \cdot X_i^p}{\sum_{i=1}^{M} K_i^p + \sum_{i=1}^{N} K_i^r} . \qquad (5.6)$$

Moments are summed about point C to obtain

$$\sum_{i=1}^{M} F_i^p \cdot (X^p + X_i^p) + \sum_{i=1}^{N} F_i^r \cdot (X^r + X_i^r) = M_G \qquad (5.7)$$

where M_G is the bending moment at the sliding connection. The lateral forces in Equation (5.7) are expressed in terms of θ using Equation (5.3), which results in

$$\theta = \frac{M_G}{\sum_{i=1}^{M} K_i^p \cdot (X^p + X_i^p)^2 + \sum_{i=1}^{N} K_i^r \cdot (X^r + X_i^r)^2} \qquad (5.8)$$

The displacements at the piston head front edge and at the stuffing box outside edge are,

$$\delta_f^p = (X^p + PHL) \cdot \theta \qquad (5.9)$$

and

$$\delta_f^r = (X^r + SBL) \cdot \theta \qquad (5.10)$$

where

PHL = piston head length; and

SBL = stuffing box length.

For a certain value of moment, if either δ_f^p is greater than PCL (piston clearance from cylinder wall), or δ_f^r is greater than RCL (rod clearance from stuffing box), the next case with one kinematic constraint should be considered. If both the displacements are greater than the corresponding clearances, the proper type of one kinematic constraint case to be used is determined by noting whether δ_f^p exceeds PCL first or δ_f^r exceeds RCL as θ is increased in Equations (5.9) and (5.10). If δ_f^p exceeds PCL, the case with one kinematic constraint at the piston head front edge results, and if δ_f^r exceeds RCL, the case with one kinematic constraint at the outside edge of the stuffing box should be considered.

Presence of One Kinematic Constraint

Contact at the Piston Head Front Edge

The metal-to-metal contact of the front edge of the piston head with the cylinder wall (Figure 18) establishes that

$$\delta_f^p = \text{PCL}. \tag{5.11}$$

The crookedness angle is expressed as

$$\theta = \frac{\text{PCL}}{X^p + \text{PHL}} \tag{5.12}$$

with the sign of the moment at the sliding connection.

Summation of vertical forces gives,

$$F_f^p + \sum_{i=1}^{M} F_i^p = \sum_{i=1}^{N} F_i^r \tag{5.13}$$

where F_f^p = lateral contact point force at piston head front edge. Bearing forces in terms of θ, Equation (5.3), are substituted in Equation (5.13), and the equation for the lateral contact point force may be expressed as

$$F_f^p = \theta\cdot\{\sum_{i=1}^{N} K_i^r\cdot X_i^r + \text{GC}\cdot\sum_{i=1}^{N} K_i^r - \sum_{i=1}^{M} K_i^p\cdot X_i^p - X^p\cdot(\sum_{i=1}^{M} K_i^p + \sum_{i=1}^{N} K_i^r)\}. \tag{5.14}$$

A summation of moments about the contact point yields

$$- \sum_{i=1}^{M} F_i^p \cdot (PHL - X_i^p) + \sum_{i=1}^{N} F_i^r \cdot (PHL + GC + X_i^r) = M_G \tag{5.15}$$

Equations (5.3) and (5.12) are equated to provide

$$F_i^p = \frac{PCL \cdot K_i^p \cdot (X^p + X_i^p)}{X^p + PHL} \; ; \quad i = 1 \text{ to } M$$

and

$$F_i^r = \frac{PCL \cdot K_i^r \cdot (GC - X^p + X_i^r)}{X^p + PHL} \; ; \quad i = 1 \text{ to } N. \tag{5.16}$$

Combination of Equations (5.15) and (5.16) results in

$$X^p = \frac{\sum_{i=1}^{N} (GC+X_i^r) \cdot (PHL+GC+X_i^r) \cdot K_i^r - \sum_{i=1}^{M} (PHL-X_i^r) \cdot X_i^r \cdot K_i^r - \frac{M_G \cdot PHL}{PCL}}{\frac{M_G}{PCL} + \sum_{i=1}^{M} K_i^p \cdot (PHL-X_i^p) + \sum_{i=1}^{N} K_i^r \cdot (PHL+GC+X_i^r)} \tag{5.17}$$

For all signs to be consistent, PCL must have the same sign as M_G; hence, M_G/PCL is always positive.

The displacements at the piston head back edge and at the stuffing box outside edge are,

$$\delta_b^p = X^p \cdot \theta \tag{5.18}$$

and

$$\delta_f^r = (X^r + SBL) \cdot \theta. \tag{5.19}$$

For a certain value of moment, if either δ_b^p is greater than PCL, or δ_f^r is greater than RCL, the next case with two kinematic constraints should be considered. If both the displacements are greater than the corresponding clearances, the proper case of two kinematic constraints to be used is determined by noting whether δ_b^p exceeds PCL first or δ_f^r exceeds RCL as θ is increased in the Equations (5.18) and (5.19). If δ_b^p exceeds PCL, the case with kinematic constraints at both edges of the piston head should be used, or if δ_f^r exceeds RCL, the case with kinematic constraints at the piston head front edge and at the stuffing box outside edge should be considered.

Contact at the Stuffing Box Outside Edge

The metal-to-metal contact of the stuffing box outside edge with the rod (Figure 19) establishes that,

$$\delta_f^r = \text{RCL} \qquad (5.20)$$

The crookedness angle is expressed as

$$\theta = \frac{\text{RCL}}{\text{GC} - X^p + \text{SBL}} \qquad (5.21)$$

with the sign of the moment at the sliding connection.

In the same manner as in the previous case, summation of vertical forces gives,

$$\sum_{i=1}^{M} F_i^p = \sum_{i=1}^{N} F_i^r + F_f^r \qquad (5.22)$$

when bearing forces in terms of θ, Equation (5.3) is substituted in Equation (5.22), the lateral contact point force at the stuffing box outside edge is

$$F_f^r = \theta \cdot \{X^p \cdot (\sum_{i=1}^{M} K_i^p + \sum_{i=1}^{N} K_i^r) - (\sum_{i=1}^{N} K_i^r \cdot X_i^r + \text{GC} \cdot \sum_{i=1}^{N} K_i^r - \sum_{i=1}^{M} K_i^p \cdot X_i^p)\} \qquad (5.23)$$

Moments are summed about the contact point to obtain

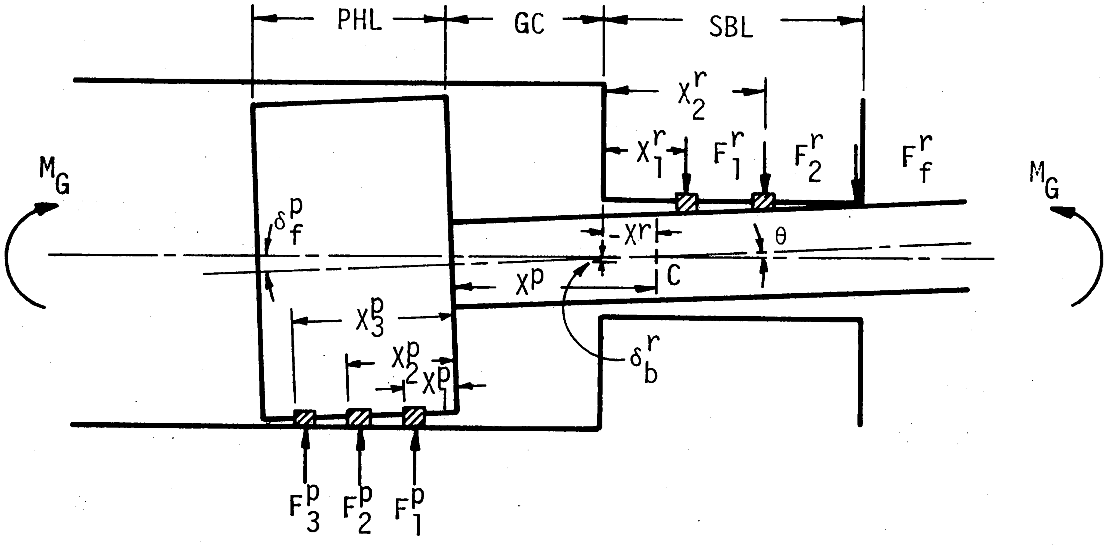


Figure 19. Contact at Stuffing Box Outside Edge

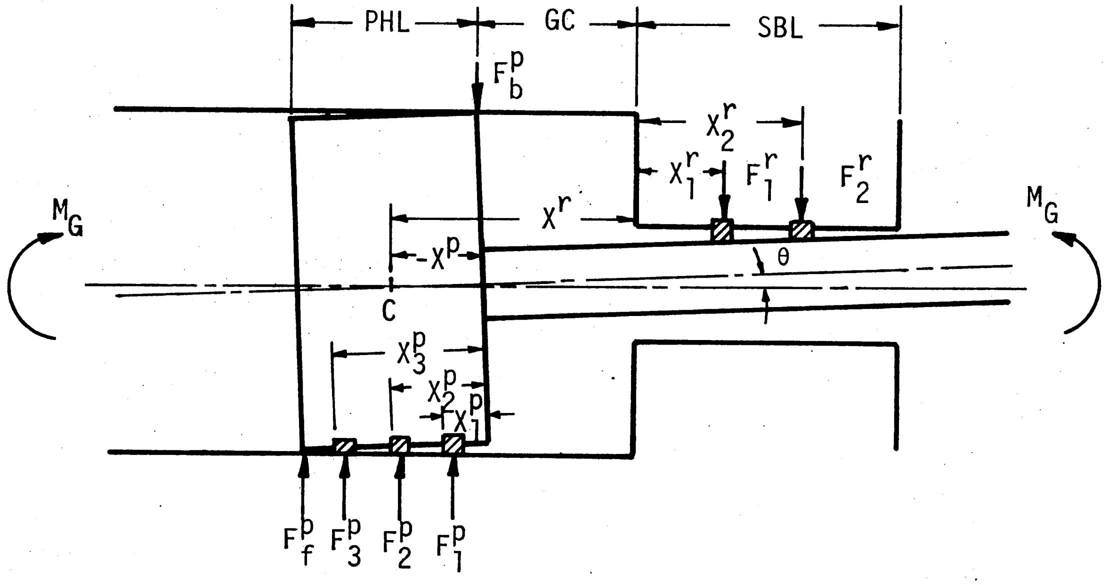


Figure 20. Contact at Piston Head Edges

$$\sum_{i=1}^{M} F_i^p \cdot (SBL+GC+X_i^p) - \sum_{i=1}^{N} F_i^r \cdot (SBL-X_i^r) = M_G. \tag{5.24}$$

Equations (5.3) and (5.21) are equated to provide

$$F_i^p = \frac{RCL \cdot K_i^p \cdot (X^p + X_i^p)}{GC - X^p + SBL} \; ; \quad i = 1 \text{ to } M$$

and

$$F_i^r = \frac{RCL \cdot K_i^r \cdot (GC - X^p + X_i^r)}{GC - X^p + SBL} \; ; \quad i = 1 \text{ to } N. \tag{5.25}$$

Equation (5.25) is substituted in Equation (5.24) to yield

$$X^p = \frac{\sum_{i=1}^{N} (GC+X_i^r) \cdot (SBL-X_i^r) \cdot K_i^r - \sum_{i=1}^{M} (SBL+GC+X_i^p) \cdot X_i^p \cdot K_i^p + \frac{M_G \cdot (GC+SBL)}{RCL}}{\frac{M_G}{RCL} + \sum_{i=1}^{M} K_i^p \cdot (SBL+GC+X_i^p) + \sum_{i=1}^{N} K_i^r \cdot (SBL-X_i^r)} \tag{5.26}$$

Again, for all signs to be consistent, RCL must have the same sign as M_G; hence, M_G/RCL is always positive.

The displacements at the piston head front edge and at the stuffing box inside edge are,

$$\delta_f^p = (X^p + PHL) \cdot \theta \tag{5.27}$$

and

$$\delta_b^r = X^r \cdot \theta. \tag{5.28}$$

For a certain value of moment, if either δ_f^p is greater than PCL, or δ_b^r is greater than RCL, the next case with two kinematic constraints should be considered. If both the displacements are greater than the corresponding clearances, the proper case of two kinematic constraints to be used is determined by noting whether δ_f^p exceeds PCL first or δ_b^r

exceeds RCL as θ is increased in Equations (5.27) and (5.28). If δ_f^p exceeds PCL, the case with kinematic constraints at the piston head front edge and at the stuffing box outside edge should be used, or if δ_b^r exceeds RCL, the case with kinematic constraints at both edges of the stuffing box should be considered.

Presence of Two Kinematic Constraints

Contact at Piston Head Edges

The metal-to-metal contact at the piston head edges with the cylinder wall (Figure 20) establishes that,

$$X^p = -PHL/2\cdot 0 \tag{5.29}$$

and also,

$$\theta = 2\cdot 0(PCL)/PHL \tag{5.30}$$

with the sign of the moment at the sliding connection.

Moments are summed about the piston head backside contact point,

$$F_f^p\cdot PHL + \sum_{i=1}^{M} F_i^p\cdot X_i^p + \sum_{i=1}^{N} F_i^r\cdot(GC + X_i^r) = M_G$$

from which

$$F_f^p = \frac{M_G - \sum_{i=1}^{M} F_i^p\cdot X_i^p - \sum_{i=1}^{N} F_i^r\cdot(GC + X_i^r)}{PHL}\ . \tag{5.31}$$

Summation of vertical forces gives the backside piston head edge contact point force,

$$F_b^p = F_f^p + \sum_{i=1}^{M} F_i^p - \sum_{i=1}^{N} F_i^r. \tag{5.32}$$

Contact at Stuffing Box Edges

The metal-to-metal contact at the stuffing box edges with the rod (Figure 21) establishes that,

$$X^p = GC + SBL/2{\cdot}0 \tag{5.33}$$

and also,

$$\theta = 2{\cdot}0(RCL)/SBL \tag{5.34}$$

with the sign of the moment at the sliding connection.

Moments are summed about the stuffing box inside edge contact point,

$$F_f^r{\cdot}SBL + \sum_{i=1}^{M} F_i^p{\cdot}(GC + X_i^p) + \sum_{i=1}^{N} F_i^r{\cdot}X_i^r = M_G$$

from which

$$F_f^r = \frac{M_G - \sum_{i=1}^{M} F_i^p{\cdot}(GC + X_i^p) - \sum_{i=1}^{N} F_i^r{\cdot}X_i^r}{SBL}\,. \tag{5.35}$$

The stuffing box inside contact point force is obtained from summation of vertical forces,

$$F_b^r = F_f^r + \sum_{i=1}^{N} F_i^r - \sum_{i=1}^{M} F_i^p. \tag{5.36}$$

Contact at Piston Head Front and Stuffing Box Outside Edges

The metal-to-metal contact at the piston head front edge with the cylinder wall and the stuffing box outside edge with the rod (Figure 22) establishes that,

$$\theta = \frac{PCL + RCL}{PHL + GC + SBL} \tag{5.37}$$

with the sign of the moment at the sliding connection.

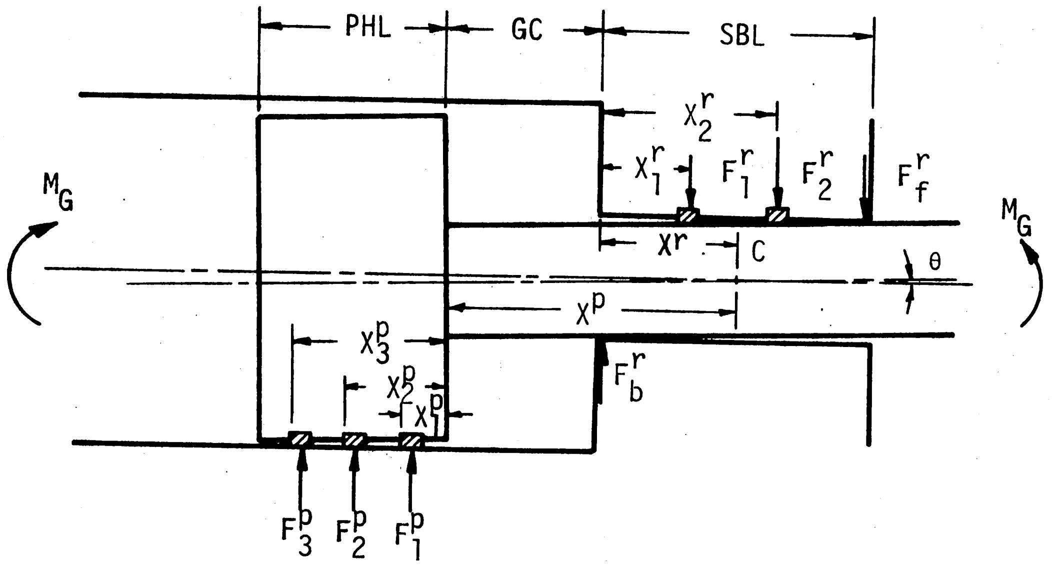


Figure 21. Contact at Stuffing Box Edges

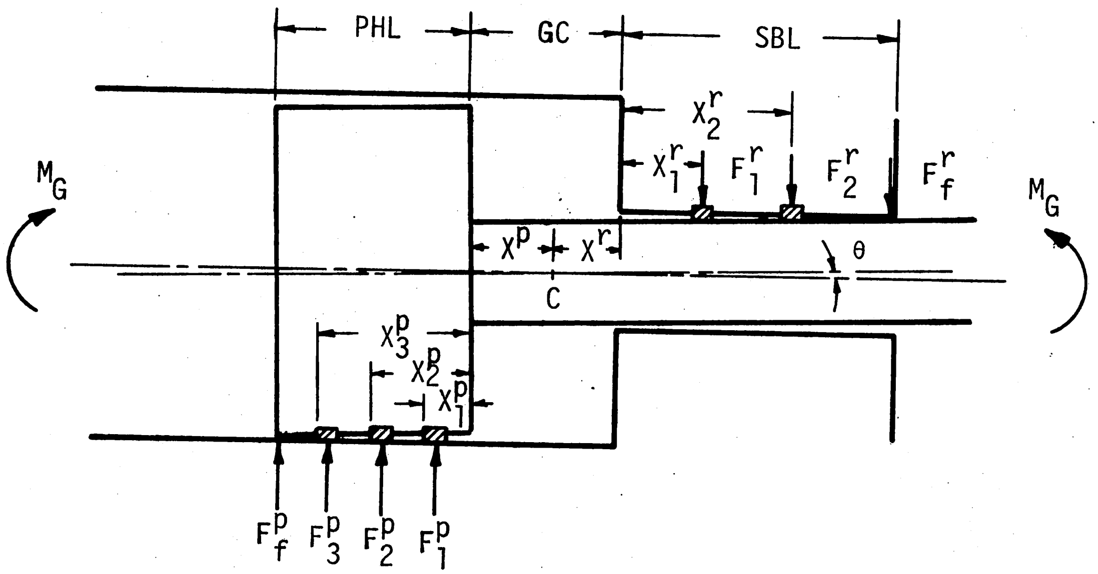


Figure 22. Contact at Piston Head Front and Stuffing Box Outside Edges

The distance of point C from the piston head backface is given by,

$$X^p = \frac{PCL}{\theta} - PHL \tag{5.38}$$

with PCL/θ being always positive for consistent sign convention.

Summation of moments about the stuffing box outside contact point gives,

$$F_f^p = \frac{M_G - \sum_{i=1}^{M} F_i^p \cdot (SBL + GC + X_i^p) + \sum_{i=1}^{N} F_i^r \cdot (SBL - X_i^r)}{PHL + GC + SBL} \tag{5.39}$$

Summation of vertical forces gives,

$$F_f^r = F_f^p + \sum_{i=1}^{M} F_i^p - \sum_{i=1}^{N} F_i^r . \tag{5.40}$$

Lateral Forces on Bearings and Seals

In all cases, after the crookedness angle, θ, is calculated, the lateral forces on the bearings and seals are calculated with Equation (5.3).

CHAPTER VI

ANALYSIS OF REGULAR CYLINDERS

Equations for moments, slopes and deflections at all points along the length of the cylinder are developed in this chapter for regular cylinders. The problem definition, assumptions and limitations and the modeling method are given in Chapter IV. Figure 23 shows the resulting system for regular cylinders with all forces and reactions.

In this analysis, differential equations for deflections are written for the cylinder and rod parts of the deflected cylinder. These differential equations are solved using the boundary and compatibility conditions to obtain the deflection equations. The slope equations are then obtained by differentiation of the deflection equations.

A line diagram of a typical hydraulic cylinder is shown in Figure 24 in three possible positions: perfectly straight; with an initial crookedness angle, θ', at no axial load; and in a loaded condition with crookedness angle, θ, which increases with load. The system will progress through these three positions as an axial load is applied at the ends. It is clear that the deflection at any point in the system is partly due to the presence of the crookedness angle and partly due to the bending of the cylinder and rod elements. In Figure 24, the portion of the deflection from the perfectly straight position to the position indicated by the dotted lines is due to the crookedness angle, and the portion from the dotted lines to the bent position is due to the bending

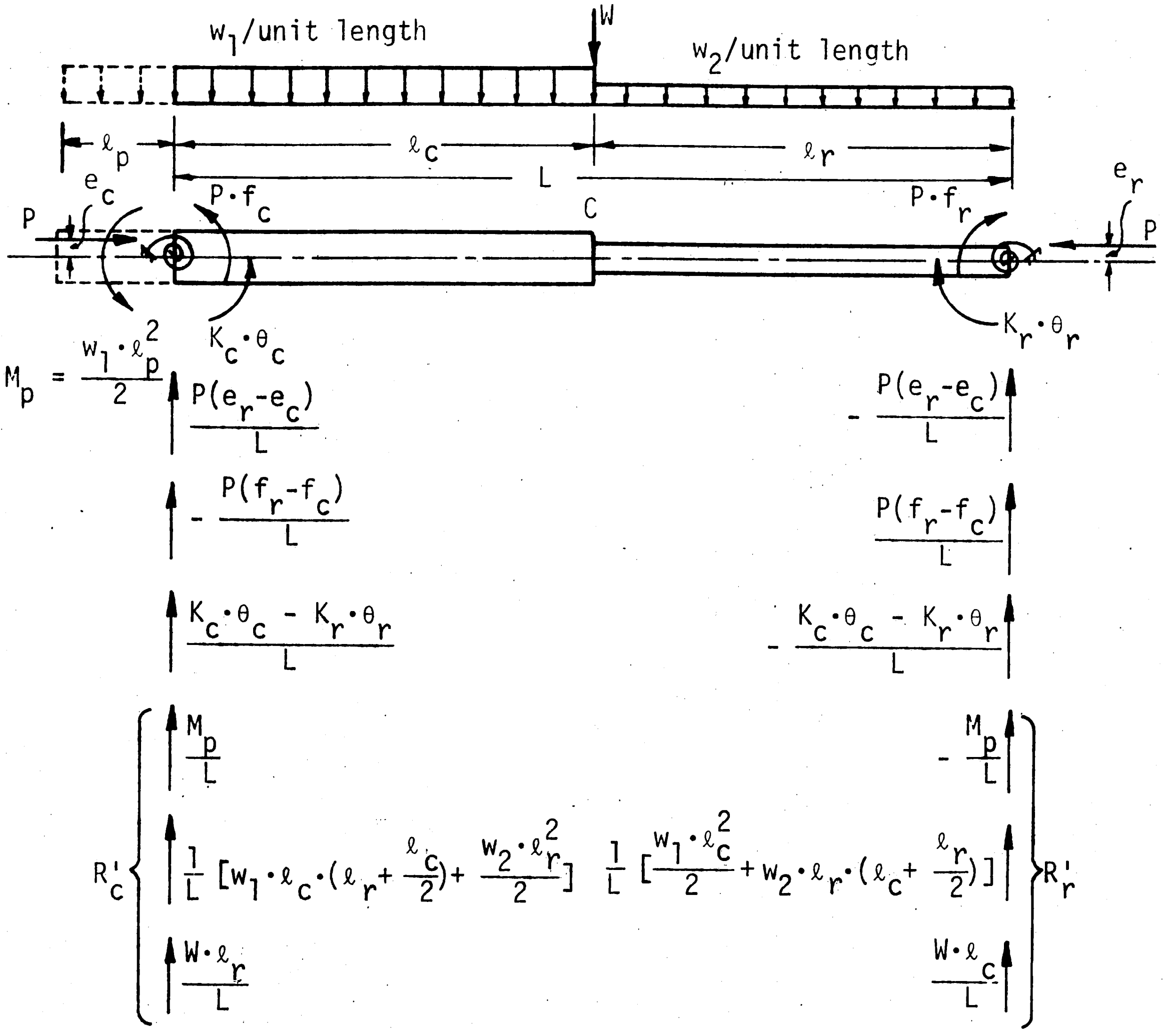


Figure 23. Forces and Reactions in a Regular Cylinder System

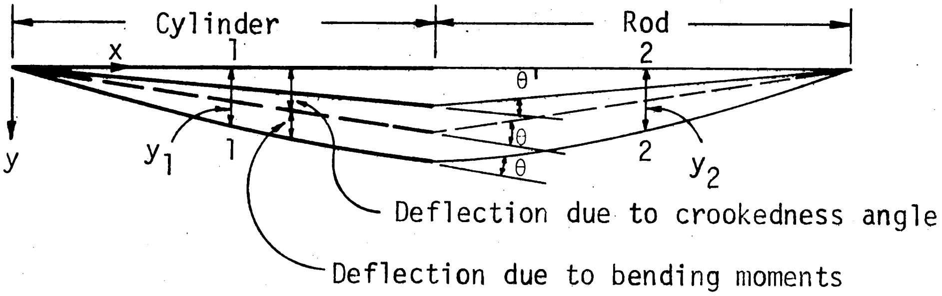


Figure 24. Line Diagram Showing the Deflected Positions of a Typical Hydraulic Cylinder

moments in the system. The differential equations in this analysis are written in terms of the total deflection.

At a typical section in the cylinder portion, e.g., Section 1-1, Figure 24, the bending moment due to curvature obtained from ordinary bending theory is

$$M_1 = -E_1 \cdot I_1 \cdot \frac{d^2 y_1}{dx^2} \tag{6.1}$$

where

E_1 = modulus of elasticity of the cylinder material; and

I_1 = moment of inertia of the cylinder part.

The bending moment at the same location due to the external loads and reactions is

$$M_1 = \frac{P \cdot (e_r - e_c)}{L} \cdot x - \frac{P \cdot (f_r - f_c)}{L} \cdot x + \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{L} \cdot x$$

$$+ R_c' \cdot x - M_p - P \cdot f_c - K_c \cdot \theta_c - \frac{w_1}{2} \cdot x^2 + P \cdot (e_c + y_1) \tag{6.2}$$

where

P = axial load on the cylinder;

L = length of the cylinder between supports;

e_c and e_r = eccentricities of loading at cylinder and rod supports, respectively;

θ_c and θ_r = slopes of the cylinder axis and rod axis at the cylinder support and rod support, respectively;

K_c and K_r = stiffnesses of the rotational springs at the cylinder and rod pin supports, respectively;

f_c and f_r = friction coefficient times the radius of the support pin at the cylinder and rod supports, respectively;

R_c' = lateral reaction at the cylinder support due to self weights of the system (see Figure 23);

M_p = moment at the cylinder support due to the self weight of the overhanging part of the cylinder;

w_1 = weight per unit length of the cylinder part; and

y_1 = deflection at any distance x in the cylinder part from the cylinder support.

For equilibrium, the internal and external moments must be equal; hence, Equations (6.1) and (6.2) may be combined to yield

$$\frac{d^2y_1}{dx^2} + K_1^2 \cdot y_1 = K_1^2 \cdot [- \frac{e_r - e_c}{L} \cdot x + \frac{f_r - f_c}{L} \cdot x - \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{P \cdot L} \cdot x - \frac{R'_c}{P} \cdot x + \frac{M_p}{P} + f_c + \frac{K_c \cdot \theta_c}{P} + \frac{w_1}{2 \cdot P} \cdot x^2 - e_c] \quad (6.3)$$

where

$$K_1^2 = \frac{P}{E_1 \cdot I_1}$$

A similar analysis of a typical section in the rod portion, e.g., Section 2-2, results in

$$\frac{d^2y_2}{dx^2} + K_2^2 \cdot y_2 = K_2^2 \cdot [\frac{e_r - e_c}{L} \cdot (L-x) - \frac{f_r - f_c}{L} \cdot (L-x) + \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{P \cdot L} \cdot (L-x) - \frac{R'_r}{P} \cdot (L-x) + f_r + \frac{K_r \cdot \theta_r}{P} + \frac{w_2}{2 \cdot P} \cdot (L-x)^2 - e_r] \quad (6.4)$$

where

$$K_2^2 = \frac{P}{E_2 \cdot I_2}$$

R'_r = lateral reaction at the rod support due to self weights of the system (see Figure 23);

w_2 = weight per unit length of the rod part;

and other variables are as defined earlier. Differential Equations (6.3) and (6.4) describe the load deflection behavior of the cylinder and rod portions of the system.

The boundary and compatibility conditions which are to be enforced on the solutions of these equations are:

$$x = 0 \qquad y_1 = 0$$

$$x = L \qquad y_2 = 0$$

$$x = \ell_c \qquad y_1 = y_2$$

and

$$x = \ell_c \qquad \frac{dy_1}{dx} - \theta = \frac{dy_2}{dx} \tag{6.5}$$

The general solutions of Equations (6.3) and (6.4) are

$$y_1 = C_1 \cdot \cos(K_1 \cdot x) + D_1 \cdot \sin(K_1 \cdot x) - \frac{e_r - e_c}{L} \cdot x + \frac{f_r - f_c}{L} \cdot x - \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{P \cdot L} \cdot x - \frac{R'_c}{P} \cdot x + T_1 + \frac{K_c \cdot \theta_c}{P} + \frac{w_1}{2 \cdot P} \cdot x^2 \qquad (o \leq x \leq \ell_c) \tag{6.6}$$

and

$$y_2 = C_2 \cdot \cos(K_2 \cdot x) + D_2 \cdot \sin(K_2 \cdot x) + \frac{e_r - e_c}{L} \cdot (L-x) - \frac{f_r - f_c}{L} \cdot (L-x) + \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{P \cdot L} \cdot (L-x) - \frac{R'_r}{P} \cdot (L-x) + T_2 + \frac{K_r \cdot \theta_r}{P} + \frac{w_2}{2 \cdot P} \cdot (L-x)^2 \qquad (\ell_c \leq x \leq L) \tag{6.7}$$

where,

$$T_1 = \frac{M_p}{P} + f_c - e_c - \frac{w_1}{P \cdot K_1^2} \tag{6.8}$$

and

$$T_2 = f_r - e_r - \frac{w_2}{P \cdot K_2^2} \, . \tag{6.9}$$

C_1, C_2, D_1, and D_2 are constants to be determined using the boundary and compatibility conditions, Equation (6.5).

Application of the deflection boundary conditions at the ends yields:

$$C_1 = -T_1 - \frac{K_c \cdot \theta_c}{P} \qquad (6.10)$$

and

$$C_2 = [-D_2 \cdot \sin(K_2 \cdot L) - T_2 - \frac{K_r \cdot \theta_r}{P}] \cdot \frac{1}{\cos(K_2 \cdot L)} \qquad (6.11)$$

Application of the deflection compatibility condition at the sliding connection, i.e., at $x = \ell_c$, and substituting for C_1 and C_2 from Equations (6.10) and (6.11) yields

$$D_1 \cdot \sin(K_1 \cdot \ell_c) + D_2 \cdot \frac{\sin(K_2 \cdot \ell_r)}{\cos(K_2 \cdot L)} = (T_1 + \frac{K_c \cdot \theta_c}{P}) \cdot \cos(K_1 \cdot \ell_c)$$

$$- (T_2 + \frac{K_r \cdot \theta_r}{P}) \cdot \frac{\cos(K_2 \cdot \ell_c)}{\cos(K_2 \cdot L)} - T_3 \qquad (6.12)$$

where

$$T_3 = \frac{w_2}{P \cdot K_2^2} - \frac{w_1}{P \cdot K_1^2} \, . \qquad (6.13)$$

The equations for slopes are equal to the first derivative of the deflection Equations (6.6) and (6.7). These slope equations are

$$\frac{dy_1}{dx} = -C_1 \cdot K_1 \cdot \sin(K_1 \cdot x) + D_1 \cdot K_1 \cdot \cos(K_1 \cdot x) - \frac{e_r - e_c}{L} + \frac{f_r - f_c}{L}$$

$$- \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{P \cdot L} - \frac{R_c'}{P} + \frac{w_1}{P} \cdot x \qquad (o \leq x \leq \ell_c) \qquad (6.14)$$

and

$$\frac{dy_2}{dx} = -C_2 \cdot K_2 \cdot \sin(K_2 \cdot x) + D_2 \cdot K_2 \cdot \cos(K_2 \cdot x) - \frac{e_r - e_c}{L} + \frac{f_r - f_c}{L}$$

$$- \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{P \cdot L} + \frac{R'_r}{P} - \frac{w_2}{P} \cdot (L-x) \qquad (\ell_c \le x \le L).$$

(6.15)

Application of the slope compatibility condition at the sliding connection, Equation (6.5), and substitution for C_1 and C_2 from Equations (6.10) and (6.11) yield:

$$D_1 \cdot K_1 \cdot \cos(K_1 \cdot \ell_c) - D_2 \cdot K_2 \cdot \frac{\cos(K_2 \cdot \ell_r)}{\cos(K_2 \cdot L)}$$

$$= (-T_1 - \frac{K_c \cdot \theta_c}{P}) \cdot K_1 \cdot \sin(K_1 \cdot \ell_c)$$

$$+ (T_2 + \frac{K_r \cdot \theta_r}{P}) \cdot \frac{K_2 \cdot \sin(K_2 \cdot \ell_c)}{\cos(K_2 \cdot L)} + \frac{W_1}{P} + \theta \qquad (6.16)$$

where

$$W_1 = R'_c + R'_r - w_1 \cdot \ell_c - w_2 \cdot \ell_r .$$

Equations (6.12) and (6.16) are solved simultaneously to obtain

$$D_1 = \frac{1}{Q} \cdot [(T_1 + \frac{K_c \cdot \theta_c}{P}) \cdot \frac{K_2 - K_1 \cdot \tan(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_r)}{\tan(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_r)}$$

$$- (T_2 + \frac{K_r \cdot \theta_r}{P}) \cdot \frac{K_2}{\sin(K_1 \cdot \ell_c) \cdot \sin(K_2 \cdot \ell_r)}$$

$$- T_3 \cdot \frac{K_2}{\sin(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_r)} + (\theta + \frac{W_1}{P}) \cdot \frac{1}{\sin(K_1 \cdot \ell_c)}]$$

(6.17)

and

$$D_2 = \frac{1}{Q} \cdot [(T_1 + \frac{K_c \cdot \theta_c}{P}) \cdot \frac{K_1 \cdot \cos(K_2 \cdot L)}{\sin(K_1 \cdot \ell_c) \cdot \sin(K_2 \cdot \ell_r)}$$

$$- (T_2 + \frac{K_r \cdot \theta_r}{P}) \cdot \frac{K_2 \cdot \tan(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_c) + K_1}{\tan(K_1 \cdot \ell_c) \cdot \sin(K_2 \cdot \ell_r)} \cdot \cos(K_2 \cdot \ell_c)$$

$$- T_3 \cdot \frac{K_1 \cdot \cos(K_2 \cdot L)}{\tan(K_1 \cdot \ell_c) \cdot \sin(K_2 \cdot \ell_r)} - (\theta + \frac{W_1}{P}) \cdot \frac{\cos(K_2 \cdot L)}{\sin(K_2 \cdot \ell_r)} \quad (6.18)$$

where,

$$Q = \frac{K_1}{\tan(K_1 \cdot \ell_c)} + \frac{K_2}{\tan(K_2 \cdot \ell_r)} \quad (6.19)$$

The values of the constants C_1, C_2, D_1, and D_2 in the deflection Equations (6.6) and (6.7), and in the slope Equations (6.14) and (6.15) are given by Equations (6.10), (6.11), (6.17), and (6.18), respectively. The crookedness angle, θ, is determined by the method explained in Chapter V. Two other unknowns, θ_c and θ_r, exist in the deflection and slope equations and in the equations for the constants C_1, C_2, D_1, and D_2. These two unknown slopes at the supports are determined from the following slope boundary conditions.

$$x = 0 \qquad \frac{dy_1}{dx} = \theta_c$$

and

$$x = L \qquad \frac{dy_2}{dx} = \theta_r \quad (6.20)$$

Combination of Equations (6.10, 6.11, 6.14, 6.15, 6.17, 6.18, and 6.20) yields two equations of the form:

$$\theta_c \cdot A_{11} + \theta_r \cdot A_{12} = B_1 \quad (6.21)$$

and

$$\theta_c \cdot A_{21} + \theta_r \cdot A_{22} = B_2 \quad (6.22)$$

where,

$$A_{11} = 1 - \frac{K_c}{P} \cdot \frac{K_1 \cdot (K_2 - K_1 \cdot \tan(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_r))}{K_1 \cdot \tan(K_2 \cdot \ell_r) + K_2 \cdot \tan(K_1 \cdot \ell_c)} + \frac{K_c}{P \cdot L} \quad (6.23)$$

$$A_{12} = \frac{K_r}{P} \cdot \frac{K_1 \cdot K_2}{K_1 \cdot \tan(K_2 \cdot \ell_r) + K_2 \cdot \tan(K_1 \cdot \ell_c)} \cdot \frac{1}{\cos(K_1 \cdot \ell_c) \cdot \cos(K_2 \cdot \ell_r)}$$

$$- \frac{K_r}{P \cdot L} \tag{6.24}$$

$$B_1 = \frac{K_1}{Q} \cdot [T_1 \cdot \frac{K_2 - K_1 \cdot \tan(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_r)}{\tan(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_r)}$$

$$- T_2 \cdot \frac{K_2}{\sin(K_1 \cdot \ell_c) \cdot \sin(K_2 \cdot \ell_r)} - T_3 \cdot \frac{K_2}{\sin(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_r)}$$

$$+ (\theta + \frac{W_1}{P}) \cdot \frac{1}{\sin(K_1 \cdot \ell_c)}] - \frac{e_r - e_c}{L} + \frac{f_r - f_c}{L} - \frac{R'_c}{P} \tag{6.25}$$

$$A_{21} = - \frac{K_c}{P} \cdot \frac{K_1 \; K_2}{K_1 \cdot \tan(K_2 \cdot \ell_r) + K_2 \cdot \tan(K_1 \cdot \ell_c)} \cdot \frac{1}{\cos(K_1 \cdot \ell_c) \cdot \cos(K_2 \cdot \ell_r)}$$

$$+ \frac{K_c}{P \cdot L} \tag{6.26}$$

$$A_{22} = 1 + \frac{K_r}{P} \cdot \frac{K_2 \cdot \tan(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_c) + K_1}{K_1 \cdot \tan(K_2 \cdot \ell_r) + K_2 \cdot \tan(K_1 \cdot \ell_c)} \cdot \frac{K_2 \cdot \cos(K_2 \cdot \ell_c)}{\cos(K_2 \cdot \ell_r) \cdot \cos(K_2 \cdot L)}$$

$$- \frac{K_r}{P} \cdot \frac{K_2 \cdot \sin(K_2 \cdot L)}{\cos(K_2 \cdot L)} - \frac{K_r}{P \cdot L} \tag{6.27}$$

$$B_2 = \frac{K_2}{Q} \cdot [T_1 \cdot \frac{K_1}{\sin(K_1 \cdot \ell_c) \cdot \sin(K_2 \cdot \ell_r)}$$

$$- T_2 \cdot \frac{K_2 \cdot \tan(K_1 \cdot \ell_c) \cdot \tan(K_2 \cdot \ell_c) + K_1}{\tan(K_1 \cdot \ell_c) \cdot \sin(K_2 \cdot \ell_r)} \cdot \frac{\cos(K_2 \cdot \ell_c)}{\cos(K_2 \cdot L)}$$

$$- T_3 \cdot \frac{K_1}{\tan(K_1 \cdot \ell_c) \cdot \sin(K_2 \cdot \ell_r)} - (\theta + \frac{W_1}{P}) \cdot \frac{1}{\sin(K_2 \cdot \ell_r)}]$$

$$+ T_2 \cdot K_2 \cdot \tan(K_2 \cdot L) - \frac{e_r - e_c}{L} + \frac{f_r - f_c}{L} + \frac{R'_r}{P} . \tag{6.28}$$

Simultaneous solution of Equations (6.21) and (6.22) gives

$$\theta_c = \frac{B_1 \cdot A_{22} - A_{12} \cdot B_2}{A_{11} \cdot A_{22} - A_{12} \cdot A_{21}} \tag{6.29}$$

and

$$\theta_r = \frac{B_2 \cdot A_{11} - A_{21} \cdot B_1}{A_{11} \cdot A_{22} - A_{12} \cdot A_{21}} \tag{6.30}$$

Equations (6.10), (6.11), (6.17), (6.18), (6.29), and (6.30) give the values of all the six unknowns, C_1, C_2, D_1, D_2, θ_c, and θ_r, respectively, in the deflection Equations (6.6) and (6.7), and in the slope Equations (6.14) and (6.15).

The moment equation for the cylinder portion is given by Equation (6.2). Similarly, the moment equation for the rod portion is given by

$$\begin{aligned} M_2 = &- \frac{P \cdot (e_r - e_c)}{L} \cdot (L-x) + \frac{P \cdot (f_r - f_c)}{L} \cdot (L-x) \\ &- \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{L} \cdot (L - x) + R_r' \cdot (L-x) - P \cdot f_r - K_r \cdot \theta_r \\ &- \frac{w_2}{2} \cdot (L-x)^2 + P \cdot (e_r + y_2) \end{aligned} \tag{6.31}$$

CHAPTER VII

ANALYSIS OF TELESCOPING CYLINDERS

The analysis of a telescoping cylinder with an arbitrary number of tubes is developed in this chapter. For a cylinder with n tubes, there will be n-1 sliding connections. The numbering system for tubes and sliding connections is shown in Figure 25. This figure also shows the forces and reactions on a modeled telescoping cylinder. The modeling is the same as for regular cylinders and corresponds to the problem definition, assumptions, and limitations stated in Chapter IV.

The method of analysis is the same as for regular cylinders. Differential equations relating the deflections and loads are written for each tube and are solved using appropriate boundary and compatibility conditions. The solution of each differential equation will have two unknown constants, and in addition the slopes at the supports are unknowns in all equations. These (2n + 2) unknowns are determined using two deflection boundary conditions at the supports, two slope boundary conditions at the supports, and a deflection and a slope continuity compatibility condition at each sliding connection.

The bending moment at any section in the first tube portion, Figure 25, due to the external forces and reactions is

$$\begin{aligned} M_1 = {} & \frac{P\cdot(e_r-e_c)}{L}\cdot x - \frac{P\cdot(f_r-f_c)}{L}\cdot x + \frac{K_c\cdot\theta_c - K_r\cdot\theta_r}{L}\cdot x + R_c'\cdot x \\ & - M_p - P\cdot f_c - K_c\cdot\theta_c - \frac{w_1}{2}\cdot x^2 + P\cdot(e_c + y_1). \end{aligned} \tag{7.1}$$

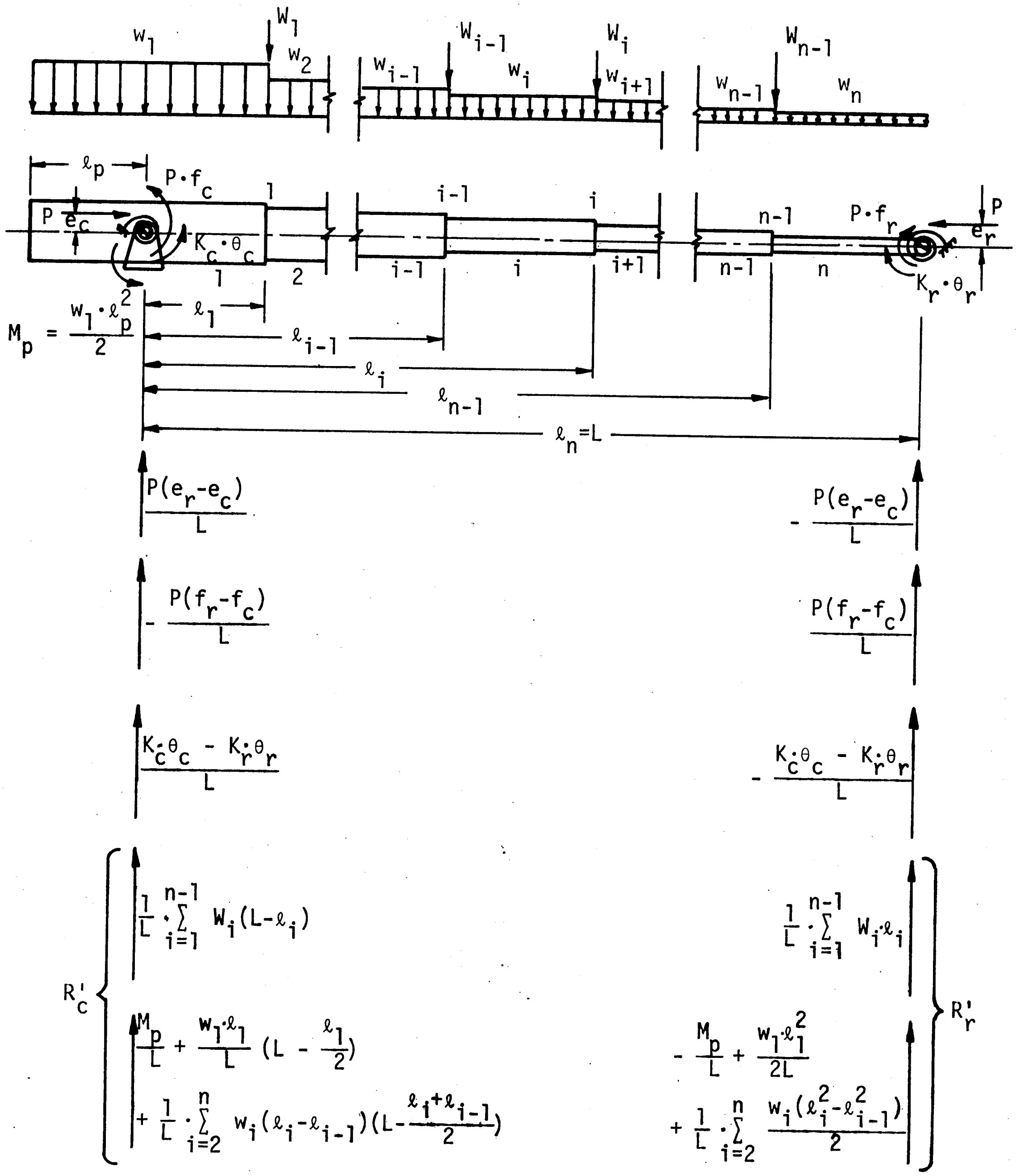


Figure 25. Forces and Reactions in a Telescoping Cylinder System

Similarly, for the second tube portion,

$$M_2 = \frac{P\cdot(e_r-e_c)}{L}\cdot x - \frac{P\cdot(f_r-f_c)}{L}\cdot x + \frac{K_c\cdot\theta_c - K_r\cdot\theta_r}{L}\cdot x + R_c'\cdot x$$

$$- M_p - P\cdot f_c - K_c\cdot\theta_c - w_1\cdot\ell_1\cdot(x - \frac{\ell_1}{2}) - \frac{w_2}{2}\cdot(x - \ell_1)^2$$

$$- W_1\cdot(x - \ell_1) + P\cdot(e_c + y_2). \qquad (7.2)$$

For the tube portions 3 to n,

$$M_i = \frac{P\cdot(e_r-e_c)}{L}\cdot x - \frac{P\cdot(f_r-f_c)}{L}\cdot x + \frac{K_c\cdot\theta_c - K_r\cdot\theta_r}{L}\cdot x + R_c'\cdot x$$

$$- M_p - P\cdot f_c - K_c\cdot\theta_c - w_1\cdot\ell_1\cdot(x - \frac{\ell_1}{2})$$

$$- \sum_{j=2}^{i-1} w_j\cdot(\ell_j-\ell_{j-1})\cdot(x - \frac{\ell_j+\ell_{j-1}}{2}) - \frac{w_i}{2}\cdot(x - \ell_{i-1})^2$$

$$- \sum_{j=1}^{i-1} W_j\cdot(x-\ell_j) + P\cdot(e_c+y_i); \quad i = 3 \text{ to } n \qquad (7.3)$$

where the variables are as defined in Chapter VI.

At any section, the internal bending moment due to the curvature obtained from ordinary bending theory is

$$M_i = -E_i\cdot I_i\cdot \frac{d^2y_i}{dx^2}; \quad i = 1 \text{ to } n. \qquad (7.4)$$

For equilibrium, the internal and external moments must be equal; hence, Equations (7.1), (7.2), and (7.3) may be combined with Equation (7.4) to yield

$$\frac{d^2y_1}{dx^2} + K_1^2\cdot y_1 = -(Y_{c1}\cdot x + Y_{c2})\cdot K_1^2 + \frac{K_1^2\cdot w_1}{2\cdot P}\cdot x^2 \qquad (7.5)$$

$$\frac{d^2y_2}{dx^2} + K_2^2\cdot y_2 = -(Y_{c1}\cdot x + Y_{c2})\cdot K_2^2 + \frac{w_1\cdot\ell_1\cdot K_2^2}{P}\cdot(x - \frac{\ell_1}{2})$$

$$+ \frac{w_2 \cdot K_2^2}{2 \cdot P} \cdot (x - \ell_1)^2 + \frac{W_1 \cdot K_2^2}{P} \cdot (x - \ell_1) \tag{7.6}$$

$$\begin{aligned}\frac{d^2 y_i}{dx^2} + K_i^2 \cdot y_i &= -(Y_{c1} \cdot x + Y_{c2}) \cdot K_i^2 + \frac{w_1 \cdot \ell_1 \cdot K_i^2}{P} \cdot (x - \frac{\ell_1}{2}) \\ &+ \frac{K_i^2}{P} \cdot \sum_{j=2}^{i-1} w_j \cdot (\ell_j - \ell_{j-1}) \cdot (x - \frac{\ell_j + \ell_{j-1}}{2}) \\ &+ \frac{w_i \cdot K_i^2}{2 \cdot P} \cdot (x - \ell_{i-1})^2 + \frac{K_i^2}{P} \cdot \sum_{j=1}^{i-1} W_j \cdot (x - \ell_j); \quad i = 3 \text{ to } n\end{aligned} \tag{7.7}$$

where

$$K_i^2 = \frac{P}{E_i \cdot I_i}; \quad i = 1 \text{ to } n \tag{7.8}$$

$$Y_{c1} = \frac{e_r - e_c}{L} - \frac{f_r - f_c}{L} + \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{P \cdot L} + \frac{R'_c}{P} \tag{7.9}$$

and

$$Y_{c2} = -\frac{M_p}{P} - f_c - \frac{K_c \cdot \theta_c}{P} + e_c. \tag{7.10}$$

The general solution of Equations (7.5), (7.6), and (7.7) yields the deflection equations.

For tube portion 1,

$$y_1 = C_1 \cdot \cos(K_1 \cdot x) + D_1 \cdot \sin(K_1 \cdot x) - Y_{c1} \cdot x - Y_{c2} + \frac{w_1}{2 \cdot P} \cdot x^2 - \frac{w_1}{P \cdot K_1^2} \tag{7.11}$$

For tube portion 2,

$$y_2 = C_2 \cdot \cos(K_2 \cdot x) + D_2 \cdot \sin(K_2 \cdot x) - Y_{c1} \cdot x - Y_{c2}$$

$$+ \frac{w_1 \cdot \ell_1}{P} \cdot \left(x - \frac{\ell_1}{2}\right) + \frac{w_2}{2 \cdot P}(x - \ell_1)^2 - \frac{w_2}{P \cdot K_2^2} + \frac{W_1}{P} \cdot (x - \ell_1)$$

(7.12)

For tube portions 3 to n,

$$y_i = C_i \cdot \cos(K_i \cdot x) + D_i \cdot \sin(K_i \cdot x) - Y_{c1} \cdot x - Y_{c2}$$

$$+ \frac{w_1 \cdot \ell_1}{P} \cdot \left(x - \frac{\ell_1}{2}\right) + \frac{1}{P} \cdot \sum_{j=2}^{i-1} w_j \cdot (\ell_j - \ell_{j-1}) \cdot \left(x - \frac{\ell_j + \ell_{j-1}}{2}\right)$$

$$+ \frac{w_i}{2 \cdot P} \cdot (x - \ell_{i-1})^2 - \frac{w_i}{P \cdot K_i^2} + \frac{1}{P} \cdot \sum_{j=1}^{i-1} W_j \cdot (x - \ell_j); \quad i = 3 \text{ to } n$$

(7.13)

The equations for slopes are obtained from the first derivatives of the deflection Equations (7.11), (7.12), and (7.13). These slope equations are:

For tube portion 1,

$$\frac{dy_1}{dx} = -C_1 \cdot K_1 \cdot \sin(K_1 \cdot x) + D_1 \cdot K_1 \cdot \cos(K_1 \cdot x) - Y_{c1} + \frac{w_1}{P} \cdot x \quad (7.14)$$

For tube portion 2,

$$\frac{dy_2}{dx} = -C_2 \cdot K_2 \cdot \sin(K_2 \cdot x) + D_2 \cdot K_2 \cdot \cos(K_2 \cdot x) - Y_{c1} + \frac{w_1 \cdot \ell_1}{P}$$

$$+ \frac{w_2}{P} \cdot (x - \ell_1) + \frac{W_1}{P} \quad (7.15)$$

For tube portions 3 to n,

$$\frac{dy_i}{dx} = -C_i \cdot K_i \cdot \sin(K_i \cdot x) + D_i \cdot K_i \cdot \cos(K_i \cdot x) - Y_{c1} + \frac{w_1 \cdot \ell_1}{P}$$

$$+ \frac{1}{P} \cdot \sum_{j=2}^{i-1} w_j \cdot (\ell_j - \ell_{j-1}) + \frac{w_i}{P} \cdot (x - \ell_{i-1}) + \frac{1}{P} \cdot \sum_{j=1}^{i-1} W_j;$$

$$i = 3 \text{ to } n \quad (7.16)$$

In the above slope and deflection equations C_i and D_i, i = 1 to n, and θ_c and θ_r are the (2n + 2) unknowns. The following (2n + 2) boundary and compatibility conditions are used to determine these unknown constants.

The boundary conditions at the cylinder and rod supports are

$$x = 0 \qquad \frac{dy_1}{dx} = \theta_c \tag{7.17}$$

$$x = 0 \qquad y_1 = 0 \tag{7.18}$$

$$x = L \qquad \frac{dy_n}{dx} = \theta_r \tag{7.19}$$

$$x = L \qquad y_n = 0 \tag{7.20}$$

The compatibility conditions at each sliding connection are

$$x = \ell_i \qquad y_i = y_{i+1} \qquad i = 1 \text{ to } n\text{-}1 \tag{7.21}$$

$$x = \ell_i \qquad \frac{dy_i}{dx} - \theta_i = \frac{dy_{i+1}}{dx} \qquad i = 1 \text{ to } n\text{-}1 \tag{7.22}$$

Application of the boundary and compatibility conditions results in the following (2n + 2) equations. Equation (7.17) yields,

$$\theta_c \cdot \left(1 + \frac{K_c}{P \cdot L}\right) - D_1 \cdot K_1 - \theta_r \cdot \frac{K_r}{P \cdot L} = -\frac{e_r - e_c}{L} + \frac{f_r - f_c}{L} - \frac{R_c'}{P} \tag{7.23}$$

Equation (7.18) yields,

$$\theta_c \cdot \frac{K_c}{P} + C_1 = -\frac{M_p}{P} - f_c + e_c + \frac{w_1}{P \cdot K_1^2} \tag{7.24}$$

Equation (7.19) yields,

$$\theta_c \cdot \frac{K_c}{P \cdot L} + C_n \cdot K_n \cdot \sin(K_n \cdot L) - D_n \cdot K_n \cdot \cos(K_n \cdot L) + \theta_r \cdot \left(1 - \frac{K_r}{P \cdot L}\right) =$$

$$-\frac{e_r - e_c}{L} + \frac{f_r - f_c}{L} - \frac{R_c'}{P} + \frac{w_1 \cdot \ell_1}{P} + \frac{1}{P} \cdot \sum_{j=2}^{n} w_j \cdot (\ell_j - \ell_{j-1})$$

$$+ \frac{1}{P} \cdot \sum_{j=1}^{n-1} W_j \qquad (7.25)$$

Equation (7.20) yields,

$$C_n \cdot \cos(K_n \cdot L) + D_n \cdot \sin(K_n \cdot L) + \frac{K_r \cdot \theta_r}{P} = e_r - f_r - \frac{M_p}{P} + \frac{R'_c}{P} \cdot L$$

$$- \frac{w_1 \cdot \ell_1}{P} \cdot (L - \frac{\ell_1}{2}) - \frac{1}{P} \cdot \sum_{j=2}^{n} w_j \cdot (\ell_j - \ell_{j-1}) \cdot (L - \frac{\ell_j + \ell_{j-1}}{2})$$

$$+ \frac{w_n}{P \cdot K_n^2} - \frac{1}{P} \cdot \sum_{j=1}^{n-1} W_j \cdot (L - \ell_j) \qquad (7.26)$$

Equation (7.21) yields,

$$C_{i-1} \cdot \cos(K_{i-1} \cdot \ell_{i-1}) + D_{i-1} \cdot \sin(K_{i-1} \cdot \ell_{i-1}) - C_i \cdot \cos(K_i \cdot \ell_{i-1})$$

$$- D_i \cdot \sin(K_i \cdot \ell_{i-1}) = \frac{w_{i-1}}{P \cdot K_{i-1}^2} - \frac{w_i}{P \cdot K_i^2} ; \quad i = 2 \text{ to } n$$

$$(7.27)$$

Equation (7.22) yields,

$$-C_{i-1} \cdot K_{i-1} \cdot \sin(K_{i-1} \cdot \ell_{i-1}) + D_{i-1} \cdot K_{i-1} \cdot \cos(K_{i-1} \cdot \ell_{i-1})$$

$$+ C_i \cdot K_i \cdot \sin(K_i \cdot \ell_{i-1}) - D_i \cdot K_i \cdot \cos(K_i \cdot \ell_{i-1})$$

$$= \theta_{i-1} + \frac{W_{i-1}}{P} ; \quad i = 2 \text{ to } n \qquad (7.28)$$

Equations (7.23) through (7.28) are solved simultaneously to determine the unknown terms. To simplify the solution, these equations are arranged in a matrix form as shown below.

$$[S]\ \{U\} = \{R\} \qquad (7.29)$$

The matrix form, shown in Figure 26, is solved for the unknown vector $\{U\}$,

$$
\begin{bmatrix}
(1+\frac{K_c}{PL}) & 0 & -K_1 & 0 & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 & -\frac{K_r}{PL} \\
\frac{K_c}{P} & 1.0 & 0 & 0 & 0 & 0 & 0 \cdots & 0 & 0 & 0 & 0 & 0 \\
0 & C(K_1\ell_1) & S(K_1\ell_1) & -C(K_2\ell_1) & -S(K_2\ell_1) & 0 & 0 \cdots & 0 & 0 & 0 & 0 & 0 \\
0 & -K_1S(K_1\ell_1) & K_1C(K_1\ell_1) & K_2S(K_2\ell_1) & -K_2C(K_2\ell_1) & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & C(K_2\ell_2) & S(K_2\ell_2) & -C(K_3\ell_2) & -S(K_3\ell_2) & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -K_2S(K_2\ell_2) & K_2C(K_2\ell_2) & K_3S(K_3\ell_2) & -K_3C(K_3\ell_2) & 0 & 0 & 0 & 0 & 0 \\
\vdots & \vdots & \vdots & & \ddots & \ddots & \ddots & \ddots & \ddots & \vdots & \vdots & \vdots \\
\vdots & \vdots & \vdots & & & & \ddots & \ddots & \ddots & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & C(K_{n-1}\ell_{n-1}) & S(K_{n-1}\ell_{n-1}) & -C(K_n\ell_{n-1}) & -S(K_n\ell_{n-1}) & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \cdots & -K_{n-1}S(K_{n-1}\ell_{n-1}) & K_{n-1}C(K_{n-1}\ell_{n-1}) & K_nS(K_n\ell_{n-1}) & -K_nC(K_n\ell_{n-1}) & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 \cdots & 0 & 0 & C(K_nL) & S(K_nL) & \frac{K_r}{P} \\
\frac{K_c}{PL} & 0 & 0 & 0 & 0 & 0 & 0 \cdots & 0 & 0 & K_nS(K_nL) & -K_nC(K_nL) & (1-\frac{K_r}{PL})
\end{bmatrix}
\left\{\begin{matrix}
\theta_c \\ C_1 \\ D_1 \\ C_2 \\ D_2 \\ C_3 \\ \vdots \\ C_{n-1} \\ D_{n-1} \\ C_n \\ D_n \\ \theta_r
\end{matrix}\right\}
=
\left\{\begin{matrix}
-\frac{e_r - e_c}{L} + \frac{f_r - f_c}{L} - \frac{R'_c}{P} \\
e_c - f_c - \frac{M_p}{P} + \frac{w_1}{PK_1^2} \\
\frac{w_1}{PK_1^2} - \frac{w_2}{PK_2^2} \\
\theta_1 + \frac{W_1}{P} \\
\frac{w_2}{PK_2^2} - \frac{w_3}{PK_3^2} \\
\theta_2 + \frac{W_2}{P} \\
\vdots \\
\\
\frac{w_{n-1}}{PK^2_{n-1}} - \frac{w_n}{PK_n^2} \\
\theta_{n-1} + \frac{W_{n-1}}{P} \\
e_r - f_r - \frac{M_p}{P} + \frac{R'_c}{P}L - \frac{w_1\ell_1}{P}(L - \frac{\ell_1}{2}) - \frac{1}{P}\sum_{i=2}^{n} w_i(\ell_i - \ell_{i-1})(L - \frac{\ell_i + \ell_{i-1}}{2}) + \frac{w_n}{PK_n^2} - \frac{1}{P}\sum_{j=1}^{n-1} W_j (L - \ell_j) \\
-\frac{e_r - e_c}{L} + \frac{f_r - f_c}{L} - \frac{R'_c}{P} + \frac{w_1\ell_1}{P} + \frac{1}{P}\sum_{i=2}^{n} w_i(\ell_i - \ell_{i-1}) + \frac{1}{P}\sum_{j=1}^{n-1} W_j
\end{matrix}\right\}
$$

Figure 26. Matrix Form of Equations

$$\{U\} = [S]^{-1} \{R\} \tag{7.30}$$

The crookedness angle at each sliding connection is determined as described in Chapter V. Once the crookedness angles and the unknown constants C_i's and D_i's and the end slopes θ_c and θ_r are determined, the moment, deflection, and slope at any section in the system are determined from Equations (7.1) to (7.3), (7.11) to (7.13), and (7.14) to (7.16), respectively.

CHAPTER VIII

ANALYSIS OF TIE ROD CYLINDERS

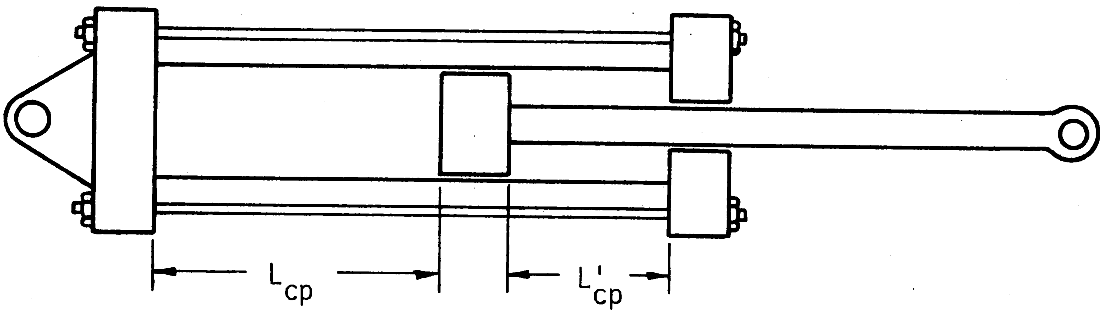
The presence of tie rods increases the capacity of the cylinder to resist bending; however, the cylinder with tie rods has an additional form of failure due to the potential separation of the cap or head from the cylinder body resulting in fluid leakage. This separation failure is mainly due to the combination of stretch in the tie rods when the fluid load is transferred through them to the mountings and longitudinal contraction with radial expansion of the cylinder due to fluid pressure. Either or both of these factors may cause the separation, depending on the cylinder mounting position, the piston head position in the cylinder, and the side on which pressure is applied.

Two independent analyses are required for cylinders with tie rods: first, to determine the separation pressures for different piston head positions and pressurized sides in a straight cylinder; and second, to determine the failure load for a fully extended cylinder due to excessive stress resulting from axial load and bending. Equations for these independent analyses are developed in the following sections.

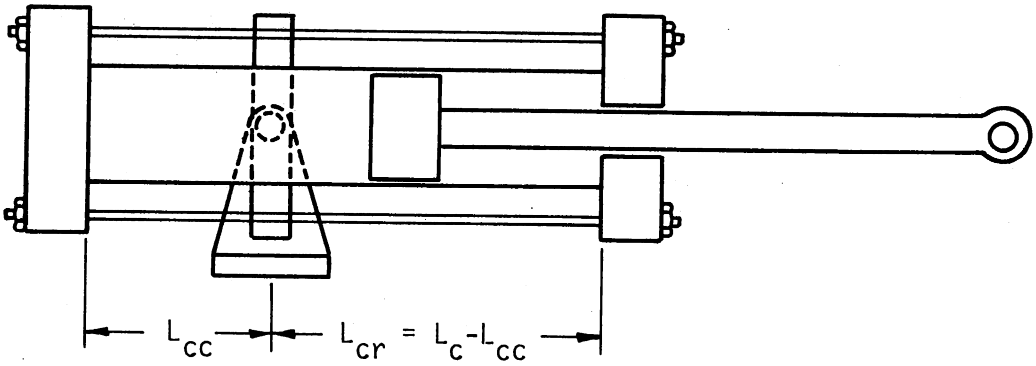
Analysis for Separation Pressures

Due to the initial tensioning of the tie rods, there exists a longitudinal compressive stress in the cylinder wall. When the cylinder is pressurized, the load on the rod end is transferred through the fluid to the cylinder mountings. Whether the load transfer takes place through the tie rods or not, and whether there is cylinder longitudinal contraction due to fluid pressure or not depends on: (1) the type of cylinder mount (cap mounting, intermediate mounting or head mounting (see Figure 27)); (2) piston head position; and (3) pressurized side (rod side or cap side).

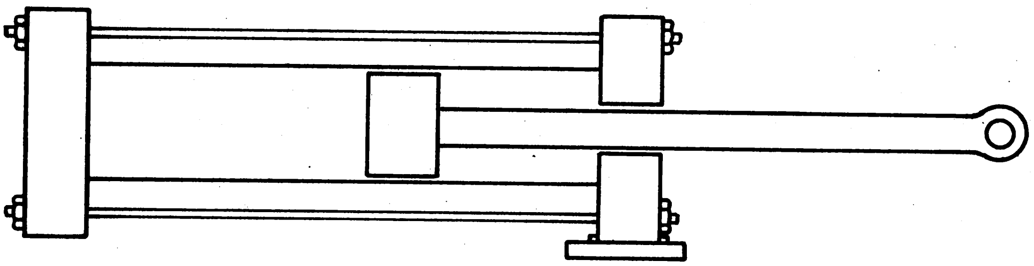
When the piston head is in the position shown in Figure 28(a) with pressure on the cap side, only a very small length of the cylinder is subjected to pressure and hence there is no axial contraction of the cylinder due to pressure. As the piston head moves away from the cap, the pressurized length of cylinder increases and the axial cylinder contraction due to hoop and radial stresses increases. The axial contraction is maximum when piston head is very close to the cylinder head or when it is in contact with the cylinder head. Depending on the type of mounting, for the fully extended position, the load may or may not be transferred through the tie rods. In cap-mounted cylinders, Figure 27(a), the load is not transferred through the tie rod during the forward stroke until the piston head comes in contact with the cylinder head. In other cases of mounting, Figures 27(b) and 27(c), the load is always carried through the tie rods. When the pressure is relieved from the cap side and applied to the rod side, initially there is no cylinder contraction, but as the piston head moves toward the cap the pressurized length of cylinder increases and hence cylinder contraction increases correspondingly. Cylinder contraction is maximum when the piston head is very close to the cap or in contact with the cap. Again, for this backward stroke, depending on the type of mounting, the load may or may not be carried through the tie rods. For each mounting style, the



(a) Cylinder Mounting at Cap

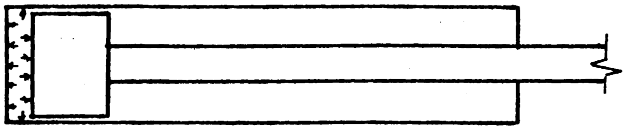


(b) Intermediate Cylinder Mounting

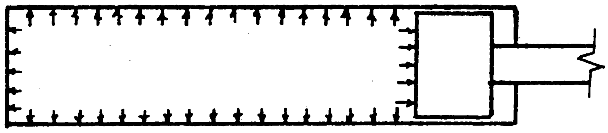


(c) Cylinder Mounting at Head

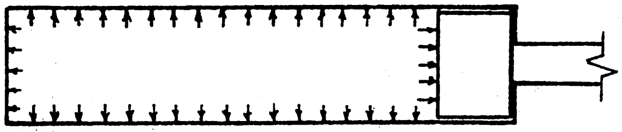
Figure 27. Cylinder Mounting Positions



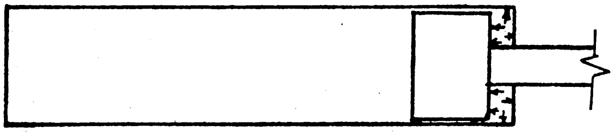
(a) Case 1: Pressure on cap side; P.H. (piston head) very close to cap



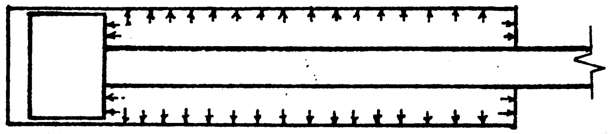
(b) Case 2: Pressure on cap side; P.H. anywhere along the length but not in contact with cylinder head



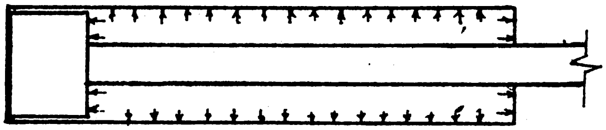
(c) Case 3: Pressure on cap side; P.H. in contact with cylinder head



(d) Case 4: Pressure on rod side; P.H. very close to cylinder head



(e) Case 5: Pressure on rod side; P.H. anywhere along the length but not in contact with cylinder cap.



(f) Case 6: Pressure on rod side; P.H. in contact with cylinder cap

Figure 28. Piston Head Positions and Pressurization Side Combinations

separation pressure for any piston head position during a cycle of operation can be defined by six equations. These equations are developed in the following sections.

The six different cases that result from different piston head positions and pressurized side are shown in Figure 28. Separation occurs when the longitudinal compressive load on the cylinder wall reduces to zero due to tie-rod stretch and longitudinal contraction of the cylinder. To develop the equations for compressive load on the cylinder, the following equilibrium equations and compatibility conditions are used.

Combinations of forces at the cap and head ends of the cylinder and at an intermediate support are shown in Figure 29, for the mounting cases shown in Figure 27, and piston/pressure cases shown in Figure 28. Equilibrium is described by the following equations.

At cap end:

$$F_t - (F_c \text{ or } F_{cc}) - (P \text{ or } P' \text{ or zero}) = 0 \tag{8.1}$$

At intermediate support:

$$F_{cc} - F_{cr} \pm (P \text{ or } P' \text{ or zero}) = 0 \tag{8.2}$$

At head end:

$$(F_c \text{ or } F_{cr}) - F_t + (P \text{ or } P' \text{ or zero}) = 0 \tag{8.3}$$

where

F_t = final force in tie rods;

F_c = final axial force on cylinder wall;

F_{cc} and F_{cr} = final axial force on cylinder wall on the cap side and on the head side, respectively, in the cylinder supported at an intermediate point;

P = axial compressive load on cylinder during a forward stroke; and

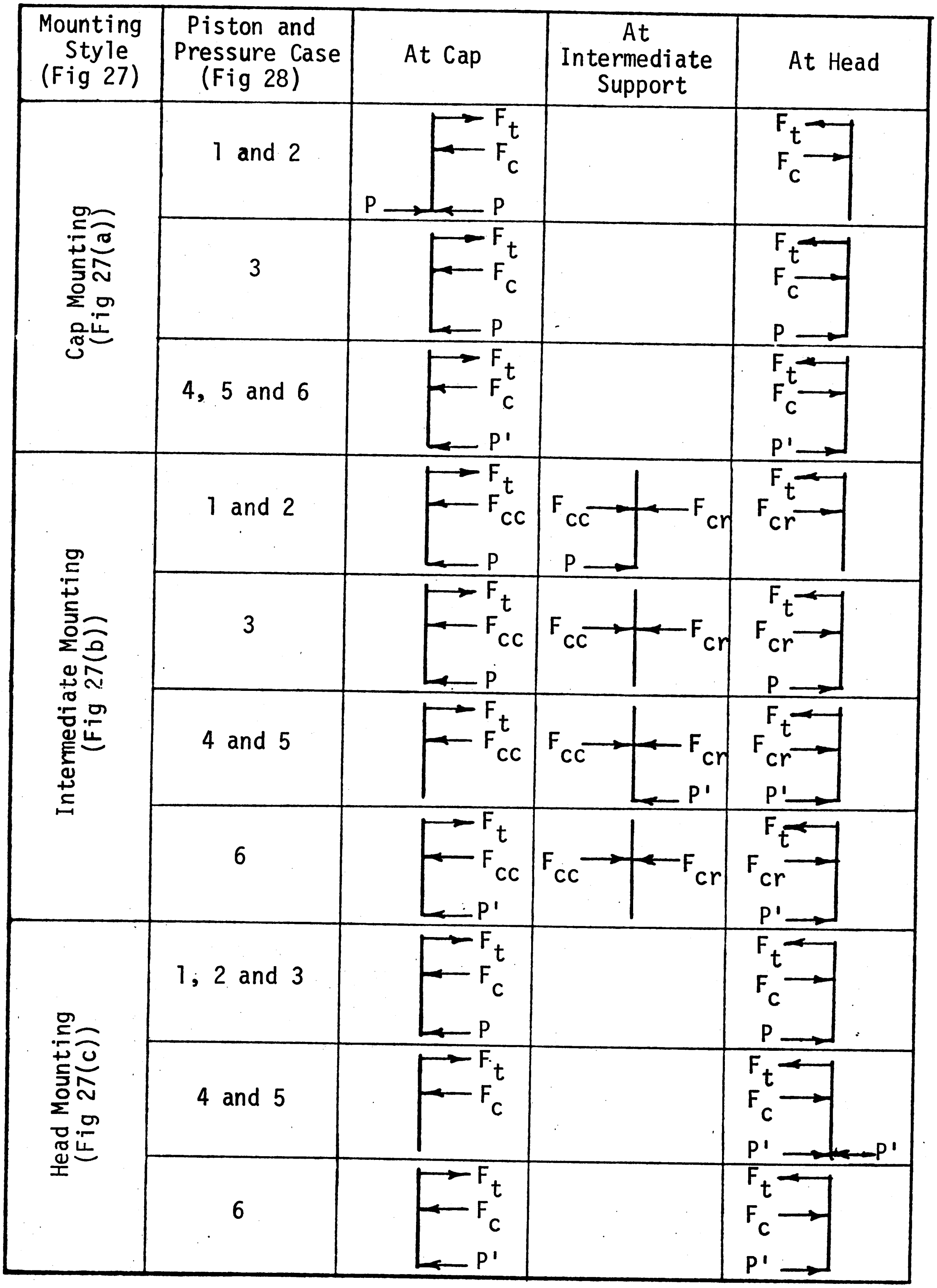


Figure 29. Equilibrium Equations

P' = axial tensile load on cylinder during a backward stroke.

The compatibility condition that applies to all the cases is

$$\delta_t + \delta_c = 0 \tag{8.4}$$

where

δ_t = change in length of the tie rods due to pressurization of the cylinder; and

δ_c = change in length of the cylinder tube due to pressurization of the cylinder.

The change in length of tie rods, δ_t, for all cases is given by

$$\delta_t = -\frac{(F_i - F_t)\cdot L_t}{A_t\cdot E_t} \tag{8.5}$$

where

F_i = force in tie rods = force on cylinder wall, before pressurization;

L_t = length of tie rods between tie rod nuts;

A_t = total cross sectional area of tie rods; and

E_t = modulus of elasticity of tie rod material.

The change in length of the cylinder, δ_c, is due to two effects: first, δ_{chr}, due to hoop and radial stresses in the pressurized part of the cylinder; and second, δ'_c, due to change in axial force on the cylinder wall.

$$\delta_c = \delta_{chr} + \delta'_c \tag{8.6}$$

The change in length of the cylinder due to hoop and radial stresses is due to the Poisson's ratio effect and is given by

$$\delta_{chr} = \frac{\mu_c}{E_c}\cdot(S_h + S_r)\cdot L_x \tag{8.7}$$

where

μ_c = Poisson's ratio of the cylinder material; and

E_c = modulus of elasticity of the cylinder material.

L_x is either L_{cp} or L'_{cp}, Figure 27(a), the pressurized length of the cylinder, depending on which side of the piston head is pressurized. S_h and S_r, the hoop and radial stresses, respectively, at any radial distance, r, are given by

$$S_h = \frac{a^2 \cdot \bar{p}}{b^2 - a^2} \cdot \left(1 + \frac{b^2}{r^2}\right) = \frac{A_b \cdot \bar{p}}{A_c} \cdot \left(1 + \frac{b^2}{r^2}\right) \tag{8.8}$$

and

$$S_r = \frac{a^2 \cdot \bar{p}}{b^2 - a^2} \cdot \left(1 - \frac{b^2}{r^2}\right) = \frac{A_b \cdot \bar{p}}{A_c} \cdot \left(1 - \frac{b^2}{r^2}\right) \tag{8.9}$$

where

a = inner radii of the cylinder tube;

b = outer radii of the cylinder tube;

A_b = bore area of the cylinder tube; and

A_c = cross sectional area of the cylinder wall.

$\bar{p}$ is either p or p', depending on which side of the piston head is pressurized, where p is the fluid pressure on the cap side and p' is the fluid pressure on the head side.

Substitution of Equations (8.8) and (8.9) in Equation (8.7) yields

$$\delta_{chr} = \frac{\mu_c}{E_c} \cdot \left(2 \cdot \bar{p} \cdot \frac{A_b}{A_c}\right) \cdot L_x \tag{8.10}$$

which is independent of the radial distance, and hence, the axial contraction of the cylinder due to hoop and radial stresses is constant at all radial distances.

The change in length of the cylinder due to change in the axial force, δ'_c, depends on the type of mounting. For cap or head mounting,

$$\delta_c' = -\frac{(F_i - F_c)\cdot L_c}{A_c\cdot E_c} \tag{8.11}$$

where L_c = length of the cylinder tube.

In the case of intermediate mounting, the axial force in the cylinder to the left of the mounting differs from that to the right by a quantity equal to P or P', or may be the same on both sides (see equilibrium equations, Figure 29), depending on the piston head position. Hence,

$$\delta_c' = -\frac{(F_i - F_{cc})\cdot L_{cc}}{A_c\cdot E_c} - \frac{(F_i - F_{cr})\cdot(L_c - L_{cc})}{A_c\cdot E_c}\ . \tag{8.12}$$

Substitution of Equations (8.5) and (8.10) and either Equations (8.11) and (8.12) as appropriate into the compatibility condition, Equation (8.4), and into the corresponding equilibrium condition, from Figure 29, permits evaluation of the compressive force on the cylinder and the tension in the tie rods for all cases of mountings, piston head positions and pressurized sides. Once the equations for the axial force in the cylinder wall are determined, the separation pressures, p_s, are evaluated by equating the cylinder wall force to zero and solving for P or P' (which is p_s times the corresponding bore area, A_b or A_b'). The resulting equations for the forces in the cylinder wall and tie rods and for the separation pressures for all six cases (Figure 28) of each mounting position (Figure 27) are given in the following sections.

Cylinder Mounted at Cap

Case 1 (Figure 28(a)):

$$F_c = F_i = F_t. \tag{8.13}$$

Separation will not occur at any pressure.

Case 2 (Figure 28(b)):

$$F_c = F_i - 2\cdot P\cdot\mu_c\cdot\frac{L_{cp}}{A_c\cdot E_c}\cdot Z = F_t \tag{8.14}$$

where

$$Z = \frac{1}{\dfrac{L_t}{A_t\cdot E_t} + \dfrac{L_c}{A_c\cdot E_c}} \tag{8.15}$$

$$p_s = \frac{F_i/A_b}{2\cdot\mu_c\cdot\dfrac{L_{cp}}{A_c\cdot E_c}\cdot Z}\ . \tag{8.16}$$

Case 3 (Figure 28(c)):

$$F_c = F_i + \frac{P\cdot L_c}{A_c\cdot E_c}\cdot(1 - 2\cdot\mu_c\cdot\frac{L_{cp}}{L_c})\cdot Z - P \tag{8.17}$$

$$F_t = F_c + P \tag{8.18}$$

$$p_s = \frac{F_i/A_b}{1 - \dfrac{L_c}{A_c\cdot E_c}\cdot(1 - 2\cdot\mu_c\cdot\dfrac{L_{cp}}{L_c})\cdot Z} \tag{8.19}$$

Case 4 (Figure 28(d)):

$$F_c = F_i - P' + \frac{P'\cdot L_c}{A_c\cdot E_c}\cdot Z \tag{8.20}$$

$$F_t = F_c + P' \tag{8.21}$$

$$p_s = \frac{F_i/A_b'}{1 - \dfrac{L_c}{A_c\cdot E_c}\cdot Z} \tag{8.22}$$

Cases 5 and 6 (Figures 28(e) and (f)):

$$F_c = F_i - P' + \frac{P'\cdot L_c}{A_c\cdot E_c}\cdot(1 - 2\cdot\mu_c\cdot\frac{A_b\cdot L_{cp}'}{A_b'\cdot L_c})\cdot Z \tag{8.23}$$

$$F_t = F_c + P' \tag{8.24}$$

$$p_s = \frac{F_i/A_b'}{1 - \frac{L_c}{A_c \cdot E_c} \cdot \left(1 - 2 \cdot \mu_c \cdot \frac{A_b \cdot L_{cp}'}{A_b' \cdot L_c}\right) \cdot Z} \tag{8.25}$$

Cylinder With Intermediate Mount

Case 1 (Figure 28(a)):

$$F_{cc} = F_i + \frac{P \cdot L_{cc}}{A_c \cdot E_c} \cdot Z - P \tag{8.26}$$

$$F_{cr} = F_{cc} + P = F_t \tag{8.27}$$

$$p_s = \frac{F_i/A_b}{1 - \frac{L_{cc}}{A_c \cdot E_c} \cdot Z} \tag{8.28}$$

Case 2 (Figure 28(b)):

$$F_{cc} = F_i - P + \frac{P \cdot L_{cc}}{A_c \cdot E_c} \cdot \left(1 - 2 \cdot \mu_c \cdot \frac{L_{cp}}{L_{cc}}\right) \cdot Z \tag{8.29}$$

$$F_{cr} = F_{cc} + P = F_t \tag{8.30}$$

$$p_s = \frac{F_i/A_b}{1 - \frac{L_{cc}}{A_c \cdot E_c} \cdot \left(1 - 2 \cdot \mu_c \cdot \frac{L_{cp}}{L_{cc}}\right) \cdot Z} \tag{8.31}$$

Case 3 (Figure 28(c)):

$$F_{cc} = F_{cr} = F_i + \frac{P \cdot L_c}{A_c \cdot E_c} \cdot \left(1 - 2 \cdot \mu_c \cdot \frac{L_{cp}}{L_c}\right) \cdot Z - P \tag{8.32}$$

$$F_t = F_{cc} + P \tag{8.33}$$

$$p_s = \frac{F_i/A_b}{1 - \frac{L_c}{A_c \cdot E_c} \cdot \left(1 - 2 \cdot \mu_c \cdot \frac{L_{cp}}{L_c}\right) \cdot Z} \tag{8.34}$$

Case 4 (Figure 28(d)):

$$F_{cc} = F_i + \frac{P'\cdot L_c}{A_c\cdot E_c}\cdot\left(1 - \frac{L_{cc}}{L_c}\right)\cdot Z = F_t \tag{8.35}$$

$$F_{cr} = F_{cc} - P' \tag{8.36}$$

$$p_s = \frac{F_i/A_b'}{1 - \frac{L_c}{A_c\cdot E_c}\cdot\left(1 - \frac{L_{cc}}{L_c}\right)\cdot Z} \tag{8.37}$$

Case 5 (Figure 28(e)):

$$F_{cc} = F_i + \frac{P'\cdot L_c}{A_c\cdot E_c}\cdot\left(1 - \frac{L_{cc}}{L_c} - 2\cdot\mu_c\cdot\frac{L_{cp}'\cdot A_b}{L_c\cdot A_b'}\right)\cdot Z = F_t \tag{8.38}$$

$$F_{cr} = F_{cc} - P' \tag{8.39}$$

$$p_s = \frac{F_i/A_b'}{1 - \frac{L_c}{A_c\cdot E_c}\cdot\left(1 - \frac{L_{cc}}{L_c} - 2\cdot\mu_c\cdot\frac{L_{cp}'\cdot A_b}{L_c\cdot A_b'}\right)\cdot Z} \tag{8.40}$$

Case 6 (Figure 28(f)):

$$F_{cc} = F_{cr} = F_i - P' + \frac{P'\cdot L_c}{A_c\cdot E_c}\cdot\left(1 - 2\cdot\mu_c\cdot\frac{A_b\cdot L_{cp}'}{A_b'\cdot L_c}\right)\cdot Z \tag{8.41}$$

$$F_t = F_{cc} + P' \tag{8.42}$$

$$p_s = \frac{F_i/A_b'}{1 - \frac{L_c}{A_c\cdot E_c}\cdot\left(1 - 2\cdot\mu_c\cdot\frac{A_b\cdot L_{cp}'}{A_b'\cdot L_c}\right)\cdot Z} \tag{8.43}$$

Cylinder Mounted at Head

Case 1 (Figure 28(a)):

$$F_c = F_i + \frac{P\cdot L_c}{A_c\cdot E_c}\cdot Z - P \tag{8.44}$$

$$F_t = F_c + P \tag{8.45}$$

$$p_s = \frac{F_i/A_b}{1 - \frac{L_c}{A_c \cdot E_c} \cdot Z} \tag{8.46}$$

Cases 2 and 3 (Figures 28(b) and (c)):

$$F_c = F_i + \frac{P \cdot L_c}{A_c \cdot E_c} \cdot (1 - 2 \cdot \mu_c \cdot \frac{L_{cp}}{L_c}) \cdot Z - P \tag{8.47}$$

$$F_t = F_c + P \tag{8.48}$$

$$p_s = \frac{F_i/A_b}{1 - \frac{L_c}{A_c \cdot E_c} \cdot (1 - 2 \cdot \mu_c \cdot \frac{L_{cp}}{L_c}) \cdot Z} \tag{8.49}$$

Case 4 (Figure 28(d)):

$$F_c = F_i = F_t \tag{8.50}$$

Separation will not occur at any pressure.

Case 5 (Figure 28(e)):

$$F_c = F_i - 2 \cdot \mu_c \cdot P' \cdot \frac{L'_{cp} \cdot A_b}{A_c \cdot E_c \cdot A'_c} \cdot Z = F_t \tag{8.51}$$

$$p_s = \frac{F_i/A'_b}{2 \cdot \mu_c \cdot \frac{L_{cp} \cdot A_b}{A_c \cdot E_c \cdot A'_b} \cdot Z} \tag{8.52}$$

Case 6 (Figure 28(f)):

$$F_c = F_i - P' + \frac{P' \cdot L_c}{A_c \cdot E_c} \cdot (1 - 2 \cdot \mu_c \cdot \frac{A_b \cdot L'_{cp}}{A'_b \cdot L_c}) \cdot Z \tag{8.53}$$

$$F_t = F_c + P' \tag{8.54}$$

$$p_s = \frac{F_i/A'_b}{1 - \frac{L_c}{A_c \cdot E_c} \cdot (1 - 2 \cdot \mu_c \cdot \frac{A_b \cdot L'_{cp}}{A'_b \cdot L_c}) \cdot Z} \tag{8.55}$$

Bending Analysis

The procedure for bending analysis of cylinders with tie rods is virtually the same as that for regular cylinders except that modifications to account for the effects of tie rod forces are required. When the cylinder is deflected due to loading, the cylinder bends, but the tie rods, due to initial tensioning, remain straight. Forces in all tie rods are initially equal; however, due to curvature of the cylinder, the end blocks rotate and result in unequal tie rod forces across the cylinder. This difference in forces develops a constant moment along the cylinder part which acts in an opposite direction to the moments due to applied loads. Hence, the addition of tie rods increases the bending capacity of the cylinder. The method of analysis is as described in Chapter IV.

The tie rod moment for any deflected shape of the cylinder is determined as follows. As indicated in Figure 30, the change in length of the top tie rods due to bending, δ_{tm}, is

$$\delta_{tm} = R \cdot (\theta_c - \theta_g) \tag{8.56}$$

where

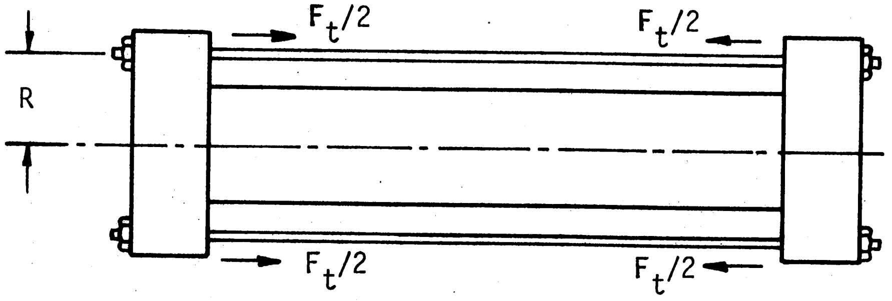
R = distance of the axis of the top or bottom tie rods from the axis of the cylinder in the plane of bending (see Figure 30(a));

θ_c = slope of the cylinder at the cylinder support; and

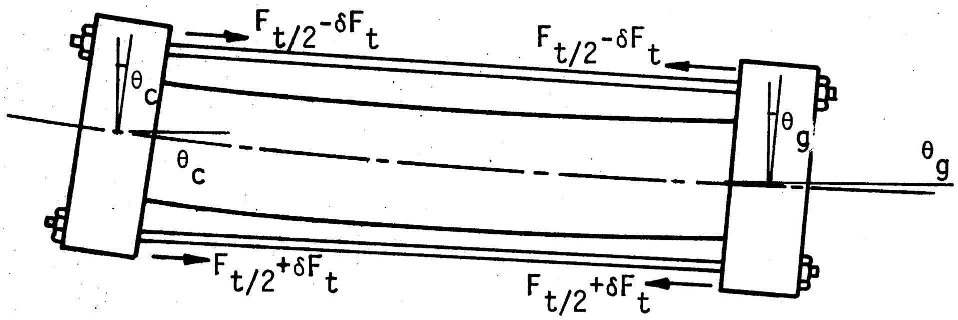
θ_g = slope of the cylinder at the step point c.

By linear stress-strain relations, the change in top tie rods force, δF_t, is

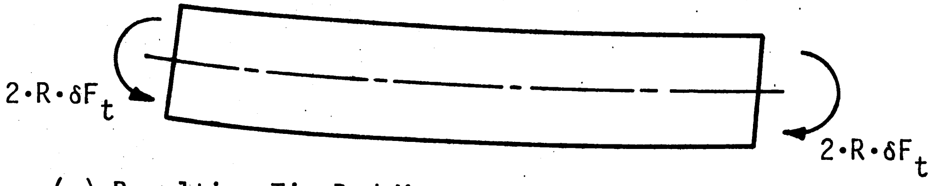
$$\delta F_t = \frac{\delta_{tm} \cdot (A_t/2) \cdot E_t}{L_t} = \frac{\delta_{tm}}{2} \cdot \frac{A_t \cdot E_t}{L_t} \; . \tag{8.57}$$



(a) Initial Tie Rod Forces in Straight Position



(b) Final Tie Rod Forces in Deflected Position



(c) Resulting Tie Rod Moment on Cylinder

Figure 30. Determination of Tie Rod Moment

The force in the top tie rods with the cylinder straight and pressurized is $F_t/2$. The tie rod force, F_t, is determined from Equation (8.14) or (8.30), depending on the mounting position. Final force in the top tie rods is

$$F_{top} = \frac{F_t}{2} - \delta F_t \tag{8.58}$$

By symmetry, the final force in the bottom tie rods is

$$F_{bot} = \frac{F_t}{2} + \delta F_t \tag{8.59}$$

The tie rod moment due to the difference in tie rods force is

$$M_t = 2 \cdot R \cdot \delta F_t = R^2 \cdot (\theta_c - \theta_g) \cdot \frac{A_t \cdot E_t}{L_t} \tag{8.60}$$

In the analysis the tie rod stresses are checked for yielding and for compressive stress.

The equations for moments, slopes, and deflections are the same as developed for regular cylinders with the following modifications to account for the tie rod moment.

The moment equation for the cylinder portion is obtained by adding a term $(-M_t)$ to Equation (6.2). The moment equation for the rod portion remains the same as Equation (6.31).

The equations for slopes and deflections in the cylinder portion and rod portion and the equations for slopes at the supports are the same as slope Equations (6.14) and (6.15) and deflection Equations (6.6) and (6.7), and slope at support Equations (6.29) and (6.30) with T_1' and T_3' instead of T_1 and T_3 in all these equations and in all other equations (Equations (6.10) (6.17) (6.18) (6.25) and (6.28)) in regular cylinder analysis involving T_1 and T_3 where,

$$T_1' = T_1 + \frac{M_t}{P} \tag{8.61}$$

and

$$T_3' = T_3 + \frac{M_t}{P} . \tag{8.62}$$

In the tie rod moment Equation (8.60), the cylinder part slope at the sliding connection, θ_g, is an unknown, which is obtained by evaluation of Equation (6.14) at $x = \ell_1$,

$$\theta_g = -C_1 \cdot K_1 \cdot \sin(K_1 \cdot \ell_1) + D_1 \cdot K_1 \cdot \cos(K_1 \cdot \ell_1) - \frac{e_r - e_c}{L}$$

$$+ \frac{f_r - f_c}{L} - \frac{K_c \cdot \theta_c - K_r \cdot \theta_r}{P \cdot L} - \frac{R_c'}{P} + \frac{\omega_1 \cdot \ell_1}{P} . \tag{8.63}$$

CHAPTER IX

STRESS CALCULATIONS

Failures in cylinders can occur due to: excessive axial stress; excessive hoop stress; a combination of axial, bending, and hoop stresses resulting in excessive axial and shear stresses; or, excessive lateral deflection. The methods for calculation of these stresses are developed in the following sections.

The analyses developed in Chapters VI, VII, and VIII give the equations for moments, slopes, and deflections in the cases of regular, telescoping, and tie rod cylinders. The bending stresses can be determined from the bending moments by ordinary bending theory. For any particular values of axial load and corresponding fluid pressure, the axial direct stress and the hoop stresses can be calculated. Shear stresses resulting from the combination of axial, bending, and hoop stresses can be calculated by the theory of elasticity. The equations for calculation of these stresses for the three types of cylinders are given below.

Axial Stresses

Axial stresses act parallel to axis of the cylinder and are produced by the axial loading on the system. Due to the presence of the sliding connection, there are no axial stresses in regular and tie rod cylinders. The axial stress in the rod part is compressive and is given by one of the following equations depending on whether the rod is solid, or hollow with or without internal fluid pressure.

Solid rod:

$$\sigma_a = \frac{4 \cdot P}{\pi \cdot d_{ro}^2} ; \tag{9.1}$$

Hollow rod without fluid pressure:

$$\sigma_a = \frac{4 \cdot P}{\pi \cdot (d_{ro}^2 - d_{ri}^2)} ; \tag{9.2}$$

Hollow rod with fluid pressure:

$$\sigma_a = \frac{p \cdot (d_{ci}^2 - d_{ri}^2)}{(d_{ro}^2 - d_{ri}^2)} ; \tag{9.3}$$

where

d_{ro} = outer diameter of the rod;

d_{ri} = inner diameter of the rod; and

d_{ci} = inner diameter of the cylinder tube.

In telescoping cylinders, there will be uniform axial compressive stress in the innermost tube (or rod) due to the axial loading given by Equations (9.1), (9.2), or (9.3) depending on whether the rod is solid, hollow without fluid pressure or hollow with fluid pressure. In Equation (9.3), d_{ci} is the inner diameter of the second innermost tube. There will be no axial stress due to axial loading or fluid pressure in the second innermost tube. In the remaining tubes there will be uniform axial tensile stresses due to the fluid pressure (Figure 31). The general equation for calculating this tensile stress in any tube in a telescoping cylinder with n tubes is

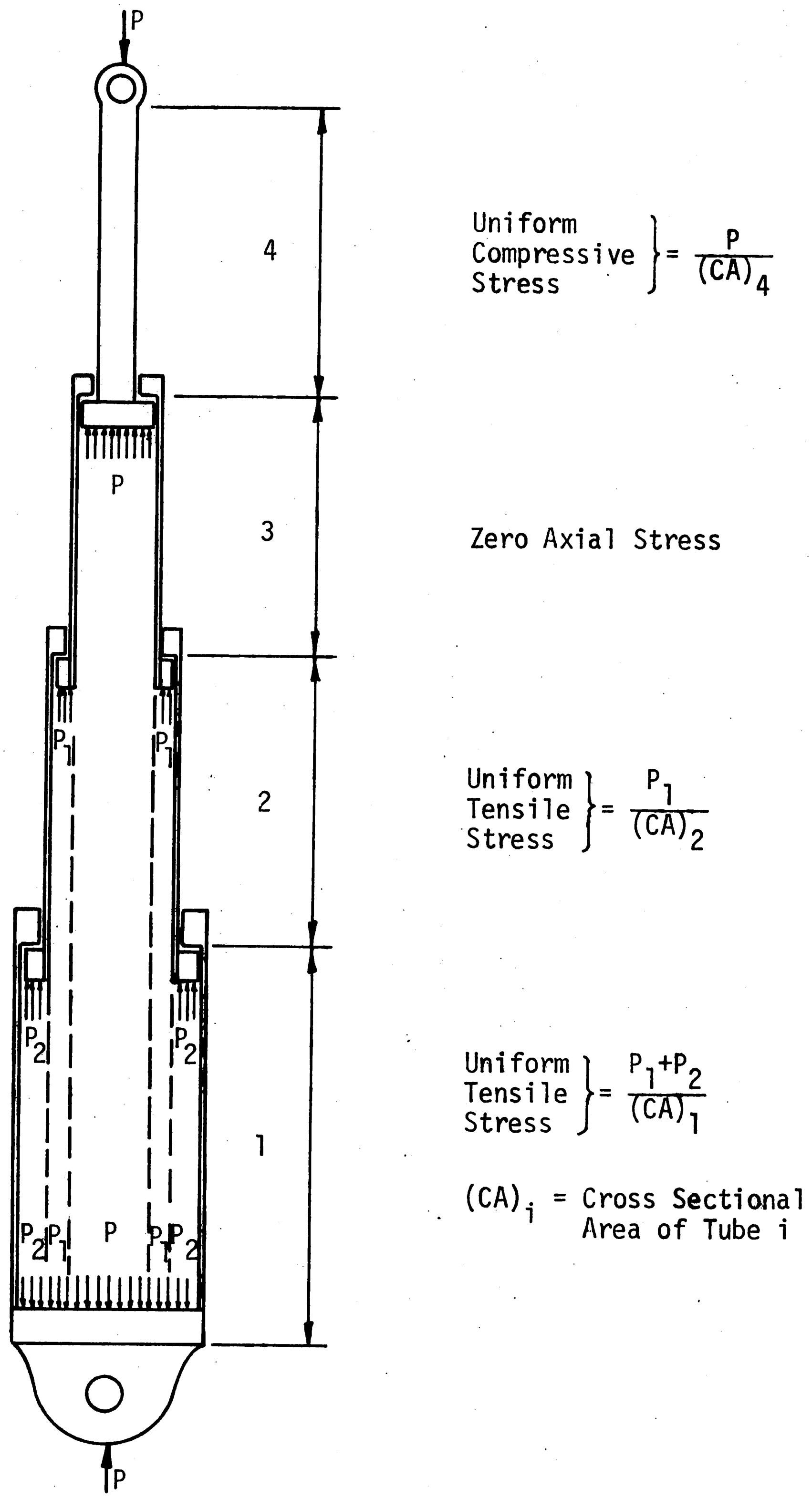


Figure 31. Axial Stresses in a Telescopic Cylinder

$$\sigma_a = \frac{p\cdot(d_{i,j}^2 - d_{i,n-1}^2)}{(d_{o,j}^2 - d_{i,j}^2)} \; ; \; j = 1 \text{ to } n-2 \qquad (9.4)$$

where

$d_{i,j}$ = inner diameter of the jth tube; and

$d_{o,j}$ = outer diameter of the jth tube.

Bending Stresses

The bending stress at any point in the system is given by

$$\sigma_b = \frac{BM\cdot r}{MI} \qquad (9.5)$$

The bending moment, BM, at any section is given by the moment equations derived in earlier chapters. r is the radial distance from the centroidal axis at which bending stress is required. MI is the moment of inertia at the section.

Bending stresses and axial stresses both act in the axial direction and may be either additive or subtractive. Maximum bending stresses at a section occur at the extreme fibers and, in a span of constant cross section, at the location of maximum bending moment. The maximum bending moment in a span with constant cross section is determined from the moment equations derived earlier for each type of cylinder.

Hoop Stresses

Hoop stress varies from a maximum at the inner surface of a tube to a minimum at the outer surface. At the inner surface of a pressurized tube the hoop stress is

$$\sigma_{hi} = p \cdot \frac{d_{o,j}^2 + d_{i,j}^2}{d_{o,j}^2 - d_{i,j}^2} \; ; \; j = 1 \text{ to } n \qquad (9.6)$$

and at the outer surface is

$$\sigma_{ho} = p \cdot \frac{2 \cdot d_{i,j}^2}{d_{o,j}^2 - d_{i,j}^2} \; ; \; j = 1 \text{ to } n \tag{9.7}$$

Hoop stresses act perpendicular to the axial and bending stresses.

Shear Stresses

The stresses (axial plus bending stresses and hoop stresses) of an elemental square having sides parallel to the axis and perpendicular to the centroidal axis of the cylinder are the principal stresses. Hence, the maximum shear stress at any point is given by

$$\sigma_s = \frac{(\sigma_h) + (\sigma_a + \sigma_b)}{2} \tag{9.8}$$

with appropriate signs for σ_h, σ_a, and σ_b.

Stress Failure Criteria

The critical load occurs when the stress at any point exceeds a corresponding prescribed limiting stress. The stresses to be compared with limiting stresses in each tube are:

1. Total stress in the axial direction (axial plus bending stresses) at the extreme fibers at the point of maximum bending moment in each tube.

2. Maximum hoop stress in each tube.

3. The shear stresses at the point of maximum bending moment in each tube, at the outermost element and the innermost element of the wall. The shear stress can be maximum at the innermost element or the outermost element depending on the wall thickness of the tube, pressure in the tube, and the bending moment at the section.

CHAPTER X

COMPUTER PROGRAMS AND APPLICATIONS OF THE ANALYSES

Computer Programs

The analytical procedures described in the preceding chapters for regular, telescoping and tie rod cylinders have been programmed for solution on a digital computer. The programs are written in FORTRAN IV language and should require only minor revisions to be operable on other computers. The three programs SACREG, SACTEL, and SACTIE are for the stress and deflection analysis of regular, telescopic and tie rod cylinders, respectively.

All three programs have two options in common: (1) determination of the critical load and analysis for the critical load and for a factored load. The safety factor can be applied to either the limiting stresses or to the critical load; (2) analysis of the system for any input operating pressure. Programs SACREG and SACTIE also provide for the determination of the required stop tube length to limit the crookedness angle and the forces on the bearings to input values.

The programs generate automatically as much of the required data as possible in order to minimize the amount of input data and to permit the solution of as many problems as desired on a single run. The inputs required in general are the dimensions of the major parts, material properties, inclination, support conditions, support pin friction coefficients, and loading eccentricities at the supports.

The results given by the programs are: the critical load and the corresponding pressure, the factored load and the corresponding pressure, or load corresponding to input pressure and the required length of stop tube; the maximum longitudinal stresses, maximum deflections, their locations, and existing factor of safety on these stresses, in the cylinder tube part and rod part; hoop stresses, maximum shear stresses and their locations, and the existing factor of safety on these stresses; the longitudinal stresses at supports in the case of fixed supports and the corresponding factor of safety; the crookedness angle, lateral forces on each bearing, and the metal to metal contact forces, if any.

Descriptions of the programs, flow charts, guides for data input, example problems and results, and listings for programs SACREG, SACTEL, and SACTIE are given in Appendices A, B, and C, respectively.

Example Problems

The example problems for all three programs are given in Appendix A, B and C, respectively. The example problems for each program illustrate all options of the program and all the possible variations and alternatives in the input data. A listing of the input data is included with the results.

Parametric Studies

Limited parametric studies of regular cylinders for variations in the crookedness angle, loading eccentricity and friction coefficient have been performed. The effect of each parameter on the critical load for various stroke lengths was investigated for a horizontal cylinder with pinned ends.

Ideal conditions shown in the Figures 32, 33 and 34 are zero crookedness angle, zero friction coefficients and zero loading eccentricities. The cylinder chosen for the parametric study is the first example cylinder described in Appendix A.

Effect of Crookedness Angle

Variations in crookedness angles were introduced by varying the clearances between the piston head and cylinder wall, and between the stuffing box and rod. Figure 32 shows the variation of the critical load with respect to stroke length at several constant values of crookedness angle. The curves indicate that the effect of croodedness angle decreases as the stroke length increases.

Effect of Eccentric Loading

Figure 33 indicates that positive eccentricities decrease the critical load for all stroke lengths where the effects of self weights and eccentricities are additive. Small negative eccentricities increase the critical load for all stroke lengths because the effect of self weight is opposite to the effect of the eccentric loading. At longer strokes the interacting self weight and eccentric loading effects result in higher critical loads than for the ideal situations.

Effect of Friction Coefficients

Parametric study on friction coefficients is shown for a cylinder with rotating pins. In cylinders with rotating pins small positive friction coefficients result in slightly higher critical loads than for

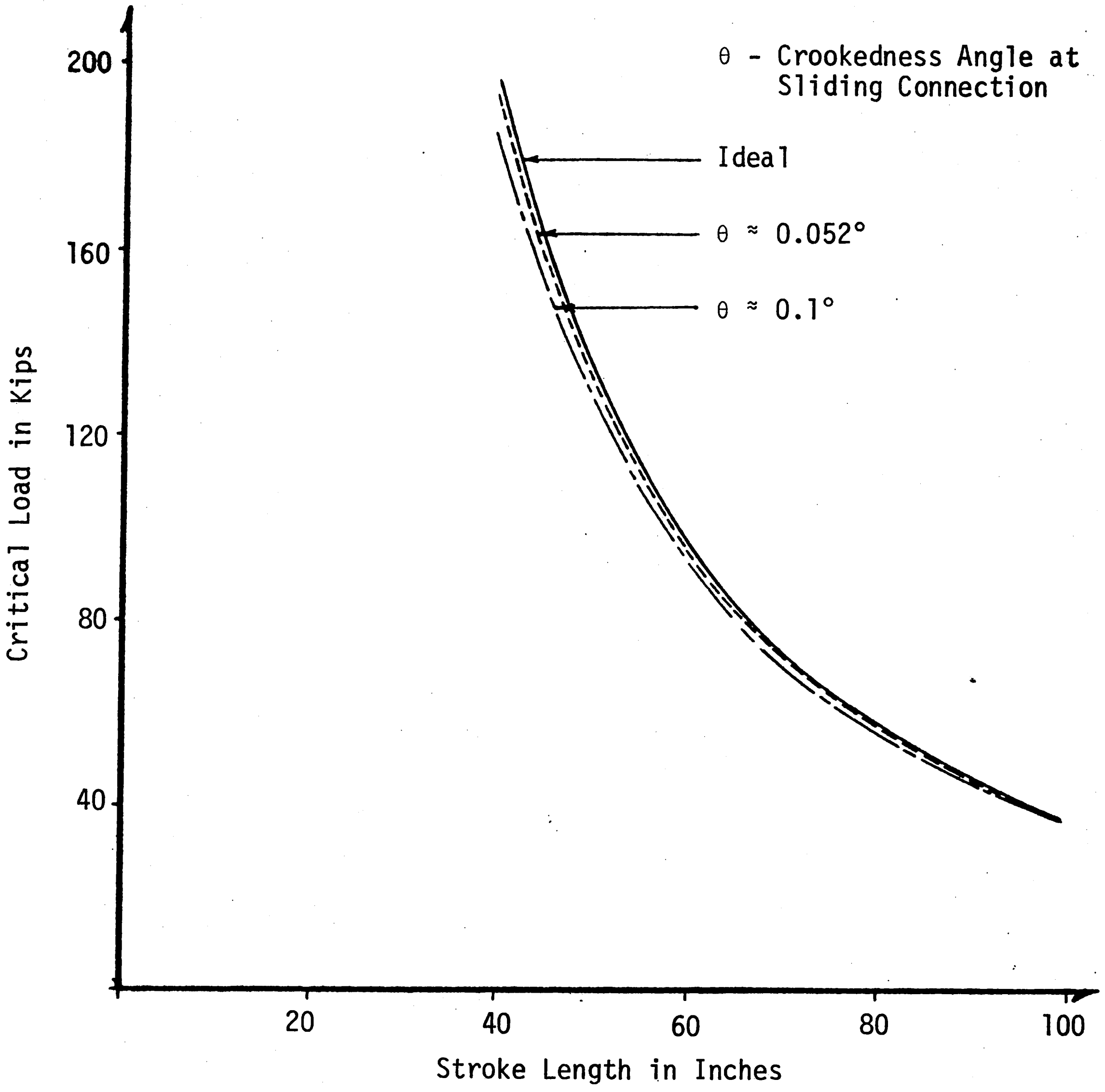


Figure 32. Effect of Crookedness Angle on Critical Load Versus Stroke Variation for Cylinder REG1

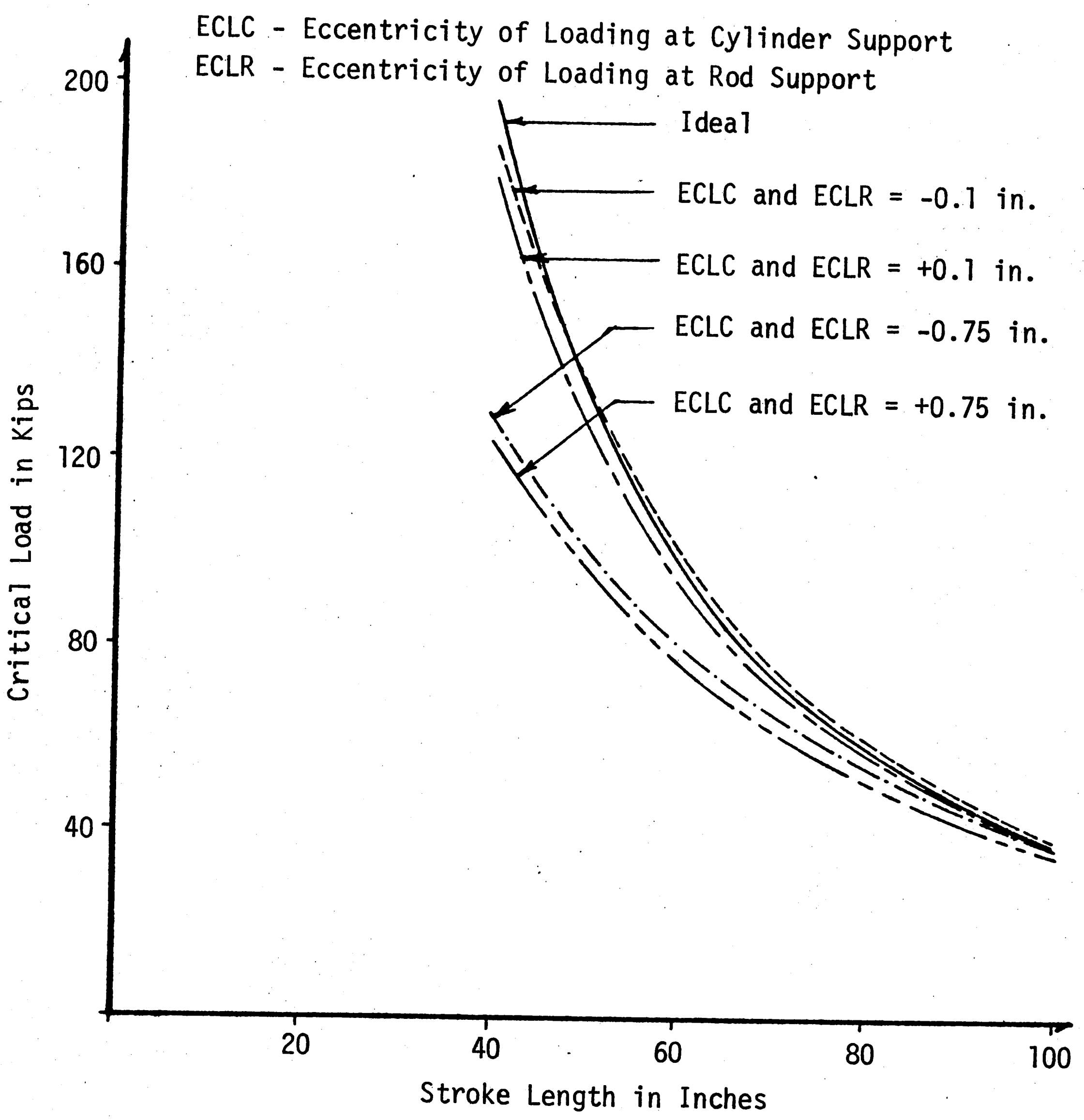


Figure 33. Effect of Loading Eccentricities on Critical Load Versus Stroke Variation for Cylinder REG1

the ideal case due to the effect of self weights and friction moments interaction (Figure 34). At higher friction coefficients, the end friction moments affect the critical load to a greater extent than the self weight, hence, the critical load is reduced. In cylinders with nonrotating pins the effect of friction is always to increase the stability of the system, and hence, the critical load.

In general, whenever the effects of eccentric loadings and friction coefficients compensate the effects of self weights, the system acquires some additional stability, and hence, results in higher load capacity than for ideal conditions.

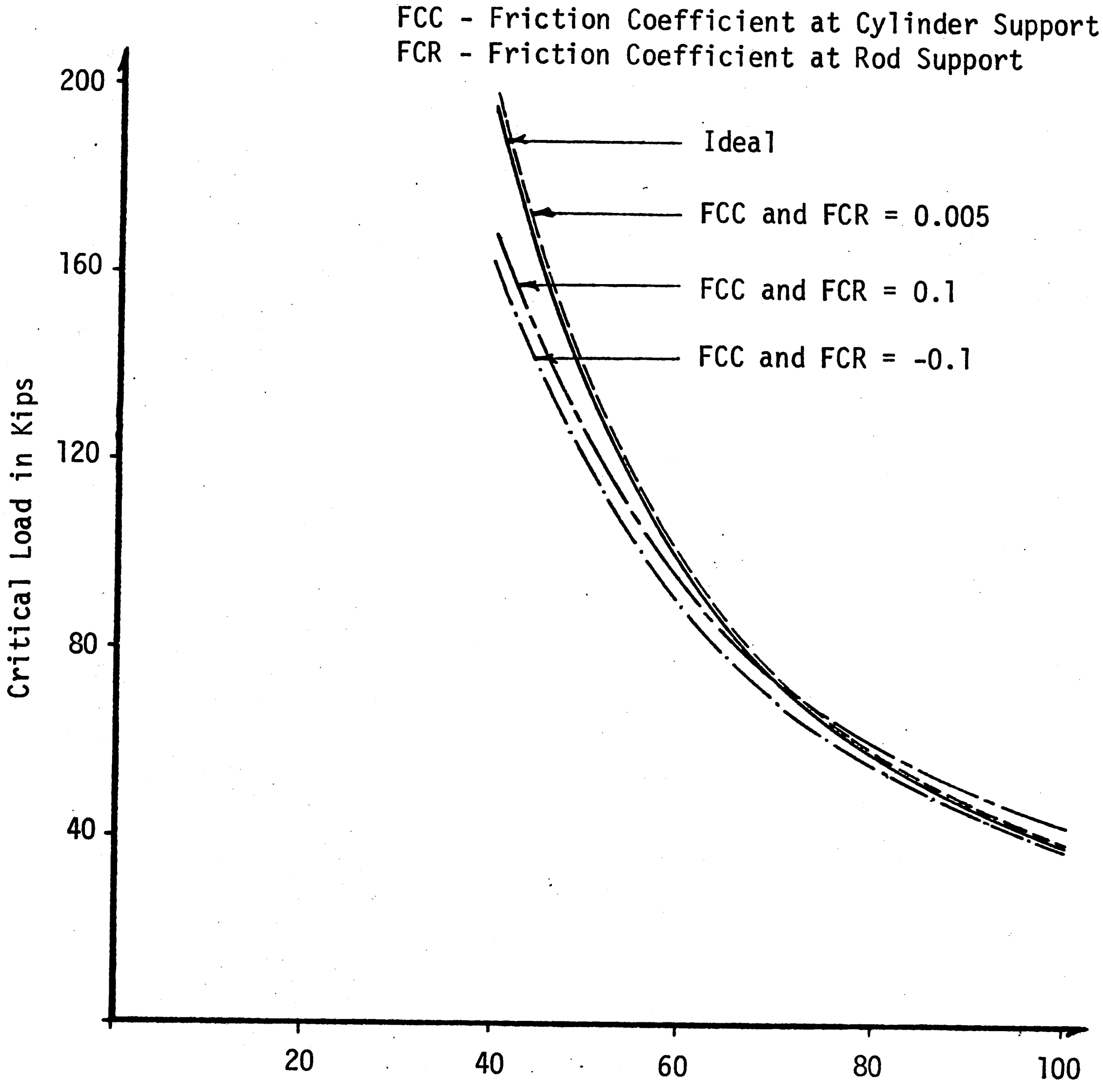


Figure 34. Effect of Friction Coefficients on Critical Load Versus Stroke Variation for Cylinder REG1

CHAPTER XI

SUMMARY AND RECOMMENDATIONS

The analyses presented here for regular, telescoping and tie rod cylinders include all the important factors that influence the capacity of a cylinder and that can be treated mathematically. These factors are: the crookedness angle at the sliding connection; the eccentricity of loading at both ends; the friction effects at both supports; self weights of the system; and stop tube and overhanging cylinder part effects. The analyses are applicable to wide variations in cylinder characteristics. The major variations are: the type of support condition, pinned, fixed, or elastically restrained; solid rod or hollow rod with or without fluid pressure; any number of piston and rod bearings and seals; and, in the case of tie rod cylinders, any number of tie rods.

The numerical values describing the effects are frequently not under the control of the designer and are hard to estimate, hence, it is necessary to develop design aids and charts for standard systems for ranges of the important parameters. The computer programs developed will be very useful in developing such design aids and charts, apart from their basic use in determining critical loads and stresses and deflections in a particular system.

Additional work should be directed toward the following points:

1. Development of design charts and graphs for standard cylinders for variations of parameters.

2. Determination of the linear spring stiffnesses and equivalent rectangular cross sections for modeling the bearings and seals to represent the real condition is difficult. Hence, experimental determination of moment-curvature relations at the sliding connection for standard cylinders and analytical modeling comparison with the experimental result are recommended.

3. In the case of tie rod cylinders, it is assumed that the end blocks remain perpendicular to the cylinder axis even after the cylinder is deflected. This assumption permits the calculation of tie rod moment analytically. There is a possibility that the end blocks may not remain perpendicular to the cylinder axis after deflections occur. An experimental varification of this is necessary, which would provide a method for estimating more correctly the value of the tie rod moment.

4. An overall experimental investigation to determine the capacity of a cylinder with sophisticated instrumentation for measuring the effects of the influencing factors would provide more complete confidence in the analytical techniques and the general purpose programs developed herein.

REFERENCES

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(2) Thompson, W. T. "Critical Load of Columns of Varying Cross Section." Journal of Applied Mechanics, Vol. 17 (June, 1950), pp. 132-134.

(3) Hoblit, Frederic M. "Buckling Load of a Stepped Column." Journal of the Aeronautical Sciences, Vol. 18 (February, 1951), pp. 124-126 and 138.

(4) Gwinn, J. M., Jr. and Roy A. Miller. "A Method for Determining the Ultimate Strength of a Column Swaged at the Ends." Journal of the Aeronautical Sciences, Vol. 2 (May, 1935), pp. 94-96.

(5) Meier, J. H. "Buckling of Uniform and Stepped Columns--I." Product Engineering, Vol. 20 (October, 1949), pp. 119-123.

(6) Wadler, Richard. "Critical Axial Buckling Load on Columns With Variable Cross-Section." Design Data, Vol. 19 (December, 1961), pp. 76-78.

(7) Mills, Blake D., Jr. "The Fluid Column." American Journal of Physics, Vol. 28 (1960), pp. 353-356.

(8) Donnell, L. H. "Analysis of Buckling Strength of Piston Rod." Benton Harbor, Mich.: Benton Harbor Engineering Division, Internal Report, 1958.

(9) Meier, J. H. "Buckling of Uniform and Stepped Columns--II." Product Engineering, Vol. 20 (November, 1949), pp. 116-118.

(10) G. L. M. "Stepped Column Analysis." South Bend, Ind.: Bendix Products Division of Bendix Corporation, Report No. 1640 (May, 1961), pp. 2.90-1-2.90-6.

(11) Berninger, John. "Tie Rod Stress in Cylinders Can Be Accurately Calculated." Product Engineering, Vol. 44 (December, 1973), pp. 40-43.

APPENDIX A

COMPUTER PROGRAM FOR REGULAR CYLINDERS--SACREG

Program SACREG

The analytical procedure for regular cylinders developed in Chapter VI has been programmed for solution on a digital computer. The program is written in FORTRAN IV language and should require only minor revisions to be operable on other computers. Double precision (16 digits accuracy) arithmetic is used, and the program can be run on any computer which has a storage capacity of 80 K bytes. A summary flow diagram is shown in Figure 35. Details of all the Subprogram Operations, Guides for Data Input, Example Problems, Listings of Input Data, and Program Outputs are given in the following sections.

Subprogram Operation

MAIN

MAIN is a driver subroutine for the complete program. MAIN sets up keys to perform different operations and calls all the major subroutines to perform the major operations in the program. For all three problem types, MAIN first goes through critical load analysis. Then, for first problem type sets up factored load analysis, and for second and third problem types checks for input pressure being greater than critical pressure; if not, it goes through corresponding type of analysis.

INPECO

Subroutine INPECO reads all the input data; checks problem name being blank for end of run; and checks the input data at several stages for proper input. If any error is observed, the error is printed out and the program terminates. Echo prints out all the input tables.

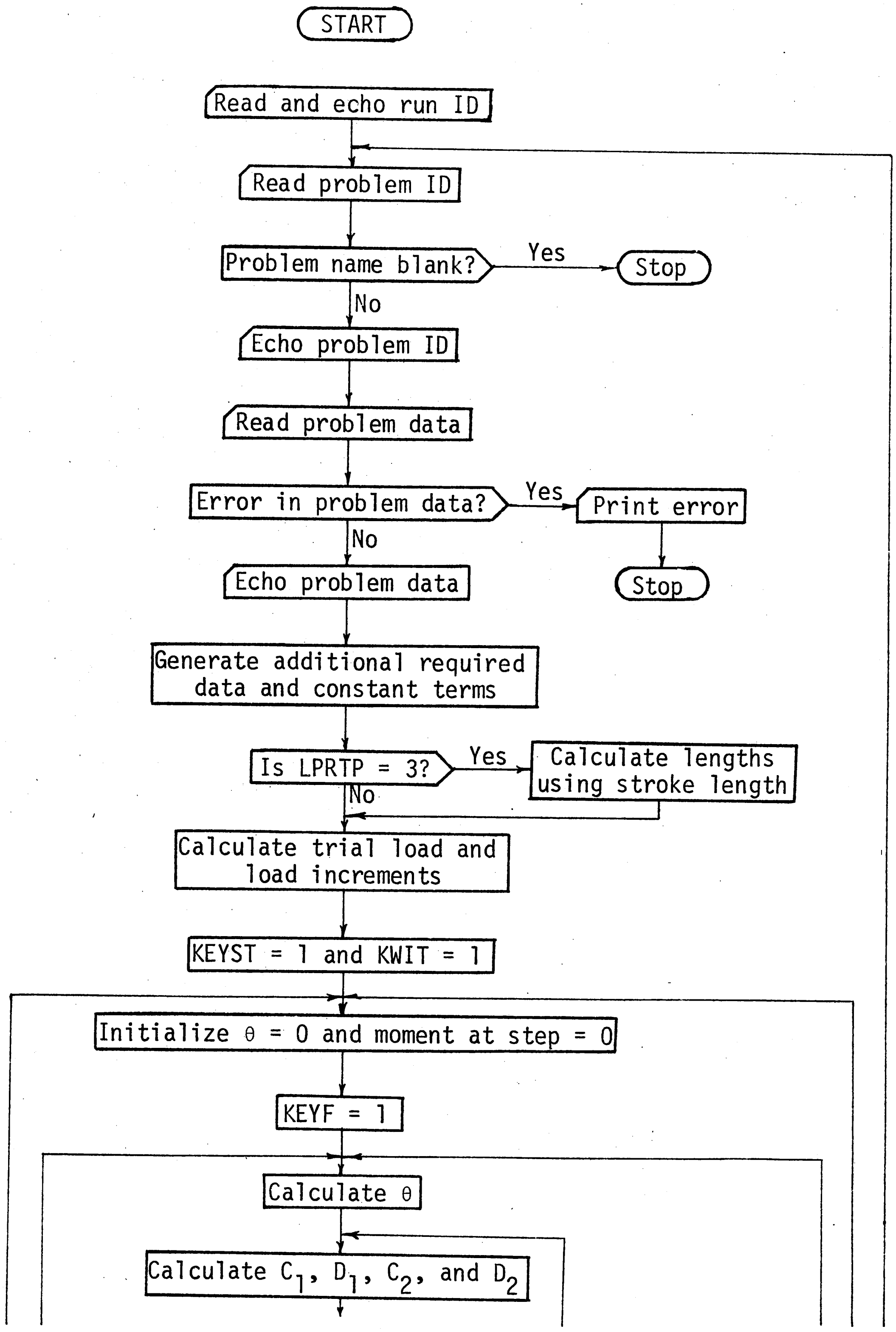


Figure 35. Summary Flow Diagram of Program SACREG

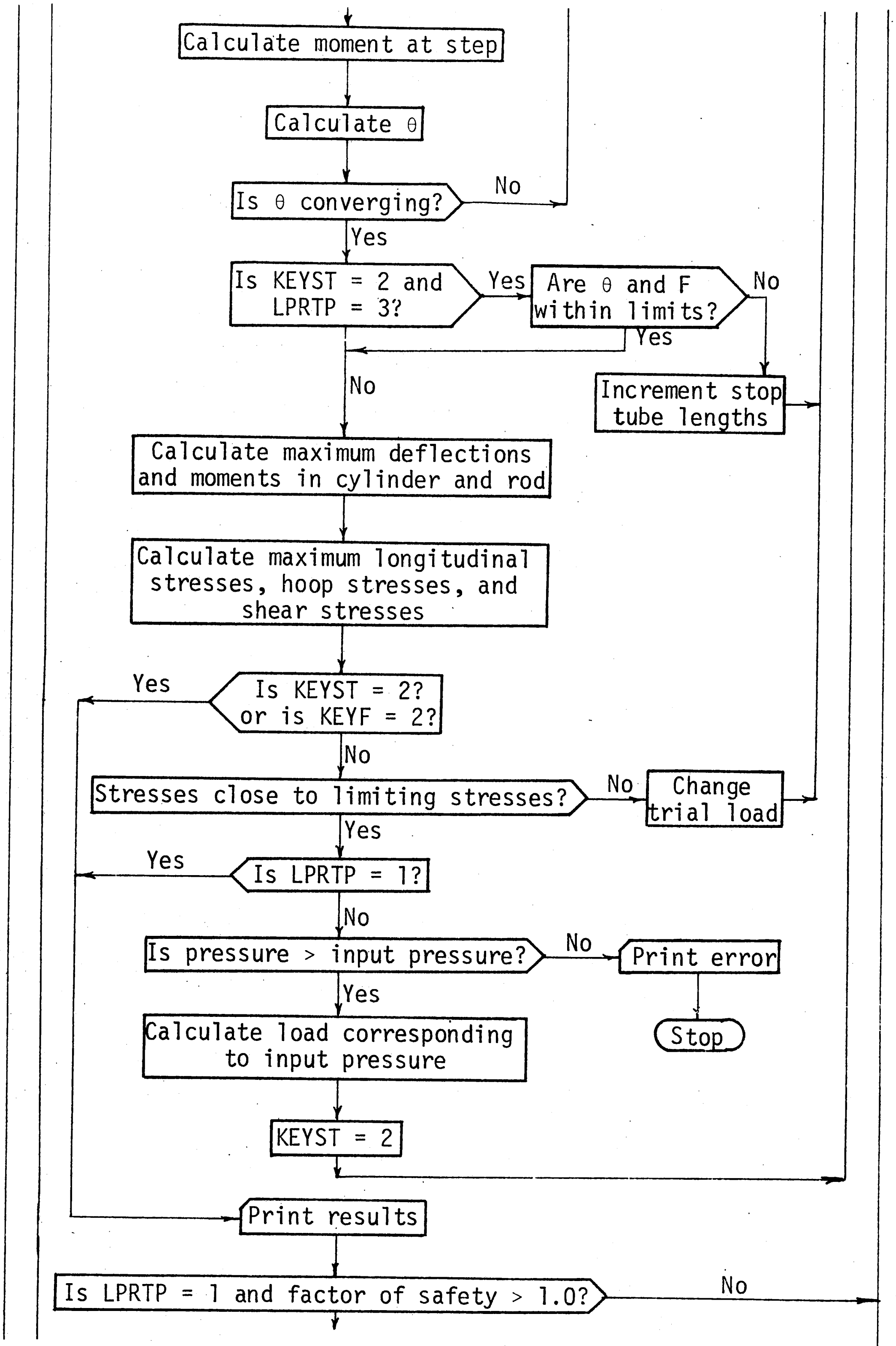


Figure 35. (Continued)

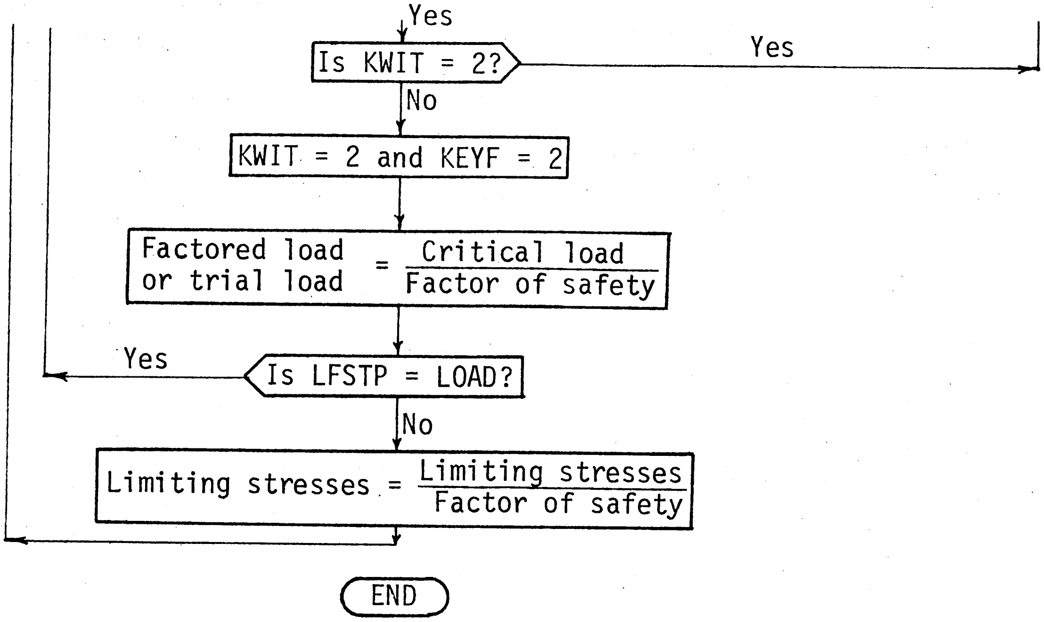


Figure 35. (Continued)

CONST1

Subroutine CONST1 calculates all the constant quantities which do not vary throughout the program. The constant quantities are: stiffnesses of bearings and seals; cross sectional properties of cylinder and rod; hoop stress coefficients; self weight reactions at supports; friction moment coefficients; and moment due to overhang in case of cylinders with overhang.

TRIALP

Subroutine TRIALP calculates a trial load and two load increments required for the iteration process in evaluating the critical load for the cylinder. The trial load is the smallest of critical load by Euler's buckling criteria considering the full length stiffness as that of rod only, critical load by hoop stress criteria for the cylinder part, and critical load by hoop stress criteria for the rod part in the case of hollow pressurized rods. The first load increment is one-fiftieth of the trial load and the second is one-thousandth. The larger load increment is for faster convergence and the smaller load increment is for better accuracy.

EQBRIM

Subroutine EQBRIM determines the equilibrium position of the system for any particular load by repeating the calculation of deflections in the system and the crookedness angle until two consecutive values of the crookedness angle are in close agreement. This subroutine calls subroutine THCDS for calculating the values of constant terms in the deflection equations and calls subroutine THETA for calculating the crookedness angle at a particular value of moment at the sliding connection.

THETA

Subroutine THETA calculates the crookedness angle at the sliding connection for any particular value of the moment at the sliding connection. This subroutine also calculates the forces on the bearings by calling subroutine GFORCE and the metal-to-metal contact forces at the sliding connection.

GFORCE

Subroutine GFORCE calculates the forces on the bearings for a particular value of crookedness angle at the sliding connection.

THCDS

Subroutine THCDS calculates the slopes at the supports and the constants in the deflection and moment equations at particular values of load and crookedness angle.

STOPTB

Subroutine STOPTB determines the required length of stop tube by incrementing the length of stop tube by small quantities and checking the crookedness angle and the lateral forces against the limiting values at each length.

XATYMX

Subroutine XATYMX determines the distances at which the maximum deflections occur in cylinder and rod parts.

YMAXS

Subroutine YMAXS calculates the maximum deflections in cylinder and rod parts at the places determined by the subroutine XATYMX.

STRCHS

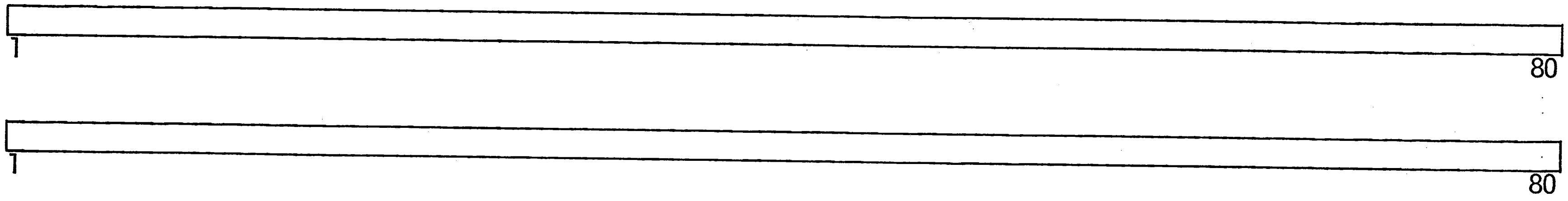
Subroutine STRCHS calculates the maximum bending moments and, hence, maximum longitudinal stresses, maximum hoop stresses, and maximum shear stresses in the cylinder and rod parts; checks these stresses against the limiting stresses and makes corresponding change in the trial load using load increments. This process is repeated until any one of the maximum stress values exceeds the limiting stress. The analysis is repeated for previous load value.

OUTPUT

Subroutine OUTPUT prints out all the results: the maximum deflections, the maximum stresses, the factor of safety existing on these stresses, and the distance from cylinder support at which the above quantities occur in the cylinder and rod parts; the crookedness angle; and the forces on the bearings.

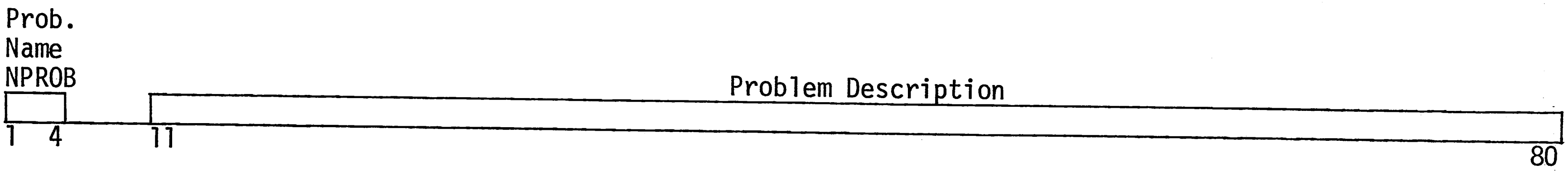
Program SACREG--Guide for Data Input

PROGRAM IDENTIFICATION (Two alphanumeric cards at the beginning of run)



Format--20A4

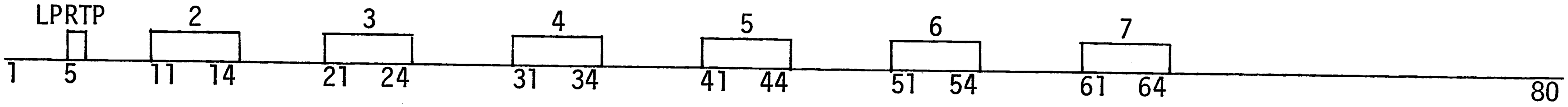
PROBLEM IDENTIFICATION (One card at the beginning of each problem)



Format--20A4

Program stops if NPROB is blank

TABLE 1: CONTROL DATA (One card for each problem)



Format--LPRTP - I1; 2 to 7 - A4

LPRTP = 1--Critical load analysis and analysis for a factored load using given factor of safety

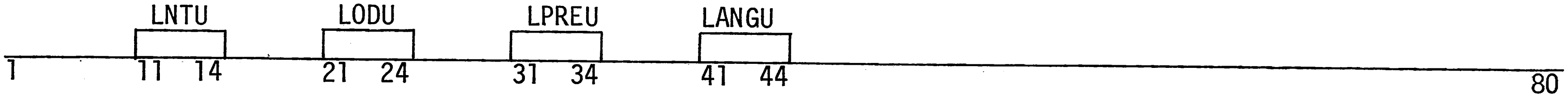
2--Analysis for a particular fluid pressure

3--Analysis to determine a stop tube length for given limiting values of crookedness angle and lateral force at the sliding connection at a given fluid pressure

If any of the following tables are same as in the previous problem and are to be retained for this problem, enter "KEEP" in the corresponding blocks 2 to 7

Enter only LPRTP for the first problem

TABLE 2: UNITS OF MEASUREMENTS (No card if TABLE 2 is retained from previous problem)



Format--A4 for all

LNTU - Unit of lengths (ex: INCH, FEET, CM, MET, etc.)

LODU - Unit of loads (ex: LBS, KIPS, KGS, etc.)

LPREU - Unit of pressures (ex: KSI, PSI, KSCM, etc.)

LANGU - Unit of angles (enter DEG or RAD starting in column 41)

TABLE 3: CYLINDER DIMENSIONS (No cards if TABLE 3 is retained from previous problem; see Figure 36 for details)

Card No. 1--Lengths

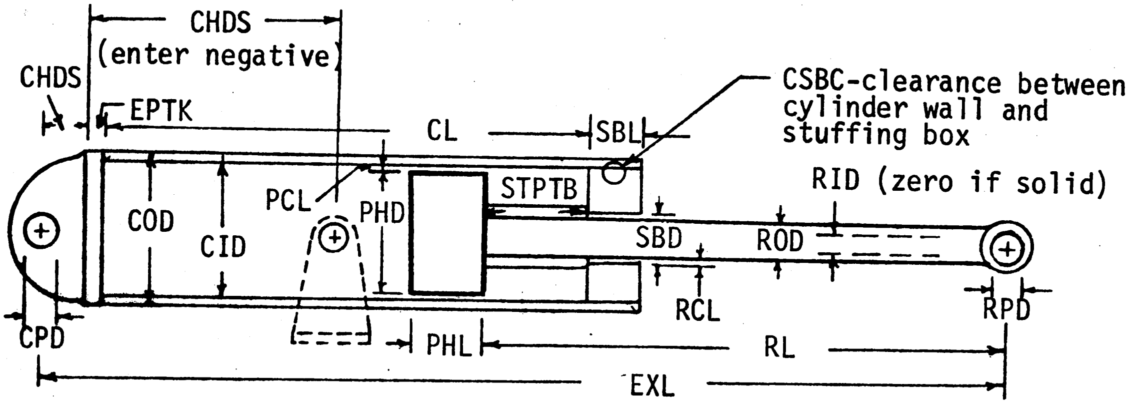


Figure 36. Cylinder Dimensions for SACREG

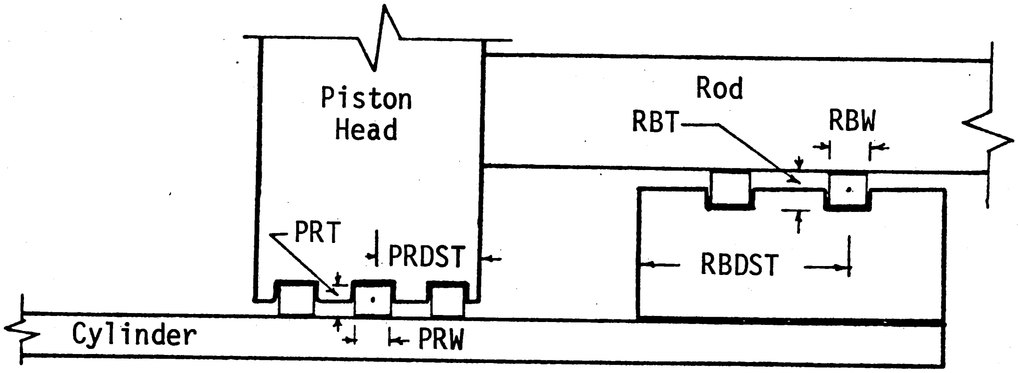


Figure 37. Dimensions of Bearings and Seals for SACREG

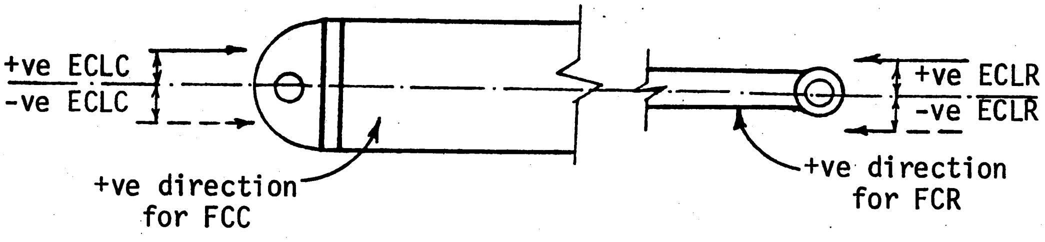
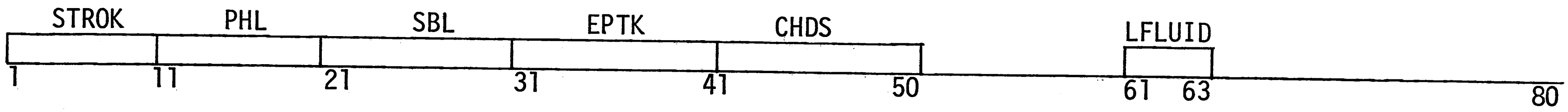


Figure 38. Sign Conventions for Eccentricities of Loading and Friction Coefficients for SACREG



Format--LFLUID--A3; E10.3 for the rest

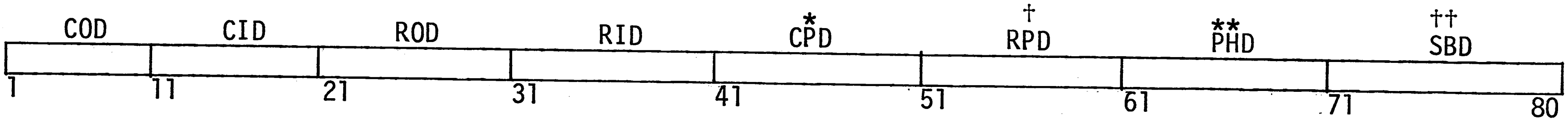
LFLUID - Enter "YES", for hollow rod with fluid

- Enter "NO" or blank, for hollow rod without fluid or solid rod

Card No. 2--Lengths (card No. 2 is not input for LPRTP = 3)

Format--E10.3 for all

Card No. 3--Diameters



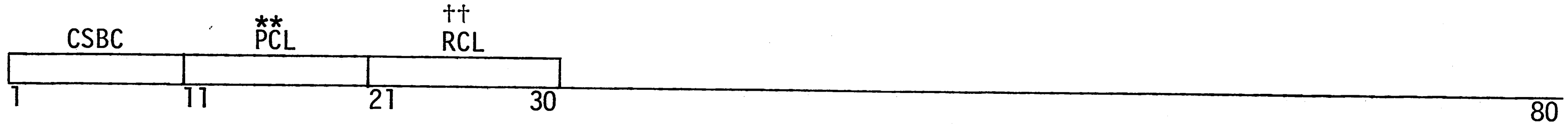
Format--E10.3 for all

* CPD - Leave blank if cylinder support is fixed

† RPD - Leave blank if rod support is fixed

** and †† - See next card

Card No. 4--Clearances



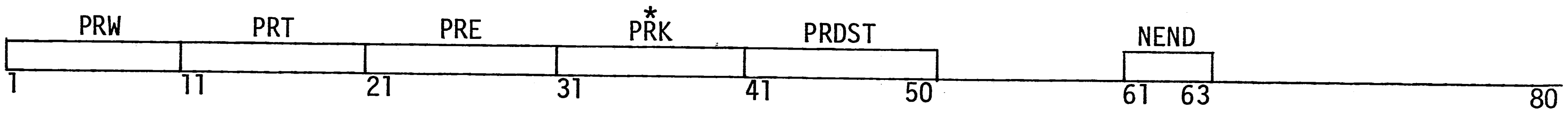
Format--E10.3 for all

**Input either PHD or PCL; if both are input, PCL will be used and PHD will be ignored

††Input either SBD or RCL; if both are input, RCL will be used and SBD will be ignored

TABLE 4: BEARINGS AND SEALS (No cards if TABLE 4 is retained from previous problem; see Figure 37 for details)

Piston Head Bearing Cards: (one card for each bearing)

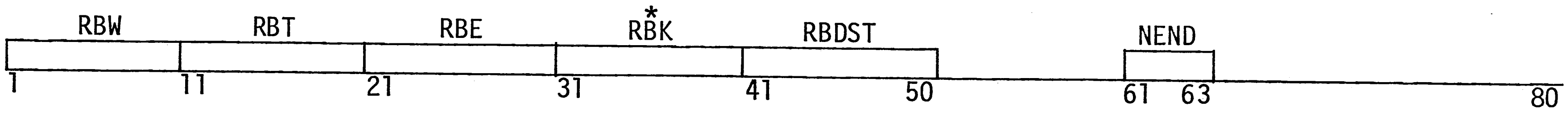


Format--NEND--A3; E10.3 for the rest

NEND - Enter "END" on the last piston head bearing card

* Input either (PRW, PRT and PRE) or (PRK); if PRK and some or all of PRW, PRT, and PRE are input, PRK will be used and the rest ignored

Rod Bearing Cards: (one card for each bearing)



Format--NEND--A3; E10.3 for the rest

NEND - Enter "END" on the last rod bearing card

* Input either (RBW, RBT, and RBE) or (RBK); if RBK and some or all of RBW, RBT and RBE are input, RBK will be used and the rest ignored

PRE and RBE - Young's modulus of piston head bearings and rod bearings

PRK and RBK - Stiffnesses of piston head bearings and rod bearings per unit length (force required to compress a unit length of bearing by one unit)

TABLE 5: WEIGHTS AND MATERIAL PROPERTIES (No card, if TABLE 5 is retained from previous problem)

WC	WR	WPH	WSB	ECYL	EROD	FYCYL	FYROD
1	11	21	31	41	51	61	71 80

Format--E10.3 for all

WC and WR - Weight of cylinder and rod per unit length

WPH - Weight of piston head

WSB - Weight of stuffing box

ECYL and EROD - Modulus of elasticity of cylinder and rod, respectively

FYCYL and FYROD - Yield stresses of cylinder and rod, respectively

TABLE 6: INCLINATION, FIXITY, FRICTION COEFFICIENTS, AND LOADING ECCENTRICITIES (No card if TABLE 6 is retained from previous problem)

CINCL		LCEND	LREND	F*CC	F*CR	E*CLC	E*CLR
1 10		31 33	36 38	41	51	61	71 80

Format--LCEND and LREND--A3; E10.3 for the rest

CINCL - Inclination of the cylinder with horizontal (always positive and between 0° and 90°)

LCEND - Enter FIX for fixed or PIN for pinned cylinder support

LREND - Enter FIX for fixed or PIN for pinned rod support

FCC - Friction coefficient at cylinder pin. Leave blank if LCEND is FIX

FCR - Friction coefficient at rod pin. Leave blank if LREND is FIX

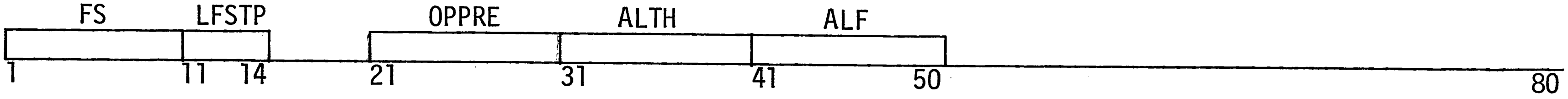
ECLC - Eccentricity of loading at cylinder end

ECLR - Eccentricity of loading at rod end

* See Figure 38 for sign convention

The direction of friction moments at the pins should be visualized by the user depending on the direction of rotation of the pins in the case of rotating pins, and depending on the predicted direction of the slopes at ends of the system for that particular loading, and accordingly proper signs should be assigned for FCC and FCR

<u>TABLE 7: FACTOR OF SAFETY, OPERATING PRESSURE, ALLOWABLE θ AND F</u> (No card if TABLE 7 is retained from previous problem)



Format--LFSTP--A4; E10.3 for the rest

If LPRTP = 1 - enter only FS and LFSTP

= 2 - enter only OPPRE

= 3 - enter only OPPRE, ALTH and ALF

FS - Factor of safety

LFSTP - Factor of safety type (enter LOAD if FS is to be applied to the critical load obtained; enter STRS if FS is to be applied to the limiting stresses)

If only critical load analysis is required and no factored load analysis is required, leave this card blank or enter FS $\leq$ 1.0, and LFSTP--LOAD or STRS or blank

OPPRE - Particular operating pressure for which analysis is required

ALTH - Allowable crookedness angle at the sliding connection

ALF - Allowable total lateral force on bearings (total force on piston head bearings or total force on rod bearings which are equal to each other)

NEXT PROBLEM

Start from "PROBLEM IDENTIFICATION" card

END OF RUN

At the end of last problem data set, insert a blank card (only first 4 columns need to be blank, the rest of the card may be used for comments)

```
C
C   -------------------------------------------------------------------------
C   |                                                                       |
C   |                                                                       |
C   |           STRESS ANALYSIS OF HYDRAULIC CYLINDERS                      |
C   |           ------ -------- -- --------- ---------                      |
C   |                                                                       |
C   |         SIMPLE, REGULAR CYLINDERS WITHOUT TIE RODS                    |
C   |                                                                       |
C   |                OCTOBER 30, 1975 VERSION                               |
C   |                                                                       |
C   |                    K. L. SESHASAI                                     |
C   |                                                                       |
C   |              SCHOOL OF CIVIL ENGINEERING                              |
C   |               OKLAHOMA STATE UNIVERSITY                               |
C   |                STILLWATER, OK - 74074                                 |
C   |                                                                       |
C   |                                                                       |
C   |  FACTORS CONSIDERED IN THE ANALYSIS:                                  |
C   |                                                                       |
C   |       1.   SELF WEIGHT                                                |
C   |       2.   LOADING ECCENTRICITY AT BOTH ENDS                          |
C   |       3.   STIFFNESSES OF BEARINGS                                    |
C   |       4.   FRICTION MOMENTS AT SUPPORTS                               |
C   |       5.   VARYING CYLINDER SUPPORT LOCATION                          |
C   |       6.   INCLINATION OF CYLINDER                                    |
C   |       7.   END CONDITIONS - PINNED OR FIXED                           |
C   |       8.   SOLID ROD OR HALLOW ROD WITH OR WITHOUT FLUID IN IT        |
C   |                                                                       |
C   |                                                                       |
C   |  TYPES OF PROBLEMS:                                                   |
C   |                                                                       |
C   |       1.   DETERMINATION OF CRITICAL LOAD AND ANALYSIS FOR            |
C   |            CRITICAL AND A FACTORED LOAD                               |
C   |       2.   ANALYSIS FOR A PARTICULAR PRESSURE                         |
C   |       3.   ANALYSIS TO DETERMINE REQUIRED LENGTH OF STOP-TUBE         |
C   |                                                                       |
C   |                                                                       |
C   |  RESULTS GIVEN BY THE COMPUTER:                                       |
C   |                                                                       |
C   |       1.   CRITICAL LOAD AND CORRESPONDING PRESSURE                   |
C   |       2.   CROOKEDNESS ANGLE                                          |
C   |       3.   MAX DEFLECTION, MAX LONGITUDINAL AND SHEAR STRESSES,       |
C   |            DISTANCE AT WHICH THEY OCCUR, FACTOR OF SAFETY'S ON        |
C   |            THESE STRESSES FOR BOTH CYL AND ROD PORTIONS               |
C   |       4.   MAXIMUM STRESSES AT SUPPORTS IN CASE OF FIXED              |
C   |            SUPPORTS AND FACTOR OF SAFETY ON THIS STRESS               |
C   |       5.   MAXIMUM HOOP STRESS IN CYLINDER, AND ROD ALSO IF           |
C   |            THE ROD IS HALLOW , AND FACTOR OF SAFETY ON THIS           |
C   |       6.   LOAD ON EACH BEARING AND AT OTHER CONTACT POINTS           |
C   |       7.   AXIAL TENSION AND END DEFLECTION IN OVERHANG IN            |
C   |            CASE OF TRUNNION MOUNT                                     |
C   |       8.   REQUIRED LENGTH OF STOP-TUBE AND CORRESPONDING             |
C   |            EXTENDED LENGTH ( IN ANALYSIS OF TYPE 3. )                 |
C   |                                                                       |
C   |                                                                       |
C   |                                                                       |
C   |-----------------------------------------------------------------------|
C
```

```
C---- >>> MAIN PROGRAM
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / BRGSTF / PRKX, SPRK, RBKY, SRBK
      COMMON / CANDDS / C1, C2, D1, D2
      COMMON / CLEAR  / PCL, RCL
      COMMON / CLERNC / CSBC, PCL1, RCL1
      COMMON / CONSTS / EEL, FFL, AKTHC, AKTHR
      COMMON / CRPROP / RDZ, CYZ, RDZI, CYZI, HSCCI, HSCCO, HSCRI,
     *                  HSCRO, BAREAC, BAREAR, CAREAC, CAREAR
      COMMON / DIAMTS / COD, CID, RCD, RID, CPD, RPD, PHD, SBD
      COMMON / ECCTRI / ECLC, ECLR
      COMMON / ENDS   / LCEND, LREND
      COMMON / FRCONS / FCCY, FCRD, CONM
      COMMON / FSOPTF / OPPRE, ALTH, ALF, FS, LFSTP
      COMMON / GLOFOR / FX(5), FY(5), F1, F2, F3, F4
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
      COMMON / INCLFR / CINCL, FCC, FCR
      COMMON / LENGTS / STRCK, PHL, SBL, EPTK, CHDS, LFLUID
      COMMON / PISTON / PRW(5), PRT(5), PRE(5), PRK(5), PRDST(5), NPHBR
      COMMON / PROPTS / ECYL, EROD, FYCYL, FYROD
      COMMON / RODBRS / RBW(5), RBT(5), RBE(5), RBK(5), RBDST(5), NRDBR
      COMMON / STPTBS / CL, RL, STPTB
      COMMON / UNITS  / LNTU, LCDU, LPREU, LANGU
      COMMON / WGTCON / WPH, WSB
      COMMON / WGTINI / WC1, WR1, WPH1, WSB1
      COMMON / WGTVER / WC, WR
C
      DATA ZERO, ONE, H180 / 0.0D00, 1.0D00, 180.0D00 /
      DATA PI / 3.14159265358979300 /
      DATA IBLNK, LOAD, LDEG / 4H    , 4HLOAD, 4HDEG  /
C
            NPROB  = IBLNK
   10 CALL INPECO ( IBLNK, GC                                          )
            FYCYLT = FYCYL
            FYRODT = FYROD
      CALL CONST1
     I          ( ECYL, EROD, CHDS, LANGU,
     O            RDI, CYK, RDK, CSSTF, RSSTF                          )
      CALL TRIALP
     I          ( EROD, LPRTP, RDI, FYCYL, BAREAC, HSCCI, LCEND, FYROD,
     I            BAREAR, HSCRI,
     O            PINCR1, PINCR2                                       )
C
C---- >>> KEY-- KWIT IS SETUP TO APPLY FACTOR OF SAFETY AND REPEAT
C           ANALYSIS FOR FACTORED LOAD
C
            KWIT   = 1
C
C---- >>> KEY-- KEYF IS SETUP TO QUIT LOOP AT FINAL ITERATION
C
   20       KEYF   = 1
C
C---- >>> KEY-- KEYST IS SETUP TO CHECK INPUT PRESSURE AGAINST CRIT. PRE
C
            KEYST  = 1
C
```

```
C---- >>> KEY'S-- KEYT AND KEYP ARE SETUP TO MAKE PROPER LOAD INCREMENTS
C
                  KEYT    = 1
                  KEYP    = 1
C
C---- >>> INITIALIZE TETA AND BMG = ZERO
C
                  TETA    = ZERO
                  BMG     = ZERO
   30 CALL EQBRIM
     I            ( PRK, PRDST, RBK, RBDST, NPHBR, NRDBR, CYK, RDK, LPRTP,
     I             GC, RPD, BMG, CSSTF, RSSTF,
     O             CLT, RLT, CK, RK, BB1, BB2, TETA, DEFG, THC              )
            IF ( LPRTP .NE. 3 ) GO TO 40
            IF ( KEYST .EQ. 1 ) GO TO 40
C
C---- >>> CONVERT ALLOWABLE THETA TO RADIANS, IF INPUT IN DEGREES
C
                  ALTH1   = ALTH
                  TEMP    = PI / H180
            IF ( LANGU .EQ. LDEG ) ALTH1 = ALTH * TEMP
                  ITERAT = 1
      CALL STOPTB
     I            ( TETA, NPHBR, NRDBR, ALTH1, ALF, STROK, ITERAT,     GC )
            IF ( ITERAT .NE. 1 ) GC TO 30
   40 CALL XATYMX
     I            ( CLT, CK, RK, DEFG,
     O             XCY, XRD, CSLPC, CSLPR                                   )
      CALL YMAXS
     I            ( XCY, XRD, CK, RK, CSLPC, CSLPR, BB1, BB2,
     O             YCMAX, YRMAX                                             )
      CALL STRCHS
     I            ( KEYF, KEYT, KEYP, XCY, XRD, YCMAX, YRMAX, RID, CHDS,
     I             OPPRE, FYRODT, FYCYLT, PINCR1, PINCR2, KEYST, LFLUID,
     O             HSC, HSR, AXTEN, CSTR, CSTRP, RSTR, RSTRP, CSS, NCSS,
     O             RSS, NRSS                                                )
C
C---- >>> IS IT FINAL ITERATION? ? ?
C
            IF ( KEYF .NE. 3 ) GO TO 30
            IF ( KEYST .NE. 1 ) GO TO 50
            IF ( LPRTP .EQ. 1 ) GC TC 50
C
C---- >>> PROTECTION AGAINST INPUT OPERATING PRE. BEING > CRITICAL PRE.
C
                  PRES    = P / BAREAC
            IF ( OPPRE .GT. PRES ) GO TC 100
                  P       = OPPRE * BAREAC
                  KEYST   = 2
                  TETA    = ZERO
      GO TO 30
   50 CALL OUTPUT
     I            ( KWIT, BAREAC, XCY, XRD, YCMAX, YRMAX, CHDS, GC, TETA,
     I             FYCYL, FYROD, CSTR, CSTRP, RSTR, RSTRP, HSC, HSR, AXTEN,
     I             NPHBR, NRDBR, THC, CSS, NCSS, RSS, NRSS                  )
C
C---- >>> IF THIS PROBLEM IS COMPLETE GO TO NEXT PROBLEM
C
```

```
            IF ( KWIT .NE. 1 ) GO TO 10
            IF ( LPRTP .NE. 1 ) GO TO 10
            IF ( FS .LE. ONE ) GO TO 10
C
C---- >>> FACTOR OF SAFETY IS TO BE APPLIED TO STRESS OR LOAD
C
                  P       = P / FS
                  KWIT    = 2
                  TETA    = ZERO
            IF ( LFSTP .EQ. LOAD ) GO TO 30
                  FYCYLT = FYCYL / FS
                  FYRODT = FYROD / FS
            GO TO 20
C
C---- >>> ERROR MESSAGES
C
  100 PRINT 210, PRES
      GO TO 10
  210 FORMAT ( 1H1, 20(/),10(10X,21H*** *** ERROR *** ***   / ),////,
     1            10X, 38HOPERATING PRESSURE IS GREATER THAN THE     /
     2            10X, 42HCAPACITY( CRITICAL LOAD ) OF THE CYLINDER.  //
     3            10X, 37HTHE MAXIMUM PRESSURE FOR THE CYL IS =,1PD10.3,//)
      END
```

```
      SUBROUTINE INPECO ( IBLNK, GC )
C
C---- >>> SUBROUTINE TO READ AND ECHO INPUT DATA FOR SACREG
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / CLERNC / CSBC, PCL1, RCL1
      COMMON / DIAMTS / COD, CID, ROD, RID, CPD, RPD, PHD, SBD
      COMMON / ECCTRI / ECLC, ECLR
      COMMON / ENDS   / LCEND, LREND
      COMMON / FSOPTF / OPPRE, ALTH, ALF, FS, LFSTP
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
      COMMON / INCLFR / CINCL, FCC, FCR
      COMMON / LENGTS / STROK, PHL, SBL, EPTK, CHDS, LFLUID
      COMMON / PISTON / PRW(5), PRT(5), PRE(5), PRK(5), PRDST(5), NPHBR
      COMMON / PROPTS / ECYL, ERCD, FYCYL, FYROD
      COMMON / RODBRS / RBW(5), RBT(5), RBE(5), RBK(5), RBDST(5), NRDBR
      COMMON / STPTBS / CL, RL, STPTB
      COMMON / UNITS  / LNTU, LODU, LPREU, LANGU
      COMMON / WGTINI / WC1, WR1, WPH1, WSB1
C
      DIMENSION PRK1(5), RBK1(5)
C
      DATA ZERO, TWO / 0.0D00, 2.0D00 /
      DATA KEEP, IEND, LYES / 4HKEEP, 3HEND, 3HYES /
C
C---- >>> FORMATS
C
   10 FORMAT ( 20A4                                                      )
   20 FORMAT ( A4, 19A4                                                  )
   30 FORMAT ( 4X, I1, 5X, 6( A4, 6X )                                   )
   40 FORMAT ( 4X, 4( 6X, A4 )                                           )
   50 FORMAT ( 8F10.0                                                    )
   60 FORMAT ( 5F10.0, 10X, A3                                           )
   70 FORMAT ( 3F10.0, A3, 2X, A3, 2X, 4F10.0                            )
   80 FORMAT ( F10.0, A4, 6X, 3F10.0                                     )
   90 FORMAT ( 1H1, 4X, 36HPROGRAM SACREG - STRESS ANALYSIS OF ,
     1          21HCYLINDERS ( REGULAR ), //, 2( 5X, 20A4, / ), /        )
  100 FORMAT ( 5X, 8HPROBLEM , A4, //, 1X, 19A4                          )
  110 FORMAT ( /, 5X, 11HINPUT DATA:, //, 5X, 8HTABLE 1:, 5X,
     1          12HCONTROL DATA                                          )
  120 FORMAT ( /, 10X, 41HPROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS,
     1          31H & ANALYSIS FOR A FACTORED LOAD, /                    )
  130 FORMAT ( /, 10X, 27HPROBLEM TYPE = 2 - ANALYSIS,
     1          26H FOR A PARTICULAR PRESSURE, /                         )
  140 FORMAT ( /, 10X, 27HPROBLEM TYPE = 3 - ANALYSIS,
     1          39H TO DETERMINE SUITABLE STOP-TUBE LENGTH, /            )
  160 FORMAT ( /, 18X, 37HTABLES RETAINED FROM PREVIOUS PROBLEM, //,
     1          20X, 2H 2, 4X, 2H 3, 4X, 2H 4, 4X, 2H 5, 4X, 2H 6,
     2          4X, 2H 7, /, 17X, 6( 2X, A4 )                            )
  190 FORMAT ( 23X, 25HNO KEEP OPTIONS EXERCISED, /                      )
  210 FORMAT ( /, 5X, 33HTABLE 2:      UNITS OF MEASUREMENT,//, 17X,
     1          6HLENGTH, 6X, 4HLOAD, 5X, 8HPRESSURE, 3X, 7HANGULAR,
     2          //, 11X, 4( 7X, A4 )                                     )
  220 FORMAT ( //, 5X, 32HTABLE 3:      CYLINDER DIMENSIONS, //, 10X,
     1          8HLENGTHS:, //, 19X, 23HSTROKE       PISTON HEAD, 2X,
     2          40HSTUFFING BOX    END PLATE    HINGE DIST., //, 14X,
     3          5( 2X, 1PD12.5 )                                         )
  230 FORMAT ( //, 18X, 20HCYLINDER         ROD, 8X,
     1          23HEXTENDED      STOP TUBE                               )
  240 FORMAT ( /, 14X, 4( 2X, 1PD12.5 )                                  )
  250 FORMAT ( /, 15X, 23HTHESE NOT INPUT BECAUSE,
     1          35H STOP TUBE LENGTH ANALYSIS IS ASKED, /                )
  260 FORMAT ( /, 10X, 10HDIAMETERS:, //, 17X, 10HCYL. OUTER, 4X,
     1          38HCYL. INNER     ROD OUTER     ROD INNER, /             )
  270 FORMAT (     14X, 4( 2X, 1PD12.5 ), 2X, 9HSOLID ROD, /             )
  280 FORMAT (     14X, 4( 2X, 1PD12.5 ), 2X, 10HHOLLOW ROD              )
  282 FORMAT (     72X, 10HWITH FLUID                                    )
  284 FORMAT (     72X, 13HWITH NO FLUID                                 )
  290 FORMAT ( /, 18X, 23HCYL. PIN *     ROD PIN *, 3X,
     1          26HPISTON HEAD @  STUF. BOX @,//, 14X, 4( 2X, 1PD12.5 ),
     2          /, 16X, 26H(* ZERO, THE END IS FIXED),
     3          32H (@ ZERO, OTHER OPTION IS INPUT)                      )
  310 FORMAT ( /, 10X, 19HCLEARANCES BETWEEN:, //, 12X,
     1          2( 6X, 8HCYLINDER ), 8X, 3HROD, /, 9X, 3( 11X, 3HAND ),
     2          /, 16X, 12HSTUFFING BOX, 2X, 13HPISTON HEAD @, 2X,
     3          11HSTUF. BOX @,  //, 14X, 3( 2X, 1PD12.5 ), /, 29X,
     4          31H(@ ZERO, OTHER OPTION IS INPUT)                       )
  320 FORMAT ( 1H1, 4X, 31HTABLE 4:      BEARINGS AND SEALS, //, 10X,
     1          16HPISTON BEARINGS:, /                                   )
  330 FORMAT (     21X, 3( 2H A, 12X ), 2H B, 7X, 13HDISTANCE FROM, /,
     1          20X, 5HWIDTH, 7X, 9HTHICKNESS, 2X, 14HYOUNGS MODULUS, 3X,
     2          9HSTIFFNESS, 5X, 9HBACK FACE, //,
     3          5( 14X, 5( 2X, 1PD12.5 ), / )                            )
  340 FORMAT (     10X, 13HROD BEARINGS:, /                              )
  350 FORMAT (     15X, 48H(A IS USED TO CALCULATE B - HENCE, EITHER A OR
     1          , 10HB IS INPUT, /, 28X,
     2          46HZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT), /     )
  360 FORMAT ( /, 5X, 44HTABLE 5:      WEIGHTS AND MATERIAL PROPERTIES,
     1          //, 10X, 17HWEIGHTS OF PARTS:, //, 18X, 8HCYLINDER, 9X,
     2          3HROD, 7X, 11HPISTON HEAD, 2X, 12HSTUFFING BOX, /, 21X,
     3          17H(PER UNIT LENGTH), //, 14X, 4( 2X, 1PD12.5 ), /       )
  370 FORMAT ( /, 10X, 20HMATERIAL PROPERTIES:, //, 22X,
     1          14HYOUNGS MODULUS, 15X, 12HYIELD STRESS, /, 10X,
     2          2( 8X, 8HCYLINDER, 9X, 3HROD ),//, 14X, 4( 2X, 1PD12.5)/)
  380 FORMAT ( /, 5X, 43HTABLE 6:      INCLINATION, FIXITY, FRICTION ,
     1          34HCOEFFICIENTS, LOADING ECCENTRICITY, //, 10X,
     2          34HCYL INCLINATION WITH HORIZONTAL = , 1PD12.5, //, 46X,
     3          24HCYLINDER END     ROD END, //, 10X,
     4          19HSUPPORT CONDITIONS:, 21X, A3, 12X, A3, //, 10X,
     5          36HFRICTION COEFFICIENTS AT SUPPORTS:  , 2( 1PD12.5, 2X )
     6          /, 15X, 19H(ZERO IF FIXED END), /, 10X,
     7          23HLOADING ECCENTRICITIES:, 13X, 2( 1PD12.5, 2X ), /     )
  390 FORMAT ( /, 5X, 42HTABLE 7:      FACTOR OF SAFETY OR OPERATING,
     1          36H PRESSURE AND/OR ALLOWABLE THETA & F, /, 18X,
     2          25HDEPENDING ON PROBLEM TYPE, /                          )
  400 FORMAT ( /, 10X, 27HONLY CRITICAL LOAD ANALYSIS , /                )
  410 FORMAT ( /, 10X, 19HFACTOR OF SAFETY = , F6.3, 4H ON , A4, /       )
  420 FORMAT ( /, 10X, 21HOPERATING PRESSURE = , 1PD12.5, /              )
  430 FORMAT ( /, 10X, 32HOPERATING CYLINDER PRESSURE    = , 1PD12.5,//,
     1          10X, 32HALLOWABLE CROOKEDNESS ANGLE    = , 1PD12.5,
     2          10H  AT GLAND, //,10X,32HALLOWABLE TOTAL LATERAL FORCE =
     3          1PD12.5, 13H  ON BEARINGS, /                             )
  450 FORMAT ( ///, 10X, 30H*****  ERROR IN LENGTHS  *****, /            )
  460 FORMAT ( ///, 10X, 7H*****  ,
     1          32HERROR : PHD IS GREATER THAN CID , 6H *****, /         )
```

```
  470 FORMAT ( ///, 10X, 7H*****  ,
     1          37HERROR : RD IS GREATER THAN SBD  *****, /                 )
  480 FORMAT ( //, 10X, 6H***** , 19HPROGRAM TERMINATED , 5H*****           )
  490 FORMAT ( 1H1                                                          )
C
C---- >>> READ AND ECHO RUN AND PROBLEM IDENTIFICATION
C
          IF ( NPROB .NE. IBLNK ) GO TO 500
      READ ( 5, 10 ) ( IDCARD( I ), I = 1, 40 )
  500 READ ( 5, 20 ) NPROB, ( IPROB( I ), I = 1, 19 )
C
C---- >>> TEST FOR END OF RUN
C
          IF ( NPROB .EQ. IBLNK ) GO TO 1700
      PRINT 90, ( IDCARD( I ), I = 1, 40 )
      PRINT 100, NPROB, ( IPROB( I ), I = 1, 19 )
C
C---- >>> READ TABLE 1:  PROBLEM TYPE AND TABLES TO BE RETAINED FROM
C                        PREVIOUS PROBLEM
C
      READ ( 5, 30 ) LPRTP, KEEP2, KEEP3, KEEP4, KEEP5, KEEP6, KEEP7
          IF ( KEEP2 .EQ. KEEP ) GO TO 510
C
C---- >>> READ TABLE 2:  UNITS OF MEASUREMENT
C
      READ ( 5, 40 ) LNTU, LODU, LPREU, LANGU
  510     IF ( KEEP3 .EQ. KEEP ) GO TO 540
      READ ( 5, 60 ) STROK, PHL, SBL, EPTK, CHDS, LFLUID
          IF ( LPRTP .EQ. 3 ) GO TO 520
C
C---- >>> READ TABLE 3:  LENGTHS AND DIAMETERS
C
      READ ( 5, 50 ) CL, RL, EXL, STPTB
  520 READ ( 5, 50 ) COD, CID, ROD, RID, CPD, RPD, PHD, SBD
      READ ( 5, 50 ) CSBC, PCL1, RCL1
C
C---- >>> CALCULATE GLAND CLEARANCE
C
              GC      = ZERO
          IF ( LPRTP .NE. 3 ) GC = CL - STROK - PHL
C
C---- >>> TEST FOR PROPER INPUT
C
          IF ( LPRTP .EQ. 3 ) GO TO 530
              A       = EXL - CHDS - EPTK - CL - SBL - RPD / TWO
          IF ( A .LT. STROK ) GO TO 1000
  530     IF ( PCL1 .GT. ZERO .OR. RCL1 .GT. ZERO ) GO TO 540
          IF ( PHD .GT. CID ) GO TO 1100
          IF ( ROD .GT. SBD ) GO TO 1200
C
  540     IF ( KEEP4 .EQ. KEEP ) GO TO 585
C
C---- >>> READ TABLE 4:  PISTON RINGS AND ROD BEARINGS DETAILS
C
              I = 1
              J = 1
  550 READ ( 5, 60 ) PRW(I), PRT(I), PRE(I), PRK1(I), PRDST(I), NEND
              PRK(I) = PRK1(I)
          IF ( NEND .EQ. IEND ) GO TO 560
              I = I + 1
          GO TO 550
  560         NPHBR  = I
  570 READ ( 5, 60 ) RBW(J), RBT(J), RBE(J), RBK1(J), RBDST(J), NEND
              RBK(J) = RBK1(J)
          IF ( NEND .EQ. IEND ) GO TO 580
              J = J + 1
          GO TO 570
  580         NRDBR  = J
  585     IF ( KEEP5 .EQ. KEEP ) GO TO 590
C---- >>> READ TABLE 5:  WEIGHTS OF PARTS AND MATERIAL PROPERTIES
      READ ( 5, 50 ) WC1, WR1, WPH1, WSB1, ECYL, EROD, FYCYL, FYROD
  590     IF ( KEEP6 .EQ. KEEP ) GO TO 600
C
C---- >>> READ TABLE 6:  INCLINATION, END FIXITY, FRICTION COEFFICIENTS
C                        AND ECCENTRICITY OF LOADING
C
      READ ( 5, 70 ) CINCL, CSSTF, RSSTF, LCEND, LREND, FCC, FCR, ECLC,
     *                    ECLR
  600     IF ( KEEP7 .EQ. KEEP ) GO TO 610
C
C---- >>> READ TABLE 7;  FACTOR OF SAFETY AND ITS TYPE, OPERATING
C                        PRESSURE AND ALLOWABLE THETA AND LATERAL FORCE
C                        DEPENDING ON THE PROBLEM TYPE
C
      READ ( 5, 80 ) FS, LFSTP, OPPRE, ALTH, ALF
  610     CONTINUE
C
C---- >>> PRINT ALL THE TABLES READ
C
      PRINT 110
          IF ( LPRTP - 2 ) 612, 614, 616
  612 PRINT 120
          GO TO 618
  614 PRINT 130
          GO TO 618
  616 PRINT 140
  618 PRINT 160, KEEP2, KEEP3, KEEP4, KEEP5, KEEP6, KEEP7
          IF ( KEEP2 .NE. IBLNK ) GO TO 620
          IF ( KEEP3 .NE. IBLNK ) GO TO 620
          IF ( KEEP4 .NE. IBLNK ) GO TO 620
          IF ( KEEP5 .NE. IBLNK ) GO TO 620
          IF ( KEEP6 .NE. IBLNK ) GO TO 620
          IF ( KEEP7 .EQ. IBLNK ) PRINT 190
  620     CONTINUE
      PRINT 210, LNTU, LODU, LPREU, LANGU
      PRINT 220, STROK, PHL, SBL, EPTK, CHDS
      PRINT 230
          IF ( LPRTP .EQ. 3 ) GO TO 640
      PRINT 240, CL, RL, EXL, STPTB
          GO TO 650
  640 PRINT 250
  650 PRINT 260
          IF ( RID .GT. ZERO ) GO TO 670
      PRINT 270, COD, CID, ROD, RID
          GO TO 680
  670 PRINT 280, COD, CID, ROD, RID
```

```
           IF ( LFLUID .NE. LYES ) GO TO 675
      PRINT 282
           GO TO 680
  675 PRINT 284
  680 PRINT 290, CPD, RPD, PHD, SBD
      PRINT 310, CSBC, PCL1, RCL1
      PRINT 320
      PRINT 330, ( PRW(I), PRT(I), PRE(I), PRK1(I),PRDST(I),I=1, NPHBR )
      PRINT 340
      PRINT 330, ( RBW(I), RBT(I), RBE(I), RBK1(I),RBDST(I),I=1, NRDBR )
      PRINT 350
      PRINT 360, WC1, WR1, WPH1, WSB1
      PRINT 370, ECYL, EROD, FYCYL, FYROD
      PRINT 380, CINCL, LCEND, LREND, FCC, FCR, ECLC, ECLR
      PRINT 390
           IF ( LPRTP .EQ. 1 .AND. FS .LE. ONE ) GO TO 690
           IF ( LPRTP .EQ. 1 ) PRINT 410, FS, LFSTP
           GO TO 700
  690 PRINT 400
  700      IF ( LPRTP .EQ. 2 ) PRINT 420, OPPRE
           IF ( LPRTP .EQ. 3 ) PRINT 430, OPPRE, ALTH, ALF
      RETURN
C
C---- >>> DIAGONOSTICS FOR ILLEGAL INPUTS
C
 1000 PRINT 450
           GO TO 1600
 1100 PRINT 460
           GO TO 1600
 1200 PRINT 470
 1600 PRINT 480
 1700 PRINT 490
C
C---- >>> END OF RUN IF ERROR IN INPUT IS ENCOUNTERED
C
      STOP
      END
```

```
      SUBROUTINE CONST1
     I          ( ECYL, EROD, CHDS, LANGU,
     O            RDI, CYK, RDK, CSSTF, RSSTF                              )
C
C---- >>> SUBROUTINE TO CALCULATE CONSTANT TERMS FOR CONVENIENCE
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / BRGSTF / PRKX, SPRK, RBKY, SRBK
      COMMON / CRPROP / RDZ, CYZ, RDZI, CYZI, HSCCI, HSCCO, HSCRI,
     *                  HSCRO, BAREAC, BAREAR, CAREAC, CAREAR
      COMMON / CLEAR  / PCL, RCL
      COMMON / CLERNC / CSBC, PCL1, RCL1
      COMMON / DIAMTS / COD, CID, ROD, RID, CPD, RPD, PHD, SBD
      COMMON / ENDS   / LCEND, LREND
      COMMON / FRCONS / FCCY, FCRD, CONM
      COMMON / INCLFR / CINCL, FCC, FCR
      COMMON / PISTON / PRW(5), PRT(5), PRE(5), PRK(5), PRDST(5), NPHBR
      COMMON / RODBRS / RBW(5), RBT(5), RBE(5), RBK(5), RBDST(5), NRDBR
      COMMON / WGTCON / WPH, WSB
      COMMON / WGTINI / WC1, WR1, WPH1, WSB1
      COMMON / WGTVER / WC, WR
C
      DATA ZERO, TWO, FOUR, SXTFOR / 0.0D00, 2.0D00, 4.0D00, 64.0D00 /
      DATA H180, AINFIN / 180.0D00, 1.0D20 /
      DATA PI / 3.14159265358979300 /
      DATA LDEG, LFIX / 4HDEG , 3HFIX /
C
C---- >>> CALCULATE STIFFNESSES OF BEARINGS AND SEALS IF NOT INPUT
C
                SPRK    = ZERO
                PRKX    = ZERO
           DO 110 I = 1, NPHBR
           IF ( PRK(I) .GT. ZERO ) GO TO 100
                PRK(I) = CID * PRW(I) * PRE(I) / PRT(I)
  100           PRKX    = PRK(I) * PRDST(I) + PRKX
  110           SPRK    = PRK(I) + SPRK
                SRBK    = ZERO
                RBKY    = ZERO
           DO 130 I = 1, NRDBR
           IF ( RBK(I) .GT. ZERO ) GO TO 120
                RBK(I) = ROD * RBW(I) * RBE(I) / RBT(I)
  120           RBKY    = RBK(I) * RBDST(I) + RBKY
  130           SRBK    = RBK(I) + SRBK
C
C---- >>> CALCULATE CROSS SECTIONAL PROPERTIES
C
                ROD2    = ROD * ROD
                RID2    = RID * RID
                COD2    = COD * COD
                CID2    = CID * CID
                CYI     = PI * ( COD2 * COD2 - CID2 * CID2 ) / SXTFOR
                RDI     = PI * ( ROD2 * ROD2 - RID2 * RID2 ) / SXTFOR
                RDZ     = RDI * TWO / ROD
                CYZ     = CYI * TWO / COD
                RDZI    = 1.0D+20
           IF ( RID .GT. ZERO ) RDZI = RDI * TWO / RID
                CYZI    = CYI * TWO / CID
C
```

```
C---- >>> BORE AREAS AND CRUSS SECTIONAL AREAS OF CYLINDER AND ROD
C
                BAREAC = PI * CID2 / FOUR
                BAREAR = PI * RID2 / FOUR
                CAREAC = PI * ( COD2 - CID2 ) / FOUR
                CAREAR = PI * ( ROD2 - RID2 ) / FOUR
C
C---- >>> CALCULATE HOOP STRESS COEFFICIENT
C
                RDENC  = COD2 - CID2
                HSCCI  = ( COD2 + CID2 ) / RDENC
                HSCCO  = TWO * CID2 / RDENC
                RDENR  = ROD2 - RID2
                HSCRI  = ( ROD2 + RID2 ) / RDENR
                HSCRO  = TWO * RID2 / RDENR
C
                CYK    = DSQRT ( ECYL * CYI )
                RDK    = DSQRT ( EROD * RDI )
C
C---- >>> CALCULATE CLEARANCES AT PISTON HEAD AND STUFFING BOX
C
                PCL    = ( CID - PHD ) / TWO
           IF ( PCL1 .GT. ZERO ) PCL = PCL1
                RCL    = ( SBD - ROD ) / TWO + CSBC
           IF ( RCL1 .GT. ZERO ) RCL = RCL1 + CSBC
C
C---- >>> CALCULATE VERTICAL COMPONENTS OF WEIGHTS
C
                TEMP   = PI / H180
                BETA   = CINCL
           IF ( LANGU .EQ. LDEG ) BETA = CINCL * TEMP
                CB     = DCOS( BETA )
                WC     = WC1 * CB
                WR     = WR1 * CB
                WPH    = WPH1 * CB
                WSB    = WSB1 * CB
C
C---- >>> CALCULATE FRICTION MOMENT COEFFICIENTS
C
                FCCY   = FCC * CPD / TWO
                FCRD   = FCR * RPC / TWO
C
C---- >>> ESTABLISH STIFFNESSES FOR ROTATIONAL SPRINGS AT SUPPORTS
C         ZERO IF PIN; VERY HIGH IF FIX.
C
                CSSTF  = ZERO
                RSSTF  = ZERO
           IF ( LCEND .EQ. LFIX ) CSSTF = AINFIN
           IF ( LREND .EQ. LFIX ) RSSTF = AINFIN
C
C---- >>> MOMENT DUE TO OVER HANG
C
                CONM   = WC * CHDS * CHDS / TWO
           IF ( CHDS .GT. ZERO ) CONM = ZERO
           IF ( LCEND .EQ. LFIX ) CONM = ZERO
      RETURN
      END
```

```
      SUBROUTINE TRIALP
     I          ( EROD, LPRTP, RDI, FYCYL, BAREAC, HSCCI, LCEND, FYROD,
     I           BAREAR, HSCRI,
     O           PINCR1, PINCR2                                          )
C
C---- >>> SUBROUTINE TO CALCULATE TRIAL LOAD AND LOAD INCREMENTS
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P1
      COMMON / LENGTS / STROK, PHL, SBL, EPTK, CHDS, LFLUID
C
      DATA TWO, FIFTY, FIVHUN / 2.0D00, 50.0D00, 500.0D00 /
      DATA PI / 3.141592653589793D00 /
      DATA LFIX, LYES / 3HFIX, 3HYES /
C
C---- >>> IF LPRTP = 3 CALCULATE APPROXIMATE EXTENDED LENGTH
C
           IF ( LPRTP - 3 ) 110, 100, 110
  100           EXL    = STROK + STROK + PHL + SBL + CHDS + EPTK
C
C---- >>> TRIAL LOAD (1) AS PER EULERS BUCKLING, CONSIDERING FULL
C          LENGTH STIFFNESS AS THAT OF ROD ONLY
C
  110           P1     = PI * PI * EROD * RDI / ( EXL * EXL )
           IF ( LCEND .EQ. LFIX ) P1 = TWO * P1
C
C---- >>> TRIAL LOAD (2) AS PER EXCESSIVE HOOP STRESS RESTRICTION IN CYL
C
                P2     = FYCYL * BAREAC / HSCCI
C
C---- >>> TRIAL LOAD (3) AS PER EXCESSIVE HOOP STRESS RESTRICTION IN ROD
C
                P3     = FYROD * BAREAR / HSCRI
           IF ( LFLUID .NE. LYES ) P3 = P2
C
C---- >>> TRIAL LOAD, SMALLER OF (1), (2) AND (3)
C
                P1     = DMIN1( P1, P2, P3 )
C
C---- >>> CALCULATE LOAD INCREMENTS
C
                PINCR1 = P1 / FIFTY
                PINCR2 = P1 / ( FIVHUN * TWO )
      RETURN
      END
```

```
      SUBROUTINE EQBRIM
     I          ( PRK, PRDST, RBK, RBDST, NPHBR, NRDBR, CYK, RDK, LPRTP,
     I            GC, RPD, BMG, CSSTF, RSSTF,
     O            CLT, RLT, CK, RK, BB1, BB2, TETA, DEFG, THC           )
C
C---- >>> SUBROUTINE TO CALCULATE CONSISTENT VALUES OF DEFLECTIONS AND
C          CROOKEDNESS ANGLE BY ITERATING, FOR A PARTICULAR VALUE OF LOAD
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / BRGSTF / PRKX, SPRK, RBKY, SRBK
      COMMON / CANDDS / C1, C2, D1, D2
      COMMON / CLEAR  / PCL, RCL
      COMMON / CONSTS / EEL, FFL, AKTHC, AKTHR
      COMMON / ECCTRI / ECLC, ECLR
      COMMON / FRCONS / FCCY, FCRD, CONM
      COMMON / GLDFOR / FX(5), FY(5), F1, F2, F3, F4
      COMMON / LENGTS / STROK, PHL, SBL, EPTK, CHDS, LFLUID
      COMMON / REATNS / REC, RER
      COMMON / STPTBS / CL, RL, STPTB
      COMMON / WGTCON / WPH, WSB
      COMMON / WGTVER / WC, WR
C
      DIMENSION PRK( NPHBR ), PRDST( NPHBR ), RBK( NRDBR ),RBDST(NRDBR)
C
      DATA ZERO, TWO, HUNDRD / 0.0D00, 2.0D00, 100.0D00 /
      DATA LFIX / 3HFIX /
C
C---- >>> COUNTER TO QUIT LOOP AT SPECIFIED NUMBER OF ITERATIONS
C
              N       = 1
          IF ( LPRTP .NE. 3 ) GO TO 50
C
C---- >>> CALCULATE CYLINDER, ROD AND EXTENDED LENGTHS IN CASE OF
C          STOP-TUBE LENGTH DETERMINATION ANALYSIS
C
              CL      = STROK + PHL + GC
              RL      = STROK + SBL + RPD / TWO + GC
              EXL     = CL + EPTK + CHDS + RL - GC
          GO TO 50
C
C---- >>> CALCULATE TRANSFORMED CYLINDER AND ROD LENGTHS
C
   20         CLT     = CL + EPTK + CHDS - Y
              RLT     = RL - X
C
C---- >>> CALCULATE EQUIVALENT CONCENTRATED LATERAL LOAD AT STEP
C
              W       = WPH + WSB + WC * Y + WR * X
C
C---- >>> CALCULATE LATERAL REACTIONS AT SUPPORTS
C
              REC     = ( W  * RLT + CONM + WC * CLT * ( RLT + CLT / TWO
     *                  ) + WR * RLT * RLT / TWO ) / EXL
              RER     = W + WC * CLT + WR * RLT - REC
       CALL THCDS
     I        ( CYK, RDK, CLT, RLT, CSSTF, RSSTF, TETA, W,
     O         BB1, BB2, CK, RK, CK1L1, SK1L1, THC )
C
C---- >>> CALCULATE DEFLECTION AT SLIDING CONNECTION
C
              DEFG1   = ( AKTHC - AKTHR ) * CLT / EXL - WC * CLT * CLT /
     *                  ( TWO * P )
              DEFG    = C1 * CK1L1 + D1 * SK1L1 - EEL * CLT + FFL * CLT
     *                - DEFG1 + BB1 - REC * CLT / P
C
C---- >>> CALCULATE BENDING MOMENT AT INTERFACE
C
              BMG     = P * CLT * ( EEL - FFL ) + DEFG1 * P + P * ECLC
     *                + REC * CLT - CCNM - P * ( FCCY + AKTHC - DEFG )
C
C---- >>> CALCULATE CROOKEDNESS ANGLE - THETA, AT SLIDING CONNECTION
C
   50 CALL THETA
     I        ( PRK, PRDST, RBK, RBDST, NPHBR, NRDBR, GC, BMG, PHL,SBL,
     O         X, Y, TETAF  )
              N       = N + 1
          IF ( N - 2 ) 20, 20, 60
   60         DTETA   = DABS( TETA / HUNDRD )
              DIFF    = DABS( TETAF - TETA )
              TETA    = TETAF
C
C---- >>> ARE INITIAL AND FINAL THETAS CLOSE?
C
          IF ( DIFF .LT. DTETA ) RETURN
          IF ( N .GT. 25 ) RETURN
          GO TO 20
      END
```

```
      SUBROUTINE THETA
     I          ( PRK, PRDST, RBK, RBDST, NPHBR, NRDBR, GC, BMG, PHL,SBL,
     O            X, Y, TETA   )
C
C---- >>> SUBROUTINE TC CALCULATE CROOKEDNESS ANGLE AND FORCES AT
C         INTERFACE
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / BRGSTF / PRKX, SPRK, RBKY, SRBK
      COMMON / CLEAR  / PCL, RCL
      COMMON / GLDFOR / FX(5), FY(5), F1, F2, F3, F4
C
      DIMENSION PRK( NPHBR ), PRDST( NPHBR ), RBK( NRDBR ),RBDST(NRDBR)
C
      DATA ZERO, ONE, TWO / 0.0D00, 1.0D00, 2.0D00 /
C
C
C---- >>> MONITOR FOR PROPER SIGN
C
                SIGN    = ONE
          IF ( BMG ) 100, 110, 100
  100           SIGN    = BMG / DABS( BMG )
  110           SRPBK   = SRBK + SPRK
                F1      = ZERO
                F2      = ZERO
                F3      = ZERO
                F4      = ZERO
C
C---- >>> CASE 1:  NO METAL TO METAL CONTACT AT SLIDING CONNECTION
C
                X       = ( RBKY + GC * SRBK - PRKX ) / SRPBK
                Y       = GC - X
          IF ( PCL .EQ. ZERO .AND. RCL .EQ. ZERO ) GO TO 690
                CF      = ZERO
          DO 130 I = 1, NPHBR
  130           CF      = CF + PRK(I) * ( X + PRDST(I) ) * ( X + PRDST(I))
          DO 140 I = 1, NRDBR
  140           CF      = CF + RBK(I) * ( Y + RBDST(I) ) * ( Y + RBDST(I))
                TETA    = BMG / CF
                D1      = ( X + PHL ) * DABS( TETA )
                D2      = ( Y + SBL ) * DABS( TETA )
          IF ( D1 .GE. PCL .AND. D2 .GE. RCL ) GO TO 170
          IF ( D1 - PCL ) 150, 200, 200
  150     IF ( D2 - RCL ) 750, 300, 300
  170           D22     = PCL * ( Y + SBL ) / ( X + PHL )
          IF ( D22 - RCL ) 200, 300, 300
C
C---- >>> CASE 2:  CONTACT AT FRONT FACE OF PISTON HEAD
C
  200           XNUM    = ZERO
                XDEN    = ZERO
                A       = PHL + GC
                B       = DABS( BMG ) / PCL
          DO 210 I = 1, NPHBR
                TEMP    = PRK(I) * ( PHL - PRDST(I) )
                XDEN    = XDEN + TEMP
  210           XNUM    = XNUM + TEMP * PRDST(I)
                XNUM    = - XNUM
          DO 220 I = 1, NRDBR
                TEMP    = RBK(I) * ( A + RBDST(I) )
                XDEN    = XDEN + TEMP
  220           XNUM    = XNUM + TEMP * ( GC + RBDST(I) )
                XNUM    = XNUM - B * PHL
                XDEN    = B + XDEN
                X       = XNUM / XDEN
                Y       = GC - X
                TETA    = PCL / ( X + PHL ) * SIGN
                D3      = DABS( TETA * X )
                D2      = ( Y + SBL ) * DABS( TETA )
          IF ( D3 .GE. PCL .AND. D2 .GE. RCL ) GO TO 270
          IF ( D3 - PCL ) 240, 400, 400
  240     IF ( D2 - RCL ) 250, 600, 600
  250           F1      = TETA * ( RBKY + GC * SRBK - PRKX - X * SRPBK )
          GO TO 750
  270           TETA    = PCL * TWC / PHL
                D2      = ( PHL / TWO + GC + SBL ) * TETA
          IF ( D2 - RCL ) 400, 600, 600
C
C---- >>> CASE 3:  CONTACT AT FRONT FACE OF STUFFING BOX
C
  300           XNUM    = ZERO
                XDEN    = ZERO
                A       = SBL + GC
                B       = DABS( BMG ) / RCL
          DO 310 I = 1, NPHBR
                TEMP    = PRK(I) * ( A + PRDST(I) )
                XDEN    = XDEN + TEMP
  310           XNUM    = XNUM + TEMP * PRDST(I)
                XNUM    = - XNUM
          DO 320 I = 1, NRDBR
                TEMP    = RBK(I) * ( SBL - RBDST(I) )
                XDEN    = XDEN + TEMP
  320           XNUM    = XNUM + TEMP * ( GC + RBDST(I) )
                XNUM    = XNUM + B * A
                XDEN    = B + XDEN
                X       = XNUM / XDEN
                Y       = GC - X
                TETA    = RCL / ( Y + SBL ) * SIGN
                D1      = ( X + PHL ) * DABS( TETA )
                D4      = DABS( TETA * Y )
          IF ( D1 .GE. PCL .AND. D4 .GE. RCL ) GO TO 370
          IF ( D1 - PCL ) 340, 600, 600
  340     IF ( D4 - RCL ) 350, 500, 500
  350           F2      = TETA * ( X * SRPBK - RBKY - GC * SRBK + PRKX )
          GO TO 750
  370           TETA    = RCL * TWC / SBL
                D1      = ( PHL + GC + SBL / TWO ) * DABS( TETA )
          IF ( D1 - PCL ) 500, 600, 600
C
C---- >>> CASE 4:  CONTACT AT FRONT AND BACK FACES OF PISTON HEAD
C
  400           X       = - PHL / TWC
                TETA    = TWO * PCL / PHL * SIGN
                Y       = GC - X
      CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                     FX )
      CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                     FY )
```

```
            DO 470 I = 1, NPHBR
                 F3      = F3 + FX(I)
  470            F1      = F1 + FX(I) * PRDST(I)
            DO 480 I = 1, NRDBR
                 F3      = F3 - FY(I)
  480            F1      = F1 + FY(I) * ( GC + RBDST(I) )
                 F1      = ( BMG - F1 ) / PHL
                 F3      = F1 + F3
       RETURN
C
C---- >>> CASE 5:  CONTACT AT FRONT AND BACK FACES OF STUFFING BOX
C
  500            X       = GC + SBL / TWO
                 TETA    = TWO * RCL / SBL * SIGN
                 Y       = GC - X
       CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                  FX )
       CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                  FY )
            DO 570 I = 1, NPHBR
                 F2      = - FX(I) * ( GC + PRDST(I) ) + F2
  570            F4      = - FX(I) + F4
            DO 580 I = 1, NRDBR
                 F2      = F2 - FY(I) * RBDST(I)
  580            F4      = F4 + FY(I)
                 F2      = ( BMG + F2 ) / SBL
                 F4      = F2 + F4
       RETURN
C
C---- >>> CASE 6:  CONTACT AT FRONT FACE OF PISTON HEAD AND FRONT FACE
C                  OF STUFFING BOX
C
  600            TETA    = ( PCL + RCL ) / ( PHL + GC + SBL ) * SIGN
                 X       = PCL / DABS( TETA ) - PHL
                 Y       = GC - X
       CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                  FX )
       CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                  FY )
            DO 670 I = 1, NPHBR
                 F1      = - FX(I) * ( SBL + GC + PRDST(I) ) + F1
  670            F2      = FX(I) + F2
            DO 680 I = 1, NRDBR
                 F1      = F1 + FY(I) * ( SBL - RBDST(I) )
  680            F2      = - FY(I) + F2
                 F1      = ( BMG + F1 ) / ( PHL + GC + SBL )
                 F2      = F1 + F2
       RETURN
  690            TETA    = ZERO
C
  750  CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                  FX )
       CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                  FY )
       RETURN
       END
```

```
      SUBROUTINE GFORCE
     I          ( AK, DST, TETA, X, N,                                 F )
C
C---- >>> SUBROUTINE TO CALCULATE FORCES ON EACH BEARING
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      DIMENSION AK(N), DST(N), F(N)
C
          DO 100 I = 1, N
               F(I)    = AK(I) * ( X + DST(I) ) * TETA
  100     CONTINUE
      RETURN
      END
```

```
      SUBRCUTINE THCDS
     I          ( CYK, RDK, CLT, RLT, CSSTF, RSSTF, TETA, W,
     O           BB1, BB2, CK, RK, CK1L1, SK1L1, THC )
C
C---- >>> SUBROUTINE TO CALCULATE SLOPES AT SUPPORTS AND CONSTANTS IN
C         DEFLECTION EQUATIONS
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / CANDDS / C1, C2, D1, D2
      COMMON / CONSTS / EEL, FFL, AKTHC, AKTHR
      COMMON / ECCTRI / ECLC, ECLR
      COMMON / FRCONS / FCCY, FCRD, CONM
      COMMON / REATNS / REC, RER
      COMMON / WGTVER / WC, WR
C
      DATA ZERO, ONE / 0.D00, 1.D00 /
C
                SQP    = DSQRT ( P )
                CK     = SQP / CYK
                RK     = SQP / RDK
                CK2    = CK * CK
                RK2    = RK * RK
                AK1L1  = CK  * CLT
                AK2L2  = RK  * RLT
                AK2L1  = RK  * CLT
                AK2EL  = RK  * EXL
                TK1L1  = DTAN( AK1L1 )
                SK1L1  = DSIN( AK1L1 )
                CK1L1  = DCOS( AK1L1 )
                TK2L2  = DTAN( AK2L2 )
                SK2L2  = DSIN( AK2L2 )
                CK2L2  = DCOS( AK2L2 )
                CK2L1  = DCOS( AK2L1 )
                TK2L1  = DTAN( AK2L1 )
                CK2EL  = DCOS( AK2EL )
                SK2EL  = DSIN( AK2EL )
                TK2EL  = DTAN( AK2EL )
                AKCON  = CK / TK1L1 + RK / TK2L2
                BKCON  = CK * TK2L2 + RK * TK1L1
                CKCON  = RK - CK * TK1L1 * TK2L2
                DKCON  = RK * TK1L1 * TK2L1 + CK
                TT     = TK1L1 * TK2L2
                SS     = SK1L1 * SK2L2
                CC     = CK1L1 * CK2L2
                ST     = SK1L1 * TK2L2
                CCEL   = CK2L2 * CK2EL
                TS     = TK1L1 * SK2L2
                WRPK2  = WR / ( P * RK2 )
                WCPK2  = WC / ( P * CK2 )
                WCWR   = WRPK2 - WCPK2
                AKCBP  = CSSTF / P
                AKRBP  = RSSTF / P
                EEL    = ( ECLR - ECLC ) / EXL
                FFL    = ( FCRD - FCCY ) / EXL
                BB1    = CONM / P + FCCY - ECLC - WCPK2
                BB2    = FCRD - ECLR - WRPK2
                BB3    = TETA + W / P
```

```
C
C---- >>> CALCULATE SLOPES AT CYLINDER AND ROD SUPPORTS
C
                A11    = ONE - AKCBP * CK * CKCON / BKCON + AKCBP / EXL
                A12    = AKRBP * CK * RK / BKCON / CC - AKRBP / EXL
                B1     = ( BB1 * CKCON / TT - WCWR * RK / ST - BB2 * RK
     *                 / SS + BB3 / SK1L1 ) * CK / AKCON - EEL + FFL
     *                 - REC / P
                A21    = - AKCBP * CK * RK / BKCON /CC + AKCBP / EXL
                A22    = ONE + AKRBP * CK2L1 * DKCON * RK / CCEL / BKCON
     *                 - AKRBP * RK * TK2EL - AKRBP / EXL
                B2     = ( BB1 * CK / CC - BB2 * DKCON * CK2L1 / CCEL
     *                 - WCWR * CK / CK2L2 - BB3 * TK1L1 / CK2L2 ) * RK
     *                 / BKCON + BB2 * RK * TK2EL - EEL + FFL + RER / P
                THDEN  = A11 * A22 - A12 * A21
                THC    = ( B1 * A22 - A12 * B2 ) / THDEN
                THR    = ( A11 * B2 - A21 * B1 ) / THDEN
                AKTHC  = AKCBP * THC
                AKTHR  = AKRBP * THR
                BB1    = BB1 + AKTHC
                BB2    = BB2 + AKTHR
C
C---- >>> CALCULATE CONSTANTS IN DEFLECTION EQUATIONS
C
                C1     = -BB1
                D1     = ( BB1 * CKCON / TT - WCWR * RK / ST - BB2 * RK
     *                 / SS + BB3 / SK1L1 ) / AKCON
                D2     = ( BB1 * CK * CK2EL / SS - BB2 * DKCON * CK2L1
     *                 / TS - WCWR * CK * CK2EL / TS - BB3 * CK2EL
     *                 / SK2L2 ) / AKCON
                C2     = ( - D2 * SK2EL - BB2 ) / CK2EL
      RETURN
      END
```

```
      SUBROUTINE STOPTB
     I          ( TETA, NPHBR, NRDBR, ALTH, ALF, STROK, ITERAT,       GC )
C
C---- >>> SUBROUTINE TO CALCULATE THE REQUIRED LENGTH OF STOP-TUBE
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / GLDFOR / FX(5), FY(5), F1, F2, F3, F4
C
      DATA TWO, HUNDRD / 2.0D00, 100.0D00 /
C
C---- >>> INCREMENT FOR STOP-TUBE LENGTH
C
               GCI     = STROK / HUNDRD
C
C---- >>> CALCULATE TOTAL LATERAL FORCE
C
               TF      = DABS( F1 ) + DABS( F2 ) + DABS( F3 ) + DABS( F4)
         DO 100 I = 1, NPHBR
  100          TF      = TF + DABS( FX(I) )
         DO 110 I = 1, NRDBR
  110          TF      = TF + DABS( FY(I) )
               F       = TF / TWO
C
C---- >>> CHECK TOTAL FORCE AND CROOKEDNESS ANGLE LIMITS
C
         IF ( F .LT. ALF .AND. DABS( TETA ) .LT. ALTH ) RETURN
               GC      = GC + GCI
         IF ( GC - STROK / TWO / TWO ) 120, 120, 900
  120          ITERAT = 2
      RETURN
  900 PRINT 910
  910 FORMAT ( 1H1, ///, 5( 25H* * * * * ERROR * * * * *, / ),
     1          ///, 45HFORCE AND CROOKEDNESS ANGLE LIMITS AT           ,/
     2               45HSLIDING CONNECTION ARE TOO SMALL;               ,/
     3               45HRESULTS IN UNECONOMICAL DESIGN;                 ,/
     4               45HSTOP TUBE LENGTH BECOMES > STROKE / 4;          ,/
     5               45HSUGGESTION - INCREASE LIMITING VALUES.          ,/ )
      STOP
      END
```

```
      SUBROUTINE XATYMX
     I          ( CLT, CK, RK, DEFG,
     O            XCY, XRD, CSLPC, CSLPR                                  )
C
C---- >>> SUBROUTINE TO CALCULATE THE DISTANCES AT WHICH MAXIMUM
C          DEFLECTIONS OCCUR
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / CANDDS / C1, C2, D1, D2
      COMMON / CONSTS / EEL, FFL, AKTHC, AKTHR
      COMMON / REATNS / REC, RER
      COMMON / WGTVER / WC, WR
C
      DATA ZERO, HUNDRD / 0.D00, 100.D00 /
C
C---- >>> INCREMENT FOR X
C
               AINCR  = CLT / HUNDRD
               CSLP   = - EEL + FFL - ( AKTHC - AKTHR ) / EXL
               CSLPC  = CSLP - REC / P
               CSLPR  = CSLP + RER / P
               XCY    = CLT
               XRD    = CLT
C
C---- >>> POINT AT WHICH MAXIMUM DEFLECTION OCCURS IN CYLINDER
C
  100          ANG    = CK * XCY
               CSLOP  = - C1 * CK * DSIN( ANG ) + D1 * CK * DCOS( ANG )
     *                  + CSLPC + WC * XCY / P
         IF ( DEFG ) 140, 140, 120
  120    IF ( CSLOP ) 160, 160, 200
  140    IF ( CSLOP ) 200, 160, 160
  160          XCY    = XCY - AINCR
         GO TO 100
C
C---- >>> POINT AT WHICH MAXIMUM DEFLECTION OCCURS IN ROD
C
  200          ANG    = RK * XRD
               RSLOP  = - C2 * RK * DSIN( ANG ) + D2 * RK * DCOS( ANG )
     *                  + CSLPR - WR * ( EXL - XRD ) / P
         IF ( DEFG ) 240, 240, 220
  220    IF ( RSLOP ) 300, 260, 260
  240    IF ( RSLOP ) 260, 260, 300
  260          XRD    = XRD + AINCR
         GO TO 200
  300 RETURN
      END
```

```
      SUBROUTINE YMAXS
     I          ( XCY, XRD, CK, RK, CSLPC, CSLPR, BB1, BB2,
     O           YCMAX, YRMAX                                          )
C
C---- >>> SUBROUTINE TO CALCULATE MAX. DEFLECTIONS IN CYLINDER AND ROD
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / CANDOS / C1, C2, D1, D2
      COMMON / WGTVER / WC, WR
C
      DATA TWO / 2.0D00 /
C
                CANG    = XCY * CK
                RANG    = XRD * RK
                TWOP    = TWO * P
                XRDP    = EXL - XRC
C
C---- >>> MAXIMUM DEFLECTION IN CYLINDER
C
                YCMAX   = C1 * DCOS( CANG ) + D1 * DSIN( CANG )
     *                  + CSLPC * XCY + BB1 + WC * XCY * XCY / TWOP
C
C---- >>> MAXIMUM DEFLECTION IN ROD
C
                YRMAX   = C2 * DCOS( RANG ) + D2 * DSIN( RANG )
     *                  - CSLPR * XRDP + BB2 + WR * XRDP * XRDP / TWOP
      RETURN
      END
```

```
      SUBROUTINE STRCHS
     1          ( KEYF, KEYT, KEYP, XCY, XRD, YCMAX, YRMAX, RID, CHDS,
     I           OPPRE, FYRODT, FYCYLT, PINCR1, PINCR2, KEYST, LFLUID,
     O           HSC, HSR, AXTEN, CSTR, CSTRP, RSTR, RSTRP, CSS, NCSS,
     O           RSS, NRSS                                              )
C
C---- >>> SUBROUTINE TO CHECK THE MAXIMUM STRESSES WITH THE LIMITING
C         STRESSES
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / CONSTS / EEL, FFL, AKTFC, AKTHR
      COMMON / CRPROP / ROZ, CYZ, RDZI, CYZI, HSCCI, HSCCO, HSCRI,
     *                  HSCRO, BAREAC, BAREAR, CAREAC, CAREAR
      COMMON / ECCTRI / ECLC, ECLR
      COMMON / FRCONS / FCCY, FCRD, CCNM
      COMMON / REATNS / REC, RER
      COMMON / WGTVER / WC, WR
C
      DATA ZERO, TWO / 0.0D00, 2.0D00 /
      DATA LYES / 3HYES /
C
C---- >>> CALCULATE BENDING MOMENTS AT MAXIMUM DEFLECTION POINTS
C
                BMC1    = ( EEL - FFL +  ( AKTHC - AKTHR ) / EXL ) * P*XCY
                BMC     = DABS( BMC1 + REC * XCY - CONM - P * FCCY - AKTHC
     *                  * P - WC * XCY * XCY / TWO + P * ( ECLC + YCMAX ))
                XRDP    = EXL - XRD
                BMR     = DABS( - BMC1 * XRDP / XCY + RER * XRDP - P
     *                  * FCRD - AKTHR * P - WR * XRDP * XRDP / TWO
     *                  + P * ( ECLR + YRMAX ) )
C
C---- >>> CALCULATE BENDING MOMENTS AT SUPPORTS
C
                BMCP    = DABS( - CONM - P * ( FCCY + AKTHC - ECLC )  )
                BMRP    = DABS( - P * ( FCRD + AKTHR - ECLR ) )
C
C---- >>> CALCULATE ALL STRESSES
C
C               HOOP STRESSES
C
                PRE     = P / BAREAC
                HSC     = HSCCI * PRE
                HSCO    = HSCCO * PRE
                HSR     = ZERO
          IF ( LFLUID .EQ. LYES ) HSR = HSCRI * PRE
                HSRC    = ZERC
          IF ( LFLUID .EQ. LYES ) HSRC = HSCRO * PRE
C
C               LONGITUDINAL STRESSES
C
                AXTEN   = ZERO
          IF ( CHDS .LT. ZERO ) AXTEN = P / CAREAC
                CSTR    = BMC / CYZ
                CSTRI   = BMC / CYZI
                CSTRP   = BMCP / CYZ
                CSTRPI  = BMCP / CYZI
                PR      = P
```

```
      IF ( LFLUID .EQ. LYES ) PR = P - PRE * BAREAR
           AXRST  = PR / CAREAR
           RSTR   = BMR / RDZ + AXRST
           RSTRI  = BMR / RDZI + AXRST
           RSTRP  = BMRP / RDZ + AXRST
           RSTRPI = BMRP / RDZI + AXRST
C
C          SHEAR STRESSES
C
           CSSO   = HSCO + CSTR
           CSSI   = HSC + CSTRI
           CSSPO  = HSCO + CSTRP
           CSSPI  = HSC + CSTRPI
      IF (CSSPO.GT.CSSPI.AND.CSSPO.GT.CSSO.AND.CSSPO.GT.CSSI)GO TO40
      IF ( CSSPI .GT. CSSO .AND. CSSPI .GT. CSSI ) GO TO 30
      IF ( CSSO .GT. CSSI ) GO TO 20
           CSS    = CSSI
           NCSS   = 2
      GO TO 50
   20      CSS    = CSSO
           NCSS   = 1
      GO TO 50
   30      CSS    = CSSPI
           NCSS   = 2
      GO TO 50
   40      CSS    = CSSPO
           NCSS   = 1
   50      RSS    = ZERO
           NRSS   = 0
      IF ( LFLUID .NE. LYES ) GO TO 90
           RSSPO  = HSRO + RSTRP
           RSSPI  = HSR + RSTRPI
           RSSO   = HSRO + RSTR
           RSSI   = HSR + RSTRI
      IF (RSSPO.GT.RSSPI.AND.RSSPO.GT.RSSO.AND.RSSPO.GT.RSSI)GO TO80
      IF ( RSSPI .GT. RSSO .AND. RSSPI .GT. RSSI ) GO TO 70
      IF ( RSSO .GT. RSSI ) GO TO 60
           RSS    = RSSI
           NRSS   = 2
      GO TO 90
   60      RSS    = RSSO
           NRSS   = 1
      GO TO 90
   70      RSS    = RSSPI
           NRSS   = 2
      GO TO 90
   80      RSS    = RSSPO
           NRSS   = 1
   90 CONTINUE
      IF ( KEYF .NE. 1 ) GO TO 500
      IF ( KEYST .NE. 1 ) GO TO 500
C
C---- >>> CHECK WITH LIMITING STRESSES
C
           STRMX1 = DMAX1( CSTR, CSTRP, HSC, CSS )
           STRMX2 = DMAX1( RSTR, RSTRP, HSR, RSS )
      IF ( STRMX1 .GT. FYCYLT .OR. STRMX2 .GT. FYRODT ) GO TO 100
      IF ( KEYT .EQ. 2 ) GO TO 400
```

```
C
C---- >>> CHANGE THE TRIAL LOAD CORRESPONDINGLY
C
                 P      = P + PINCR1
      RETURN
  100      IF ( KEYP .EQ. 2 ) GO TO 200
                 P      = P - PINCR1 + PINCR2
                 KEYT   = 2
      RETURN
C
C---- >>> ITERATIVE REFINEMENT SECTION
C
  200            P      = P - PINCR2
                 KEYF   = 2
      RETURN
  400            P      = P + PINCR2
                 KEYP   = 2
      RETURN
  500            KEYF   = 3
      RETURN
      END
```

```
      SUBROUTINE OUTPUT
     I          ( KWIT, BAREAC, XCY, XRD, YCMAX, YRMAX, CHDS, GC, TETA,
     I           FYCYLT, FYRODT, CSTR, CSTRP, RSTR, RSTRP,HSC,HSR,AXTEN,
     I           NPHBR, NRDBR, THC, CSS, NCSS, RSS, NRSS                   )
C
C---- >>> SUBROUTINE TO PRINT ALL THE RESULTS
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / ENDS   / LCEND, LREND
      COMMON / FSOPTF / OPPRE, ALTH, ALF, FS, LFSTP
      COMMON / GLDFOR / FX(5), FY(5), F1, F2, F3, F4
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
      COMMON / UNITS  / LNTU, LODU, LPREU, LANGU
C
      DATA ZERO, TWO, H180 / 0.0D00, 2.0D00, 180.0D00 /
      DATA PI / 3.14159265358979300 /
      DATA LDEG, LFIX / 4HDEG , 3HFIX /
C
C---- >>> FORMATS
C
  100 FORMAT ( 1H1, 5X, 36HPROGRAM SACREG - STRESS ANALYSIS OF ,
     1          21HCYLINDERS ( REGULAR ), //, 2( 5X, 20A4, / ), /        )
  110 FORMAT ( 5X, 8HPROBLEM , A4, //, 1X, 19A4                          )
  120 FORMAT ( //, 5X,35HRESULTS:     CRITICAL LOAD ANALYSIS, /           )
  130 FORMAT ( //, 5X,44HRESULTS:     ANALYSIS FOR A GIVEN OPERATING ,
     1                   8HPRESSURE, /                                    )
  140 FORMAT ( //, 5X,45HRESULTS:     ANALYSIS TO DETERMINE STOP-TUBE ,
     1                   6HLENGTH, /                                      )
  150 FORMAT (  /,14X,25HCRITICAL LOAD             = ,1PD10.3, 4X, A4,
     1         //,14X,25HMAXIMUM FLUID PRESSURE = ,1PD10.3, 4X, A4,
     2         //,14X,25HCROOKEDNESS ANGLE         = ,1PD12.5, 2X, A4, /   )
  160 FORMAT (  /,14X,25HOPERATING PRESSURE        = ,1PD10.3, 4X, A4,
     1         //,14X,25HLOAD                      = ,1PD10.3, 4X, A4,
     2         //,14X,25HCROOKEDNESS ANGLE         = ,1PD12.5, 2X, A4, /   )
  180 FORMAT (  /, 5X,34HREQUIRED LENGTH OF STOP-TUBE     = 1PD10.3,4X,A4
     1         //, 5X,34HCORRESPONDING EXTENDED LENGTH    = 1PD10.3,4X,A4
     2         //, 5X,32HRESULTS WITH THIS STOP-TUBE ARE:, /              )
  250 FORMAT ( 1H1, /, 5X,40HANALYSIS AFTER APPLYING GIVEN FACTOR OF ,
     1                10HSAFETY OF , F6.3, 2X, 2HON, 2X, A4, 2H: , /      )
  260 FORMAT (  /,14X,25HLOAD                      = ,1PD10.3, 4X, A4,
     1         //,14X,25HFLUID PRESSURE            = ,1PD10.3, 4X, A4,
     2         //,14X,25HCROOKEDNESS ANGLE         = ,1PD12.5, 2X, A4, /   )
  300 FORMAT (  /, 5X, 9HCYLINDER:,
     1         //,10X,29HMAXIMUM DEFLECTION              = ,1PD10.3, 4X, A4,
     2         //,10X,29HMAXIMUM LONGITUDINAL STRESS= ,1PD10.3, 4X, A4,
     3         //,10X,29HAT A DISTANCE FROM CYL SUP = ,1PD10.3, 4X, A4,
     4         //,10X,29HFACTOR OF SAFETY ON CYL     = ,1PD10.3, /          )
  310 FORMAT (  /,10X,29HMAX LONG STRESS AT CYL END = ,1PD10.3, 4X, A4,
     1         //,10X,29HFACTOR OF SAFETY ON CYL     = ,1PD10.3, /          )
  312 FORMAT (  /,10X,29HMAX SHEAR STRESS IN CYL     = ,1PD10.3, 4X, A4,
     1          /,10X,24HAT MAX LONG STRESS POINT                           )
  314 FORMAT ( 10X, 21HAND AT CUTER SURFACE                                 )
  316 FORMAT ( 10X, 21HAND AT INNER SURFACE                                 )
  318 FORMAT (  /,10X,29HFACTOR OF SAFETY ON CYL     = ,1PD10.3, /          )
  320 FORMAT (  /,10X,29HMAXIMUM HOOP STRESS IN CYL = ,1PD10.3, 4X, A4,
     1         //,10X,29HFACTOR OF SAFETY ON CYL     = ,1PD10.3, /          )
  325 FORMAT (  /,10X,29HAXIAL TENSION IN OVER HANG = ,1PD10.3, 4X, A4,
     1         //,10X,29HFACTOR OF SAFETY ON CYL     = ,1PD10.3,
     2         //,10X,29HEND DEFLECTICN IN OVERHANG = ,1PD10.3, 4X, A4 )
  330 FORMAT (  /, 5X, 9HROD      :,
     1         //,10X,29HMAXIMUM DEFLECTION          = ,1PD10.3, 4X, A4,
     2         //,10X,29HMAXIMUM LONGITUDINAL STRESS= ,1PD10.3, 4X, A4,
     3         //,10X,29HAT A DISTANCE FROM CYL SUP = ,1PD10.3, 4X, A4,
     4         //,10X,29HFACTOR OF SAFETY ON ROD     = ,1PD10.3, /         )
  340 FORMAT (  /,10X,29HMAX LONG STRESS AT ROD END = ,1PD10.3, 4X, A4,
     1         //,10X,29HFACTOR OF SAFETY ON ROD     = ,1PD10.3, /         )
  342 FORMAT (  /,10X,29HMAX SHEAR STRESS IN ROD     = ,1PD10.3, 4X, A4,
     1          /,10X,24HAT MAX LONG STRESS POINT                          )
  348 FORMAT (  /,10X,29HFACTOR OF SAFETY ON ROD     = ,1PD10.3, /         )
  350 FORMAT (  /,10X,29HMAXIMUM HOOP STRESS IN ROD = ,1PD10.3, 4X, A4,
     1         //,10X,29HFACTOR OF SAFETY ON ROD     = ,1PD10.3, /         )
  360 FORMAT ( 1H1, //, 5X, 29HFORCES AT SLIDING CONNECTION:, //, 15X,
     1         23HPISTON BEARINGS (SEALS), 6X, 5HFORCE, /,25X, 2HNO, / )
  370 FORMAT ( /, 5( 25X, I2, 12X, 1PD10.3, 2X, A4, // )                  )
  380 FORMAT ( /,18X, 20HROD BEARINGS (SEALS), 6X, 5HFORCE,/,25X, 2HNO/)
  390 FORMAT ( //8X38HF1- FORCE AT PISTON HEAD FRONT FACE  =1PD11.3,2XA4
     1         //8X38HF2- FORCE AT STUFFING BOX FRONT FACE =1PD11.3,2XA4
     2         //8X38HF3- FORCE AT PISTON HEAD BACK FACE   =1PD11.3,2XA4
     3         //8X38HF4- FORCE AT STUFFING BOX INNER FACE =1PD11.3,2XA4
     4          /,11X,33H(ZERO FORCES INDICATE NO CONTACT) , /            )
  400 FORMAT ( ///, 10X, 39HTHETA EQUAL TO ZERO IMPLIES CONTINUOUS  ,
     1         17HCONTACT AT GLAND.   , /, 10X,
     2         34HABOVE FORCES CANNOT BE CALCULATED.
     3         33HHENCE, ARE PRINTED OUT AS ZERO'S.  ,  //                 )
C
               TEMP   = H180 / PI
           IF ( LANGU .EQ. LDEG ) TETA = TETA * TEMP
               PRE    = P / BAREAC
           IF ( KWIT .NE. 1 ) GO TO 540
C
C---- >>> PRINT ALL RESULTS
C
      PRINT 100, ( IDCARD(I), I = 1, 40 )
      PRINT 110, NPRCB, ( IPROB(I), I = 1, 19 )
          GO TO ( 510, 520, 530 ), LPRTP
  510 PRINT 120
      PRINT 150, P, LODU, PRE, LPREU, TETA, LANGU
          GO TO 550
  520 PRINT 130
      PRINT 160, OPPRE, LPREU, P, LODU, TETA, LANGU
          GO TO 550
  530 PRINT 140
      PRINT 180, GC, LNTU, EXL, LNTU
      PRINT 150, P, LODU, OPPRE, LPREU, TETA, LANGU
          GO TO 550
  540 PRINT 250, FS, LFSTP
      PRINT 260, P, LODU, PRE, LPREU, TETA, LANGU
C
C---- >>> CALCULATE THE FACTCR OF SAFETY'S ON MAXIMUM STRESSES WITH
C         LIMITING STRESSES AND PRINT
C
  550          FCSF   = FYCYLT / CSTR
      PRINT 300, YCMAX, LNTU, CSTR, LPREU, XCY, LNTU, FCSF
          IF ( CSTRP .GT. ZERO ) FCSF = FYCYLT / CSTRP
          IF ( LCEND .EQ. LFIX ) PRINT 310, CSTRP, LPREU, FCSF
```

```
                FCSF    = FYCYLT / CSS
                CSS     = CSS / TWO
      PRINT 312, CSS, LPREU
          IF ( NCSS .EQ. 1 ) PRINT 314
          IF ( NCSS .EQ. 2 ) PRINT 316
      PRINT 318, FCSF
                FCSF    = FYCYLT / HSC
      PRINT 320, HSC, LPREU, FCSF
          IF ( CHDS .GE. ZERO ) GO TO 560
                FCSF    = FYCYLT / AXTEN
                ENDDF   = THC * CHDS
      PRINT 325, AXTEN, LPREU, FCSF, ENDDF, LNTU
  560           FCSF    = FYRODT / RSTR
      PRINT 330, YRMAX, LNTU, RSTR, LPREU, XRD, LNTU, FCSF
          IF ( RSTRP .GT. ZERO ) FCSF = FYRODT / RSTRP
          IF ( LREND .EQ. LFIX ) PRINT 340, RSTRP, LPREU, FCSF
          IF ( HSR .EQ. ZERO ) GO TO 570
                FCSF    = FYRODT / RSS
                RSS     = RSS / TWO
      PRINT 342, RSS, LPREU
          IF ( NRSS .EQ. 1 ) PRINT 314
          IF ( NRSS .EQ. 2 ) PRINT 316
      PRINT 348, FCSF
                FCSF    = FYRODT / HSR
      PRINT 350, HSR, LPREU, FCSF
  570 PRINT 360
      PRINT 370, ( I, FX(I), LODU, I = 1, NPHBR )
      PRINT 380
      PRINT 370, ( I, FY(I), LODU, I = 1, NRDBR )
      PRINT 390, F1, LODU, F2, LODU, F3, LODU, F4, LODU
          IF ( TETA .EQ. ZERO ) PRINT 400
      RETURN
      END
```

```
      000000000111111111122222222223333333333444444444455555555556666666666777777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
   1  EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
   2  CODED  JUNE 9, 1976   BY   K. L. SESHASAI
   3  REG1      LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER.
   4      1
   5            INCH      KIPS      KSI.      DEG
   6  50.0      6.13      4.44      0.76      3.0                 NO
   7  56.13     56.82     116.71    0.0
   8  7.0       6.0       3.0       0.0       4.75      4.75      5.989     3.009
   9  0.0
  10  0.316     0.451     500.0               2.375
  11  0.365     0.25      1000.0              3.9
  12  0.316     0.451     500.0               5.45                END
  13  0.35      0.2       750.0               3.15                END
  14  0.0032    0.002     0.05      0.07      29000.0   29000.0   125.0     125.0
  15  0.0                           PIN  PIN  +0.025    +0.025    +0.1      +0.12
  16  2.0       LOAD
  17  REG2      LPRTP=1; P-F; HOLLOW ROD WITH NO FLUID; VERTICAL CYLINDER.
  18      1     KEEP                          KEEP
  19  50.0      6.13      4.44      0.76      3.0
  20  56.13     56.82     116.71    0.0
  21  7.0       6.0       3.0       1.5       4.75                5.989
  22  0.0                 0.009
  23                                2100.0    2.375
  24                                8800.0    3.9
  25                                2100.0    5.45                END
  26                                3900.0    3.15                END
  27  90.0                          PIN  FIX  -0.02               +0.1      -0.05
  28  4.0       STRS
  29  REG3      LPRTP=1; F-F; SOLID ROD; 30 DEG INCLINED CYL.
  30      1
  31            INCH      LBS       PSI       DEG
  32  50.0      6.13      4.44      0.76      3.0
  33  56.13     56.82     116.71
  34  7.0       6.0       3.0       0.0
  35  0.005     0.011     0.009
  36                                2100000.0 2.375
  37                                8800000.0 3.9
  38                                2100000.0 5.45                END
  39  0.35      0.2       750000.0            1.75
  40  0.35      0.4       250000.0            3.5                 END
  41  3.2       2.0       50.0      70.0      29000000. 29000000. 75000.0   125000.0
  42  30.0                          FIX  FIX                      -0.05     -0.025
  43
  44  REG4      LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER WITH A OVERHANG.
  45      1
  46            INCH      KIPS      KSI       RAD
  47  60.0      6.13      4.44      0.76      -15.0
  48  66.13     66.82     118.71    0.0
  49  6.5       5.5       2.75      0.0       2.0       3.0       5.49      2.76
  50  0.005     0.01      0.008
  51  0.316     0.451     500.0               2.375
  52                                8800.0    3.9
  53                                2100.0    5.45                END
  54  0.35      0.2       750.0               3.15                END
```

```
      000000000111111111122222222223333333333444444444455555555556666666666777777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
  55  0.003     0.00175   0.04      0.06      29000.0   29000.0   100.0     125.0
  56  0.0                           PIN  PIN  +0.05                         +0.01
  57  1.0       LOAD
  58  REG5      LPRTP=2; F-P; HOLLOW ROD WITH FLUID; INCLINED CYLINDER; METRIC UNITS.
  59      2
  60            CM        KGS       KGSC      RAD
  61  127.0     15.57     11.28     1.53      7.62                YES
  62  142.57    144.38    296.5     0.0
  63  17.78     15.24     7.62      3.8                 12.0      15.22     7.64
  64  0.01
  65  0.8       1.15      35000.0             6.0
  66  1.0       0.8       70000.0             10.0
  67                                371000.0  13.5                END
  68  1.0       0.5       50000.0             8.0                 END
  69  1.5       1.0       23.0      32.0      2100000.0 2100000.0 7050.0    6800.0
  70  0.75                          FIX  PIN            -0.05               +0.1
  71                      175.0
  72  REG6      LPRTP=3; P-P; SOLID ROD; HORIZONTAL CYLINDER.
  73      3
  74            INCH      KIPS      KSI       DEG
  75  60.0      6.13      4.44      0.76      3.0                 NO
  76  7.0       6.0       3.0       0.0       4.75      4.75      5.989     3.009
  77  0.005
  78                                2100.0    2.375
  79                                8800.0    3.9
  80                                2100.0    5.45                END
  81                                3900.0    3.15                END
  82  0.0032    0.002     0.05      0.07      29000.0   29000.0   100.0     125.0
  83  0.0                           PIN  PIN  0.0       -0.05               +0.1
  84                      2.0       0.0075    10.0
  85            THIS IS A BLANK CARD
```

```
PROGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PROBLEM REG1

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER.

INPUT DATA:

TABLE 1:      CONTROL DATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD


              TABLES RETAINED FROM PREVIOUS PROBLEM

                2     3     4     5     6     7

                   NO KEEP OPTIONS EXERCISED


TABLE 2:      UNITS OF MEASUREMENT

             LENGTH      LOAD      PRESSURE   ANGULAR

              INCH       KIPS        KSI        DEG


TABLE 3:      CYLINDER DIMENSIONS

    LENGTHS:

              STROKE       PISTON HEAD  STUFFING BOX   END PLATE    HINGE DIST.

             5.00000D 01   6.13000D 00   4.44000D 00   7.60000D-01   3.00000D 00


             CYLINDER        ROD         EXTENDED      STOP TUBE

             5.61300D 01   5.68200D 01   1.16710D 02   0.0

    DIAMETERS:

             CYL. OUTER    CYL. INNER    ROD OUTER     ROD INNER

             7.00000D 00   6.00000D 00   3.00000D 00   0.0              SOLID ROD


              CYL. PIN *    ROD PIN *    PISTON HEAD @  STUF. BOX @

             4.75000D 00   4.75000D 00   5.98900D 00   3.00900D 00
            (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

    CLEARANCES BETWEEN:

             CYLINDER      CYLINDER        ROD
               AND           AND           AND
            STUFFING BOX  PISTON HEAD @  STUF. BOX @

             0.0           0.0           0.0
                          (@ ZERO, OTHER OPTION IS INPUT)
```

```
TABLE 4:      BEARINGS AND SEALS

     PISTON BEARINGS:

                   A             A             A              B         DISTANCE FROM
                 WIDTH       THICKNESS   YOUNGS MODULUS   STIFFNESS      BACK FACE

              3.16000D-01   4.51000D-01   5.00000D 02   0.0              2.37500D 00
              3.65000D-01   2.50000D-01   1.00000D 03   0.0              3.90000D 00
              3.16000D-01   4.51000D-01   5.00000D 02   0.0              5.45000D 00

     ROD BEARINGS:

                   A             A             A              B         DISTANCE FROM
                 WIDTH       THICKNESS   YOUNGS MODULUS   STIFFNESS      BACK FACE

              3.50000D-01   2.00000D-01   7.50000D 02   0.0              3.15000D 00

            (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                      ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:      WEIGHTS AND MATERIAL PROPERTIES

     WEIGHTS OF PARTS:

              CYLINDER         ROD          PISTON HEAD  STUFFING BOX
                (PER UNIT LENGTH)

             3.20000D-03   2.00000D-03   5.00000D-02   7.00000D-02


     MATERIAL PROPERTIES:

                 YOUNGS MODULUS                   YIELD STRESS
              CYLINDER         ROD          CYLINDER         ROD

             2.90000D 04   2.90000D 04   1.25000D 02   1.25000D 02


TABLE 6:      INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =  0.0

                                               CYLINDER END     ROD END

     SUPPORT CONDITIONS:                           PIN            PIN

     FRICTION COEFFICIENTS AT SUPPORTS:       2.50000D-02    2.50000D-02
          (ZERO IF FIXED END)
     LOADING ECCENTRICITIES:                  1.00000D-01    1.20000D-01


TABLE 7:      FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
              DEPENDING ON PROBLEM TYPE


     FACTOR OF SAFETY =  2.000 ON LOAD
```

```
 PROGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PROBLEM REG1

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER.

RESULTS:     CRITICAL LOAD ANALYSIS


         CRITICAL LOAD            =  1.282D 02    KIPS

         MAXIMUM FLUID PRESSURE =  4.533D 00    KSI

         CROOKEDNESS ANGLE        =  4.79594D-02  DEG

CYLINDER:

      MAXIMUM DEFLECTION            =  1.913D 00    INCH

      MAXIMUM LONGITUDINAL STRESS=  1.676D 01    KSI

      AT A DISTANCE FROM CYL SUP =  5.898D 01    INCH

      FACTOR OF SAFETY ON CYL       =  7.460D 00


      MAX SHEAR STRESS IN CYL       =  2.200D 01    KSI
      AT MAX LONG STRESS POINT
      AND AT INNER SURFACE

      FACTOR OF SAFETY ON CYL       =  2.841D 00


      MAXIMUM HOOP STRESS IN CYL =  2.964D 01    KSI

      FACTOR OF SAFETY ON CYL       =  4.218D 00

ROD      :

      MAXIMUM DEFLECTION            =  2.083D 00    INCH

      MAXIMUM LONGITUDINAL STRESS=  1.240D 02    KSI

      AT A DISTANCE FROM CYL SUP =  7.137D 01    INCH

      FACTOR OF SAFETY ON ROD       =  1.008D 00
```

```
FORCES AT SLIDING CONNECTION:

          PISTON BEARINGS (SEALS)        FORCE
                  NO


                  1                2.532D 00  KIPS

                  2                2.173D 01  KIPS

                  3                7.942D 00  KIPS



            ROD BEARINGS (SEALS)        FORCE
                  NO


                  1                1.347D 01  KIPS



  F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0          KIPS

  F2- FORCE AT STUFFING BOX FRONT FACE =  1.874D 01   KIPS

  F3- FORCE AT PISTON HEAD BACK FACE   =  0.0          KIPS

  F4- FORCE AT STUFFING BOX INNER FACE =  0.0          KIPS
     (ZERO FORCES INDICATE NO CONTACT)
```

```
ANALYSIS AFTER APPLYING GIVEN FACTOR OF SAFETY UF  2.000  ON  LOAD:

          LOAD                      =  6.408D 01     KIPS

          FLUID PRESSURE            =  2.266D 00     KSI

          CROOKEDNESS ANGLE         =  7.469080-03   DEG

CYLINDER:

      MAXIMUM DEFLECTION          =  1.507D-01     INCH

      MAXIMUM LONGITUDINAL STRESS=  1.348D 00     KSI

      AT A DISTANCE FROM CYL SUP =  5.763D 01     INCH

      FACTOR OF SAFETY ON CYL     =  9.275D 01

      MAX SHEAR STRESS IN CYL     =  7.987D 00     KSI
      AT MAX LONG STRESS POINT
      AND AT INNER SURFACE

      FACTOR OF SAFETY ON CYL     =  7.825D 00

      MAXIMUM HOOP STRESS IN CYL =  1.482D 01     KSI

      FACTOR OF SAFETY ON CYL     =  8.435D 00

ROD      :

      MAXIMUM DEFLECTION          =  1.639D-01     INCH

      MAXIMUM LONGITUDINAL STRESS=  1.691D 01     KSI

      AT A DISTANCE FROM CYL SUP =  6.973D 01     INCH

      FACTOR OF SAFETY ON ROD     =  7.391D 00
```

```
FORCES AT SLIDING CONNECTION:

           PISTON BEARINGS (SEALS)      FORCE
                     NO

                     1              3.132D-02  KIPS

                     2              1.872D 00  KIPS

                     3              8.739D-01  KIPS


             ROD BEARINGS (SEALS)       FORCE
                     NO

                     1              2.777D 00  KIPS


  F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         KIPS

  F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         KIPS

  F3- FORCE AT PISTON HEAD BACK FACE   =  0.0         KIPS

  F4- FORCE AT STUFFING BOX INNER FACE =  0.0         KIPS
      (ZERO FORCES INDICATE NO CONTACT)
```

```
PROGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PROBLEM REG2

  LPRTP=1; P-F; HOLLOW ROD WITH NO FLUID; VERTICAL CYLINDER.

INPUT DATA:

TABLE 1:      CONTROL DATA

      PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD


               TABLES RETAINED FROM PREVIOUS PROBLEM                          )

                 2      3      4      5      6      7
                KEEP                 KEEP

TABLE 2:      UNITS OF MEASUREMENT

             LENGTH      LOAD      PRESSURE    ANGULAR

              INCH       KIPS        KSI         DEG


TABLE 3:      CYLINDER DIMENSIONS

      LENGTHS:

                 STROKE        PISTON HEAD  STUFFING BOX    END PLATE    HINGE DIST.

             5.000000D 01   6.130000D 00   4.440000D 00   7.600000D-01   3.000000D 00


              CYLINDER          ROD          EXTENDED       STOP TUBE

             5.613000D 01   5.682000D 01   1.167100D 02   0.0

      DIAMETERS:

             CYL. OUTER     CYL. INNER      ROD OUTER      ROD INNER

             7.000000D 00   6.000000D 00   3.000000D 00   1.500000D 00  HOLLOW ROD
                                                                        WITH NO FLUID

              CYL. PIN *     ROD PIN *     PISTON HEAD @  STUF. BOX @

             4.750000D 00   0.0            5.989000D 00   0.0
            (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

      CLEARANCES BETWEEN:

              CYLINDER       CYLINDER        ROD
                AND            AND           AND
            STUFFING BOX   PISTON HEAD @   STUF. BOX @

             0.0             0.0           9.000000D-03
                          (@ ZERO, OTHER OPTION IS INPUT)
```

```
TABLE 4:      BEARINGS AND SEALS

      PISTON BEARINGS:

                   A              A                A             B        DISTANCE FROM
                 WIDTH        THICKNESS    YOUNGS MODULUS    STIFFNESS      BACK FACE

               0.0            0.0            0.0            2.100000D 03   2.375000D 00
               0.0            0.0            0.0            8.800000D 03   3.900000D 00
               0.0            0.0            0.0            2.100000D 03   5.450000D 00

      ROD BEARINGS:

                   A              A                A             B        DISTANCE FROM
                 WIDTH        THICKNESS    YOUNGS MODULUS    STIFFNESS      BACK FACE

               0.0            0.0            0.0            3.900000D 03   3.150000D 00

            (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                       ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:      WEIGHTS AND MATERIAL PROPERTIES

      WEIGHTS OF PARTS:

               CYLINDER          ROD         PISTON HEAD  STUFFING BOX
                 (PER UNIT LENGTH)

             3.200000D-03   2.000000D-03   5.000000D-02   7.000000D-02


      MATERIAL PROPERTIES:

                  YOUNGS MODULUS                   YIELD STRESS
               CYLINDER           ROD          CYLINDER          ROD

             2.900000D 04   2.900000D 04   1.250000D 02   1.250000D 02

TABLE 6:      INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

      CYL INCLINATION WITH HORIZONTAL =  9.000000D 01

                                               CYLINDER END     ROD END

      SUPPORT CONDITIONS:                          PIN            FIX

      FRICTION COEFFICIENTS AT SUPPORTS:  -2.000000D-02   0.0
           (ZERO IF FIXED END)
      LOADING ECCENTRICITIES:               1.000000D-01  -5.000000D-02


TABLE 7:      FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
              DEPENDING ON PROBLEM TYPE


      FACTOR OF SAFETY =  4.000 ON STRS
```

```
PRCGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PRUBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CCDED  JUNE 9, 1976    BY    K. L. SESHASAI

PRCBLEM REG2

  LPRTP=1; P-F; HOLLOW ROD WITH NO FLUID; VERTICAL CYLINDER.

RESULTS:      CRITICAL LOAD ANALYSIS

         CRITICAL LCAD          =  2.924D 02    KIPS

         MAXIMUM FLUID PRESSURE =  1.034D 01    KSI

         CROOKEDNESS ANGLE      =  6.31454D-02  DEG

CYLINDER:

    MAXIMUM DEFLECTION          =  8.182D-01    INCH

    MAXIMUM LCNGITUDINAL STRESS=  1.132D 01    KSI

    AT A DISTANCE FROM CYL SUP =  5.761D 01    INCH

    FACTOR OF SAFETY ON CYL     =  1.104D 01

    MAX SHEAR STRESS IN CYL     =  3.866D 01    KSI
    AT MAX LONG STRESS POINT
    AND AT INNER SURFACE

    FACTOR OF SAFETY ON CYL     =  1.617D 00

    MAXIMUM HCOP STRESS IN CYL =  6.762D 01    KSI

    FACTOR OF SAFETY ON CYL     =  1.849D 00

ROD     :

    MAXIMUM DEFLECTICN          =  8.523D-01    INCH

    MAXIMUM LCNGITUDINAL STRESS=  1.246D 02    KSI

    AT A DISTANCE FROM CYL SUP =  6.453D 01    INCH

    FACTOR OF SAFETY ON RCD     =  1.003D 00

    MAX LONG STRESS AT ROD END =  1.249D 02    KSI

    FACTOR OF SAFETY ON ROD     =  1.000D 00
```

```
FCRCES AT SLIDING CONNECTION:

          PISTON BEARINGS (SEALS)      FORCE
                NO

                1                 2.287D-01  KIPS

                2                 1.575D 01  KIPS

                3                 7.345D 00  KIPS

            RCD BEARINGS (SEALS)      FORCE
                NO

                1                 2.332D 01  KIPS


F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         KIPS

F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         KIPS

F3- FORCE AT PISTCN HEAD BACK FACE   =  0.0         KIPS

F4- FORCE AT STUFFING BOX INNER FACE =  0.0         KIPS
   (ZERO FORCES INDICATE NO CONTACT)
```

```
ANALYSIS AFTER APPLYING GIVEN FACTOR OF SAFETY OF  4.000  ON  STRS:

          LOAD                     =  1.305D 02    KIPS

          FLUID PRESSURE           =  4.616D 00    KSI

          CROOKEDNESS ANGLE        =  3.929690-03  DEG

CYLINDER:

     MAXIMUM DEFLECTION            =  4.619D-02    INCH

     MAXIMUM LONGITUDINAL STRESS=  7.046D-01    KSI

     AT A DISTANCE FROM CYL SUP =  5.761D 01    INCH

     FACTOR OF SAFETY ON CYL       =  1.774D 02

     MAX SHEAR STRESS IN CYL       =  1.562D 01    KSI
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTOR OF SAFETY ON CYL       =  4.001D 00

     MAXIMUM HOOP STRESS IN CYL =  3.018D 01    KSI

     FACTOR OF SAFETY ON CYL       =  4.142D 00

ROD      :

     MAXIMUM DEFLECTION            =  4.734D-02    INCH

     MAXIMUM LONGITUDINAL STRESS=  2.855D 01    KSI

     AT A DISTANCE FROM CYL SUP =  6.280D 01    INCH

     FACTOR OF SAFETY ON ROD       =  4.378D 00

     MAX LONG STRESS AT ROD END =  2.858D 01    KSI

     FACTOR OF SAFETY ON ROD       =  4.374D 00
```

```
FORCES AT SLIDING CONNECTION:

            PISTON BEARINGS (SEALS)        FORCE
                   NO


                   1               1.423D-02  KIPS

                   2               9.801D-01  KIPS

                   3               4.571D-01  KIPS


              ROD BEARINGS (SEALS)         FORCE
                   NO


                   1               1.451D 00  KIPS


  F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         KIPS

  F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         KIPS

  F3- FORCE AT PISTON HEAD BACK FACE   =  0.0         KIPS

  F4- FORCE AT STUFFING BOX INNER FACE =  0.0         KIPS
     (ZERO FORCES INDICATE NO CONTACT)
```

```
PROGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976    BY    K. L. SESHASAI


PROBLEM REG3

  LPRTP=1; F-F; SOLID ROD; 30 DEG INCLINED CYL.

INPUT DATA:

TABLE 1:      CONTROL DATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD

             TABLES RETAINED FROM PREVIOUS PROBLEM

                2     3     4     5     6     7

                  NO KEEP OPTIONS EXERCISED

TABLE 2:      UNITS OF MEASUREMENT

            LENGTH      LOAD      PRESSURE   ANGULAR

             INCH       LBS         PSI        DEG

TABLE 3:      CYLINDER DIMENSIONS

     LENGTHS:

              STROKE      PISTON HEAD  STUFFING BOX    END PLATE    HINGE DIST.

            5.00000D 01   6.13000D 00   4.44000D 00   7.60000D-01   3.00000D 00

             CYLINDER        ROD        EXTENDED       STOP TUBE

            5.61300D 01   5.68200D 01   1.16710D 02   0.0

     DIAMETERS:

             CYL. OUTER   CYL. INNER    ROD OUTER     ROD INNER

            7.00000D 00   6.00000D 00   3.00000D 00   0.0           SOLID ROD

             CYL. PIN *    ROD PIN *   PISTON HEAD @  STUF. BOX @

            0.0           0.0           0.0           0.0
           (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

     CLEARANCES BETWEEN:

             CYLINDER      CYLINDER       ROD
               AND           AND          AND
           STUFFING BOX  PISTON HEAD @  STUF. BOX @

            5.00000D-03   1.10000D-02   9.00000D-03
                       (@ ZERO, OTHER OPTION IS INPUT)
```

```
TABLE 4:      BEARINGS AND SEALS

     PISTON BEARINGS:

                 A              A                A                B        DISTANCE FROM
               WIDTH        THICKNESS    YOUNGS MODULUS      STIFFNESS      BACK FACE

              0.0            0.0            0.0            2.10000D 06    2.37500D 00
              0.0            0.0            0.0            8.80000D 06    3.90000D 00
              0.0            0.0            0.0            2.10000D 06    5.45000D 00

     ROD BEARINGS:

                 A              A                A                B        DISTANCE FROM
               WIDTH        THICKNESS    YOUNGS MODULUS      STIFFNESS      BACK FACE

            3.50000D-01    2.00000D-01    7.50000D 05    0.0              1.75000D 00
            3.50000D-01    4.00000D-01    2.50000D 05    0.0              3.50000D 00

          (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                      ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)

TABLE 5:      WEIGHTS AND MATERIAL PROPERTIES

     WEIGHTS OF PARTS:

              CYLINDER          ROD         PISTON HEAD   STUFFING BOX
            (PER UNIT LENGTH)

            3.20000D 00   2.00000D 00   5.00000D 01   7.00000D 01

     MATERIAL PROPERTIES:

                 YOUNGS MODULUS                YIELD STRESS
             CYLINDER         ROD          CYLINDER         ROD

            2.90000D 07   2.90000D 07   7.50000D 04   1.25000D 05

TABLE 6:      INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =   3.00000D 01

                                            CYLINDER END     ROD END

     SUPPORT CONDITIONS:                        FIX            FIX

     FRICTION COEFFICIENTS AT SUPPORTS:     0.0            0.0
          (ZERO IF FIXED END)
     LOADING ECCENTRICITIES:               -5.00000D-02   -2.50000D-02

TABLE 7:      FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
              DEPENDING ON PROBLEM TYPE

     ONLY CRITICAL LOAD ANALYSIS
```

```
 PROGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED   JUNE 9, 1976    BY    K. L. SESHASAI


PRCBLEM REG3

  LPRTP=1; F-F; SOLID ROD; 30 DEG INCLINED CYL.

RESULTS:      CRITICAL LOAD ANALYSIS

          CRITICAL LOAD             =  3.212D 05    LBS

          MAXIMUM FLUID PRESSURE =  1.136D 04    PSI

          CROOKEDNESS ANGLE      =  6.91626D-04  DEG

CYLINDER:

      MAXIMUM DEFLECTION           =  8.070D-03    INCH

      MAXIMUM LCNGITUDINAL STRESS=  1.012D 02    PSI

      AT A DISTANCE FROM CYL SUP =  5.753D 01    INCH

      FACTOR OF SAFETY ON CYL      =  7.409D 02


      MAX LONG STRESS AT CYL END =  8.365D 02    PSI

      FACTOR OF SAFETY ON CYL      =  8.966D 01


      MAX SHEAR STRESS IN CYL      =  3.749D 04    PSI
      AT MAX LONG STRESS POINT
      AND AT INNER SURFACE

      FACTOR OF SAFETY ON CYL      =  1.000D 00


      MAXIMUM HCOP STRESS IN CYL =  7.427D 04    PSI

      FACTOR OF SAFETY ON CYL      =  1.010D 00

ROD       :

      MAXIMUM DEFLECTION           =  9.096D-03    INCH

      MAXIMUM LCNGITUDINAL STRESS=  4.620D 04    PSI

      AT A DISTANCE FROM CYL SUP =  6.903D 01    INCH

      FACTOR OF SAFETY ON ROD      =  2.706D 00


      MAX LONG STRESS AT ROD END =  4.649D 04    PSI

      FACTOR OF SAFETY ON ROD      =  2.689D 00
```

```
FORCES AT SLIDING CONNECTION:

          PISTCN BEARINGS (SEALS)       FORCE
                   NC


                   1                3.172D-01  LBS

                   2                1.633D 02  LBS

                   3                7.827D 01  LBS


            RCD BEARINGS (SEALS)        FORCE
                   NO


                   1                1.955D 02  LBS

                   2                4.644D 01  LBS



 F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         LBS

 F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         LBS

 F3- FCRCE AT PISTON HEAC BACK FACE   =  0.0         LBS

 F4- FORCE AT STUFFING BOX INNER FACE =  0.0         LBS
    (ZERO FORCES INDICATE NO CONTACT)
```

```
PROGRAM SACREG - STRESS ANALYSIS CF CYLINCERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976    BY    K. L. SESHASAI


PRCBLEM REG4

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER WITH A OVERHANG.

INPUT CATA:

TABLE 1:     CCNTROL DATA

     PROBLEM TYPE = 1 - CRITICAL LCAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD

             TABLES RETAINED FROM PREVICUS PROBLEM

                2     3     4     5     6     7

                  NO KEEP CPTICNS EXERCISED


TABLE 2:     UNITS OF MEASUREMENT

            LENGTH     LOAD      PRESSURE   ANGULAR

             INCH      KIPS        KSI        RAC


TABLE 3:     CYLINDER DIMENSIONS

    LENGTHS:

               STROKE      PISTON HEAD  STUFFING BOX   END PLATE   HINGE DIST.

            6.00000D 01   6.13000D 00   4.44000D 00   7.60000D-01  -1.50000D 01


             CYLINDER          ROD        EXTENDED      STOP TUBE

            6.61300D 01   6.68200D 01   1.18710D 02    0.0

    DIAMETERS:

            CYL. OUTER    CYL. INNER    ROD OUTER     ROD INNER

            6.50000D 00   5.50000D 00   2.75000D 00   0.0              SOLID ROD


             CYL. PIN *    ROD PIN *    PISTON HEAD @  STUF. BOX @

            2.00000D 00   3.00000D 00   5.49000D 00   2.76000D 00
           (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

    CLEARANCES BETWEEN:

             CYLINDER      CYLINDER       ROD
               AND           AND          AND
           STUFFING BOX  PISTON HEAD @  STUF. BOX @

            5.00000D-03   1.00000D-02   8.00000D-03
                        (@ ZERO, OTHER OPTION IS INPUT)
```

```
TABLE 4:     BEARINGS AND SEALS

    PISTON BEARINGS:

                  A             A               A               B         DISTANCE FROM
                WIDTH       THICKNESS    YOUNGS MODULUS     STIFFNESS       BACK FACE

             3.16000D-01   4.51000D-01   5.00000D 02     0.0             2.37500D 00
             0.0           0.0           0.0             8.80000D 03     3.90000D 00
             0.C           0.0           0.0             2.10000D 03     5.45000D 00
    RCD BEARINGS:

                  A             A               A               B         DISTANCE FROM
                WIDTH       THICKNESS    YOUNGS MODULUS     STIFFNESS       BACK FACE

             3.50000D-01   2.00000D-01   7.50000D 02     0.0             3.15000D 00

           (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                     ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:     WEIGHTS AND MATERIAL PROPERTIES

    WEIGHTS OF PARTS:

             CYLINDER          ROD        PISTON HEAD  STUFFING BOX
               (PER UNIT LENGTH)

            3.00000D-03   1.75000D-03   4.00000D-02   6.00000D-02


    MATERIAL PROPERTIES:

               YOUNGS MODULUS                YIELD STRESS
             CYLINDER          ROD        CYLINDER         ROD

            2.90000D 04   2.90000D 04   1.00000D 02   1.25000D 02


TABLE 6:     INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

    CYL INCLINATION WITH HCRIZCNTAL =  0.0

                                            CYLINDER END     ROD END

    SUPPORT CCNDITIONS:                         PIN            PIN

    FRICTION COEFFICIENTS AT SUPPORTS:   5.00000D-02   0.0
         (ZERC IF FIXED END)
    LOADING ECCENTRICITIES:              0.0              1.00000D-02


TABLE 7:     FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
             DEPENDING ON PROBLEM TYPE


    FACTOR OF SAFETY =  1.000 ON LOAD
```

```
 PROGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM REG4

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER WITH A OVERHANG.

RESULTS:     CRITICAL LOAD ANALYSIS

          CRITICAL LOAD            =  7.470D 01    KIPS

          MAXIMUM FLUID PRESSURE =  3.144D 00    KSI

          CROOKEDNESS ANGLE        =  1.27846D-03  RAD

CYLINDER:

      MAXIMUM DEFLECTION           =  2.512D 00    INCH

      MAXIMUM LCNGITUDINAL STRESS=  1.464D 01    KSI

      AT A DISTANCE FRGM CYL SUP =  4.952D 01    INCH

      FACTOR OF SAFETY ON CYL      =  6.829D 00

      MAX SHEAR STRESS IN CYL      =  1.569D 01    KSI
      AT MAX LONG STRESS POINT
      AND AT INNER SURFACE

      FACTOR OF SAFETY ON CYL      =  3.186D 00

      MAXIMUM HCOP STRESS IN CYL =  1.899D 01    KSI

      FACTOR OF SAFETY ON CYL      =  5.265D 00

      AXIAL TENSION IN OVER HANG =  7.925D 00    KSI

      FACTOR OF SAFETY ON CYL      =  1.262D 01

      END DEFLECTION IN OVERHANG = -7.797D-01    INCH
RCD     :

      MAXIMUM DEFLECTION           =  2.940D 00    INCH

      MAXIMUM LCNGITUDINAL STRESS=  1.224D 02    KSI

      AT A DISTANCE FROM CYL SUP =  6.784D 01    INCH

      FACTOR OF SAFETY GN ROD      =  1.022D 00
```

```
FORCES AT SLIDING CUNNECTION:

            PISTCN BEARINGS (SEALS)      FORCE
                     NO

                     1                9.637D-03  KIPS

                     2                1.720D 01  KIPS

                     3                8.266D 00  KIPS


               ROD BEARINGS (SEALS)      FURCE
                     NO

                     1                2.548D 01  KIPS


  F1- FORCE AT PISTON HEAD FRONT FACE   =  0.0         KIPS

  F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         KIPS

  F3- FCRCE AT PISTON HEAD BACK FACE    =  0.0         KIPS

  F4- FORCE AT STUFFING BOX INNER FACE =  0.0         KIPS
     (ZERO FORCES INDICATE NO CONTACT)
```

```
PROGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976    BY    K. L. SESHASAI


PROBLEM REG5

  LPRTP=2; F-P; HOLLOW ROD WITH FLUID; INCLINED CYLINDER; METRIC UNITS.

INPUT DATA:

TABLE 1:      CONTROL DATA

     PROBLEM TYPE = 2 - ANALYSIS FOR A PARTICULAR PRESSURE


             TABLES RETAINED FROM PREVIOUS PROBLEM

                2     3     4     5     6     7

                  NO KEEP OPTIONS EXERCISED


TABLE 2:      UNITS OF MEASUREMENT

            LENGTH      LOAD      PRESSURE    ANGULAR

            CM          KGS        KGSC         RAD


TABLE 3:      CYLINDER DIMENSIONS

     LENGTHS:

               STROKE      PISTON HEAD  STUFFING BOX    END PLATE     HINGE DIST.

            1.27000D 02  1.55700D 01   1.12800D 01   1.93000D 00   7.62000D 00


             CYLINDER          ROD        EXTENDED      STOP TUBE

            1.42570D 02  1.44380D 02   2.96500D 02   0.0

     DIAMETERS:

            CYL. OUTER   CYL. INNER     ROD OUTER     ROD INNER

            1.77800D 01  1.52400D 01   7.62000D 00   3.80000D 00   HOLLOW ROD
                                                                   WITH FLUID
             CYL. PIN *    ROD PIN *   PISTON HEAD @  STUF. BOX @

            0.0          1.20000D 01   1.52200D 01   7.64000D 00
           (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

     CLEARANCES BETWEEN:

             CYLINDER      CYLINDER        ROD
               AND           AND           AND
           STUFFING BOX  PISTON HEAD @  STUF. BOX @

            1.00000D-02   0.0            0.0
                        (@ ZERO, OTHER OPTION IS INPUT)
```

```
TABLE 4:      BEARINGS AND SEALS

     PISTON BEARINGS:

                 A              A                A                B         DISTANCE FROM
               WIDTH        THICKNESS    YOUNGS MODULUS     STIFFNESS       BACK FACE

            8.00000D-01   1.15000D 00   3.50000D 04   0.0                6.00000D 00
            1.00000D 00   8.00000D-01   7.00000D 04   0.0                1.00000D 01
            0.0           0.0           0.0           3.71000D 05        1.35000D 01

     ROD BEARINGS:

                 A              A                A                B         DISTANCE FROM
               WIDTH        THICKNESS    YOUNGS MODULUS     STIFFNESS       BACK FACE

            1.00000D 00   5.00000D-01   5.00000D 04   0.0                8.00000D 00

          (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                       ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:      WEIGHTS AND MATERIAL PROPERTIES

     WEIGHTS OF PARTS:

             CYLINDER          ROD         PISTON HEAD   STUFFING BOX
            (PER UNIT LENGTH)

            1.50000D 00   1.00000D 00   2.30000D 01   3.20000D 01


     MATERIAL PROPERTIES:

                YOUNGS MODULUS                 YIELD STRESS
             CYLINDER          ROD          CYLINDER          ROD

            2.10000D 06   2.10000D 06   7.05000D 03   8.80000D 03


TABLE 6:      INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =  7.50000D-01

                                           CYLINDER END      ROD END

     SUPPORT CONDITIONS:                       FIX             PIN

     FRICTION COEFFICIENTS AT SUPPORTS:    0.0            -5.00000D-02
          (ZERO IF FIXED END)
     LOADING ECCENTRICITIES:               0.0             1.00000D-01


TABLE 7:      FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
              DEPENDING ON PROBLEM TYPE


     OPERATING PRESSURE =  1.75000D 02
```

```
 PRCGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATICNS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PRCBLEM REG5

  LPRTP=2; F-P; HOLLOW ROD WITH FLUID; INCLINED CYLINDER; METRIC UNITS.

RESULTS:     ANALYSIS FOR A GIVEN OPERATING PRESSURE

        OPERATING PRESSURE      =  1.750D 02    KGSC

        LOAD                    =  3.192D 04    KGS

        CROOKEDNESS ANGLE       = -1.36932D-05  RAD

CYLINDER:

     MAXIMUM DEFLECTION         =  7.159D-02    CM

     MAXIMUM LCNGITUDINAL STRESS=  1.020D 01    KGSC

     AT A DISTANCE FROM CYL SUP =  1.470D 02    CM

     FACTOR OF SAFETY ON CYL    =  6.909D 02


     MAX LONG STRESS AT CYL END =  1.903D 02    KGSC

     FACTOR OF SAFETY ON CYL    =  3.705D 01


     MAX SHEAR STRESS IN CYL    =  6.537D 02    KGSC
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTOR OF SAFETY ON CYL    =  5.393D 00


     MAXIMUM HOOP STRESS IN CYL =  1.144D 03    KGSC

     FACTOR OF SAFETY ON CYL    =  6.161D 00

ROD     :

     MAXIMUM DEFLECTION         =  1.114D-01    CM

     MAXIMUM LONGITUDINAL STRESS=  1.091D 03    KGSC

     AT A DISTANCE FROM CYL SUP =  2.161D 02    CM

     FACTOR OF SAFETY ON ROD    =  8.063D 0C


     MAX SHEAR STRESS IN ROD    =  6.604D 02    KGSC
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTOR OF SAFETY ON ROD    =  6.662D 0C


     MAXIMUM HOOP STRESS IN RCD =  2.909D 02    KGSC

     FACTOR OF SAFETY ON RCD    =  3.026D 01
```

```
FORCES AT SLIDING CONNECTION:

          PISTCN BEARINGS (SEALS)       FORCE
                NC

                 1                -4.569D 00  KGS

                 2                -8.946D 01  KGS

                 3                -4.267D 01  KGS


            RCD BEARINGS (SEALS)        FORCE
                NO

                 1                -1.367D 02  KGS


  F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0        KGS

  F2- FORCE AT STUFFING BCX FRCNT FACE =  0.0        KGS

  F3- FORCE AT PISTON HEAD BACK FACE   =  0.0        KGS

  F4- FORCE AT STUFFING BOX INNER FACE =  0.0        KGS
     (ZERO FORCES INDICATE NO CONTACT)
```

```
PROGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PROBLEM REG6

  LPRTP=3; P-P; SOLID ROD; HORIZONTAL CYLINDER.

INPUT DATA:

TABLE 1:     CONTROL DATA

     PROBLEM TYPE = 3 - ANALYSIS TO DETERMINE SUITABLE STOP-TUBE LENGTH


             TABLES RETAINED FROM PREVIOUS PROBLEM

                2     3     4     5     6     7

                  NO KEEP OPTIONS EXERCISED


TABLE 2:     UNITS OF MEASUREMENT

            LENGTH      LOAD      PRESSURE   ANGULAR

             INCH       KIPS        KSI         DEG


TABLE 3:     CYLINDER DIMENSIONS

     LENGTHS:

             STROKE      PISTON HEAD  STUFFING BOX   END PLATE    HINGE DIST.

            6.000000 01  6.130000 00   4.440000 00   7.600000-01  3.000000 00


            CYLINDER         ROD          EXTENDED       STOP TUBE

           THESE NOT INPUT BECAUSE STOP TUBE LENGTH ANALYSIS IS ASKED


     DIAMETERS:

            CYL. OUTER    CYL. INNER     ROD OUTER      ROD INNER

            7.000000 00   6.000000 00    3.000000 00    0.0               SOLID ROD


             CYL. PIN *    ROD PIN *    PISTON HEAD @  STUF. BOX @

            4.750000 00   4.750000 00   5.989000 00    3.009000 00
           (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

     CLEARANCES BETWEEN:

             CYLINDER      CYLINDER        ROD
               AND           AND           AND
           STUFFING BOX  PISTON HEAD @  STUF. BOX @

            5.000000-03   0.0             0.0
                         (@ ZERO, OTHER OPTION IS INPUT)
```

```
TABLE 4:     BEARINGS AND SEALS

     PISTON BEARINGS:

                 A              A                 A               B          DISTANCE FROM
               WIDTH        THICKNESS   YOUNGS MODULUS        STIFFNESS        BACK FACE

              0.0             0.0            0.0             2.100000 03    2.375000 00
              0.0             0.0            0.0             8.800000 03    3.900000 00
              0.0             0.0            0.0             2.100000 03    5.450000 00

     ROD BEARINGS:

                 A              A                 A               B          DISTANCE FROM
               WIDTH        THICKNESS   YOUNGS MODULUS        STIFFNESS        BACK FACE

              0.0             0.0            0.0             3.900000 03    3.150000 00

            (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                         ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:     WEIGHTS AND MATERIAL PROPERTIES

     WEIGHTS OF PARTS:

             CYLINDER          ROD          PISTON HEAD  STUFFING BOX
               (PER UNIT LENGTH)

            3.200000-03   2.000000-03   5.000000-02   7.000000-02


     MATERIAL PROPERTIES:

                YOUNGS MODULUS                  YIELD STRESS
             CYLINDER         ROD          CYLINDER          ROD

            2.900000 04   2.900000 04   1.000000 02   1.250000 02

TABLE 6:     INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =  0.0

                                              CYLINDER END     ROD END

     SUPPORT CONDITIONS:                          PIN             PIN

     FRICTION COEFFICIENTS AT SUPPORTS:   0.0              -5.000000-02
          (ZERO IF FIXED END)
     LOADING ECCENTRICITIES:              0.0               1.000000-01


TABLE 7:     FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
             DEPENDING ON PROBLEM TYPE


     OPERATING CYLINDER PRESSURE    =  2.000000 00

     ALLOWABLE CROOKEDNESS ANGLE    =  7.500000-03  AT GLAND

     ALLOWABLE TOTAL LATERAL FORCE =  1.000000 01  ON BEARINGS
```

```
 PROGRAM SACREG - STRESS ANALYSIS OF CYLINDERS ( REGULAR )

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PROBLEM REG6

  LPRTP=3; P-P; SOLID ROD; HORIZONTAL CYLINDER.

RESULTS:     ANALYSIS TO DETERMINE STOP-TUBE LENGTH

REQUIRED LENGTH OF STOP-TUBE    =  4.200D 00    INCH

CORRESPONDING EXTENDED LENGTH   =  1.409D 02    INCH

RESULTS WITH THIS STOP-TUBE ARE:

         CRITICAL LOAD          =  5.655D 01    KIPS

         MAXIMUM FLUID PRESSURE =  2.000D 00    KSI

         CROOKEDNESS ANGLE      =  6.97722D-03  DEG

CYLINDER:

     MAXIMUM DEFLECTION         =  5.358D-01    INCH

     MAXIMUM LONGITUDINAL STRESS=  3.064D 00    KSI

     AT A DISTANCE FROM CYL SUP =  6.858D 01    INCH

     FACTOR OF SAFETY ON CYL    =  3.264D 01


     MAX SHEAR STRESS IN CYL    =  7.851D 00    KSI
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTOR OF SAFETY ON CYL    =  6.368D 00


     MAXIMUM HOOP STRESS IN CYL =  1.308D 01    KSI

     FACTOR OF SAFETY ON CYL    =  7.647D 00

ROD     :

     MAXIMUM DEFLECTION         =  5.927D-01    INCH

     MAXIMUM LONGITUDINAL STRESS=  2.706D 01    KSI

     AT A DISTANCE FROM CYL SUP =  8.504D 01    INCH

     FACTOR OF SAFETY ON ROD    =  4.619D 00
```

```
FORCES AT SLIDING CONNECTION:

           PISTON BEARINGS (SEALS)       FORCE
                      NO


                       1              2.731D-01  KIPS

                       2              2.779D 00  KIPS

                       3              1.059D 00  KIPS


             ROD BEARINGS (SEALS)       FORCE
                      NO


                       1              4.111D 00  KIPS



  F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         KIPS

  F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         KIPS

  F3- FORCE AT PISTON HEAD BACK FACE   =  0.0         KIPS

  F4- FORCE AT STUFFING BOX INNER FACE =  0.0         KIPS
     (ZERO FORCES INDICATE NO CONTACT)
```

APPENDIX B

COMPUTER PROGRAM FOR TELESCOPING CYLINDERS--SACTEL

Program SACTEL

The analytical procedure for telescoping cylinders developed in Chapter VII has been programmed for solution on a digital computer. The program is written in FORTRAN IV language and should require only minor revisions to be operable on other computers. Double precision (16 digits accuracy) arithmetic is used, and the program can be run on any computer which has a storage capacity of 80 K bytes. A summary flow diagram is shown in Figure 39. Details of all the Subprogram Operations, Guide for Data Input, Example Problems, Listings of Input Data, and Program Outputs are given in the following sections.

Subprogram Operation

MAIN

MAIN is a driver subroutine for the complete program. MAIN sets up keys to perform different operations and calls all the major subroutines to perform the major operations in the program. For both problem types MAIN first goes through critical load analysis. Then, for first problem type sets up factored load analysis, and for second problem type checks for input pressure being greater than critical pressure; if not, it goes through corresponding type of analysis.

INPECO

Subroutine INPECO reads all the input data; checks problem name being blank for end of run; checks the input data at several stages for proper input. If any error is observed the error is printed out and the program terminates. Echo prints out all the input tables.

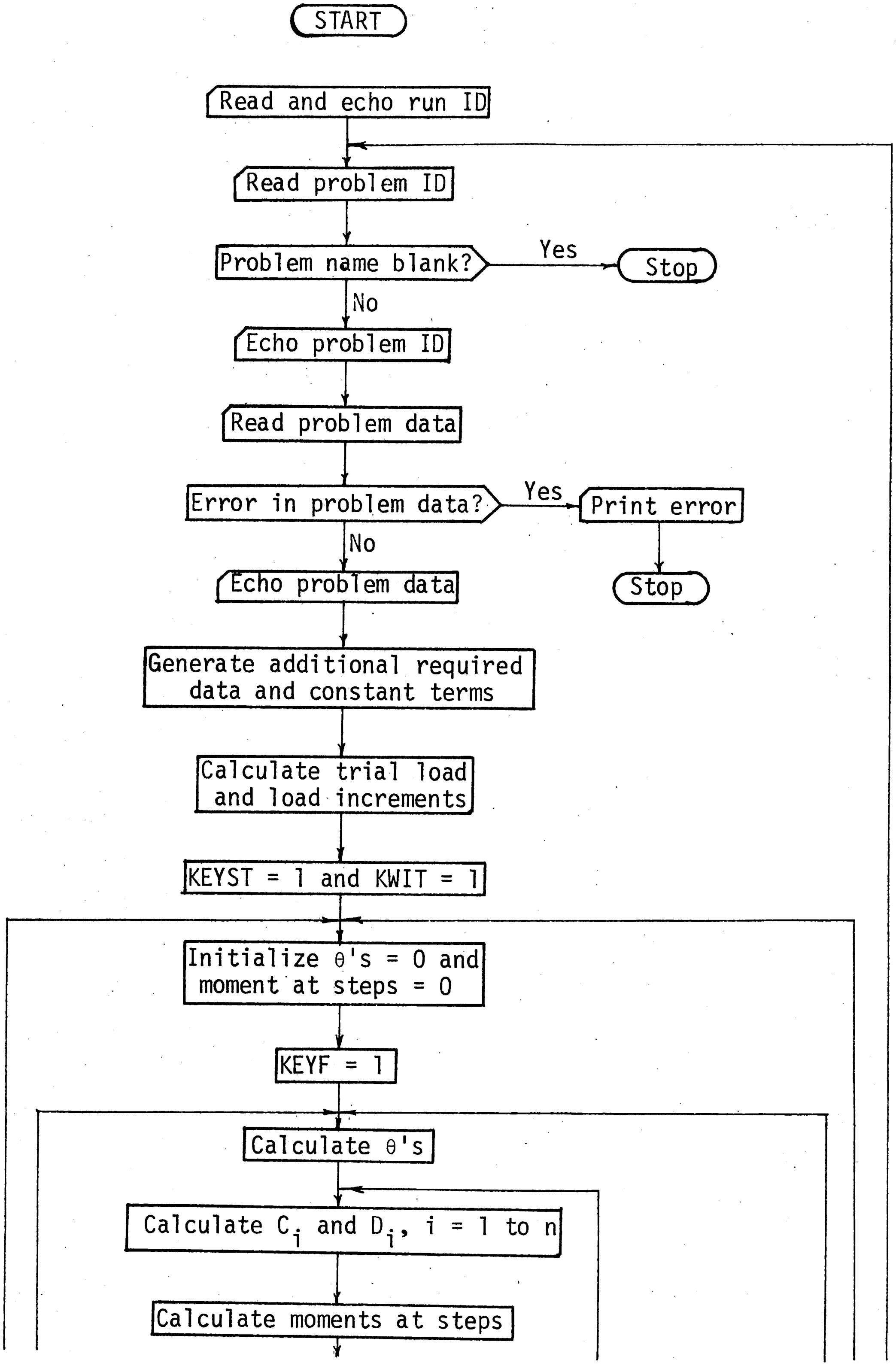


Figure 39. Summary Flow Diagram of Program SACTEL

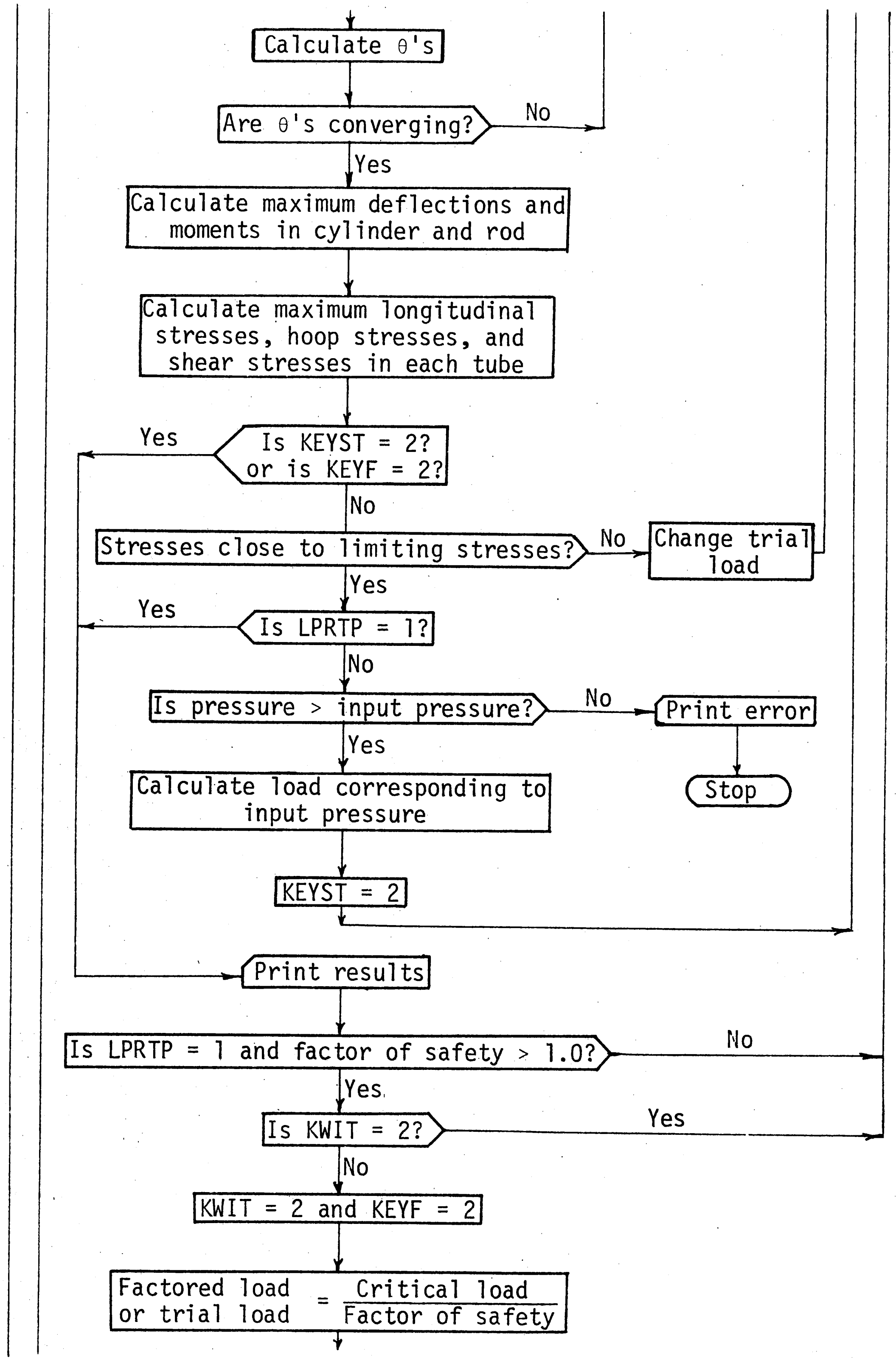


Figure 39. (Continued)

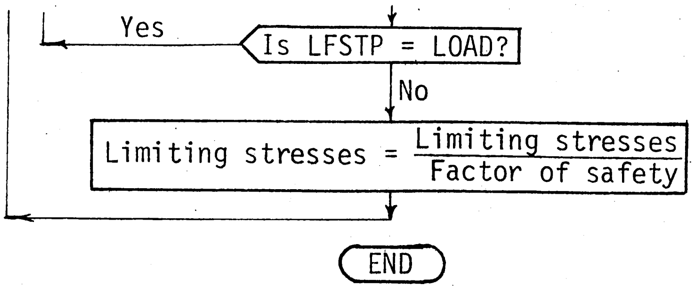


Figure 39. (Continued)

TITLE

Subroutine TITLE prints the title, and program identification and problem identification cards. TITLE also obtains the date from the machine and prints it.

CONST

Subroutine CONST calculates all the constant quantities which do not vary throughout the program. The constant quantities are: stiffnesses of bearings and seals; cross sectional properties of cylinder and rod; hoop stress coefficients; self weight reactions at supports; friction moment coefficients; and moment due to overhang in the case of cylinders with overhang.

TRIALP

Subroutine TRIALP calculates a trial load and two load increments required for the iteration process in evaluating the critical load for the cylinder. The trial load is the critical load given by Euler's buckling criteria considering the full length stiffness as that of the rod only. The first load increment is one-fiftieth of the trial load and the second is one-thousandth. The larger load increment is for faster convergence and the smaller load increment is for better accuracy.

EQBRIM

Subroutine EQBRIM determines the equilibrium position of the system for any particular load. The equilibrium position is determined by repeating the calculation of deflections, bending moments, and crookedness angles at all sliding connections until two consecutive values for all crookedness angles are in close agreement. This subroutine calls subroutine MTRXOP for calculating the values of constant terms in the deflection equations; calls subroutine DEFMOM for calculating the deflections and moments at the sliding connections; and calls subroutine THETA for calculating the crookedness angles at all the sliding connections.

THETA

Subroutine THETA calculates the crookedness angles at all the sliding connections. THETA also calculates the forces on the bearings by calling subroutine GFORCE and the metal-to-metal contact forces at all the sliding connections.

GFORCE

Subroutine GFORCE calculates the forces on the bearings at any sliding connection for a particular value of crookedness angle at that sliding connection.

MTRXOP

Subroutine MTRXOP formulates the [S] matrix and the {R} vector and solves for the unknown vector {U} by calling subroutine SIMSOL. Vector {U} is a vector consisting of the constant terms in the deflection and moment equations and the slopes at the supports.

SIMSOL

Subroutine SIMSOL solves for the unknown vector {U} by Gauss elimination in [S] * {U} = {R}.

DEFMOM

Subroutine DEFMOM calculates the deflections and moments at the input lengths. It also calculates the moments at the supports.

XATYMX

Subroutine XATYMX calculates the distances at which maximum bending moments occur in each tube.

SLOPE

Subroutine SLOPE calculates the slope at an input distance from cylinder support.

STRCHS

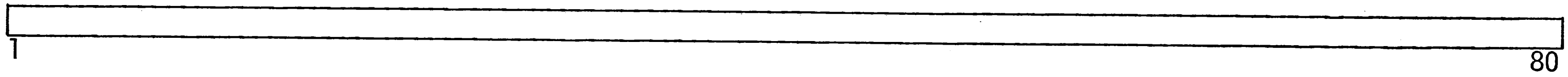
Subroutine STRCHS calculates the maximum longitudinal stress, maximum hoop stress, and maximum shear stress in each tube; checks these stresses against the limiting stresses and makes corresponding changes in the trial load using load increments. This process is repeated until any one of the maximum stress value exceeds the limiting stress. The analysis is repeated for previous load value.

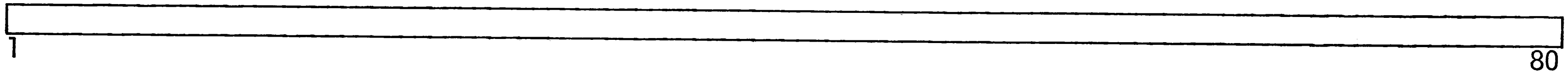
OUTPUT

Subroutine OUTPUT prints out all the results: the maximum deflections, the maximum stresses, the factor of safety existing on these stresses, and the distance from the cylinder support at which the above quantities occur in each tube; the crookedness angles; and the forces on the bearings at each sliding connection.

Program SACTEL--Guide for Data Input

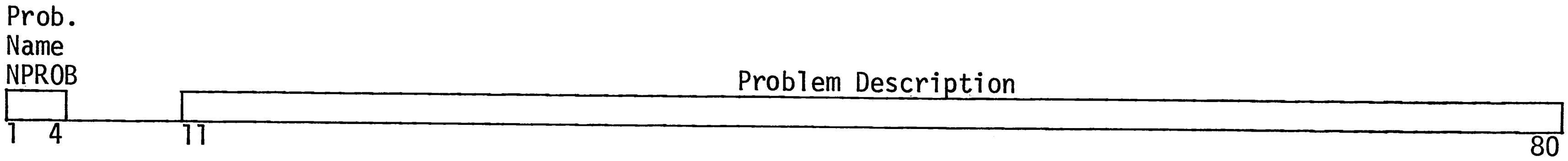
PROGRAM IDENTIFICATION (Two alphanumeric cards at the beginning of run)





Format--20A4

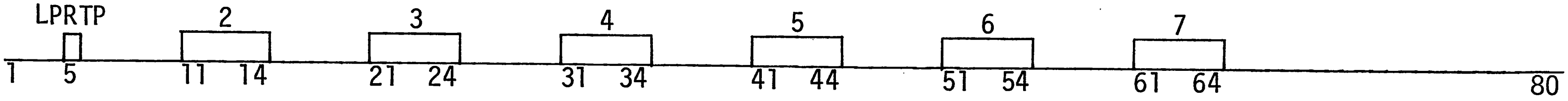
PROBLEM IDENTIFICATION (One card at the beginning of each problem)



Format--20A4

Program stops if NPROB is blank

TABLE 1: CONTROL DATA (One card for each problem)



Format--LPRTP - I1; 2 to 7 - A4

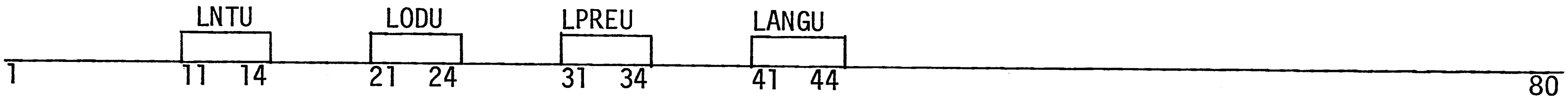
LPRTP = 1--Critical load analysis and analysis for a factored load using given factor of safety

2--Analysis for a particular fluid pressure

If any of the following tables are same as in the previous problem and are to be retained for this problem, enter "KEEP" in the corresponding blocks 2 to 7

Enter only LPRTP for the first problem

TABLE 2: UNITS OF MEASUREMENTS (No card if TABLE 2 is retained from previous problem)



Format--A4 for all

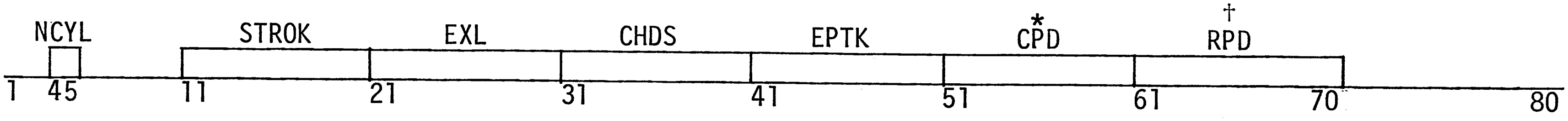
LNTU - Unit of lengths (ex: INCH, FEET, CM, MET, etc.)

LODU - Unit of loads (ex: LBS, KIPS, KGS, etc.)

LPREU - Unit of pressures (ex: KSI, PSI, KSCM, etc.)

LANGU - Unit of angles (enter DEG or RAD starting in column 41)

TABLE 3: STROKE AND EXTENDED LENGTHS AND END DIMENSIONS (No card if TABLE 3 is retained from previous problem; see Figure 40 for details)



Format--NCYL - I2; E10.3 for the rest

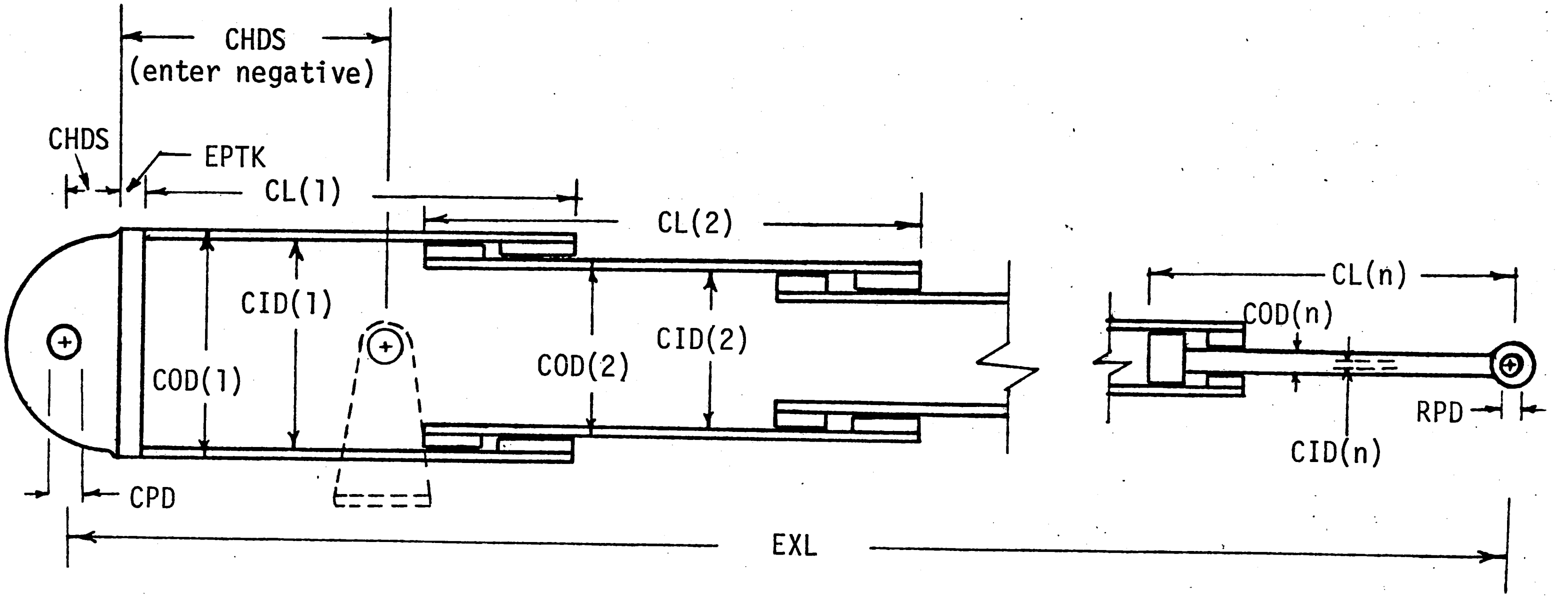


Figure 40. Lengths and Diameters of Tubes and General Dimensions for SACTEL

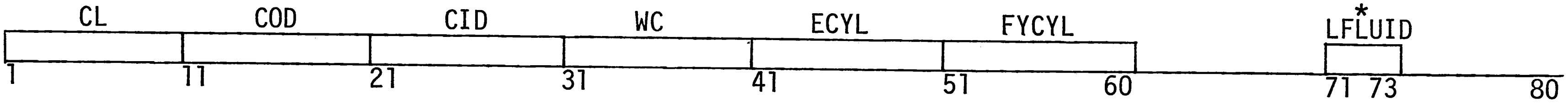
NCYL - Number of tubes (including rod)

STROK - Stroke length of the cylinder

* CPD - Leave blank if cylinder support is fixed

† RPD - Leave blank if rod support is fixed

TABLE 4: EACH TUBE DIMENSIONS AND MATERIAL PROPERTIES (No cards if TABLE 4 is retained from previous problem; one card per tube; n cards for n number of tubes; order of cards--outer tube card to inner tube card; see Figure 40 for details)



Format--LFLUID - A3; E10.3 for the rest

* Required for only last tube

LFLUID - Enter "YES", for hollow rod with fluid

- Enter "NO" or blank, for hollow rod without fluid or solid rod

WC - Weight of tube per unit length

ECYL - Modulus of elasticity of tube material

FYCYL - Yield stress for tube material

TABLE 5: INTERFACE DIMENSIONS AND DETAILS OF BEARINGS (No cards if TABLE 5 is retained from previous problem; one set of cards per interface; m sets of cards for m interfaces (m = n - 1); each set consists of two interface identification and dimensions cards, plus as many cards as the number of bearings at that interface; the sets can be in any order; see Figure 41 for details)

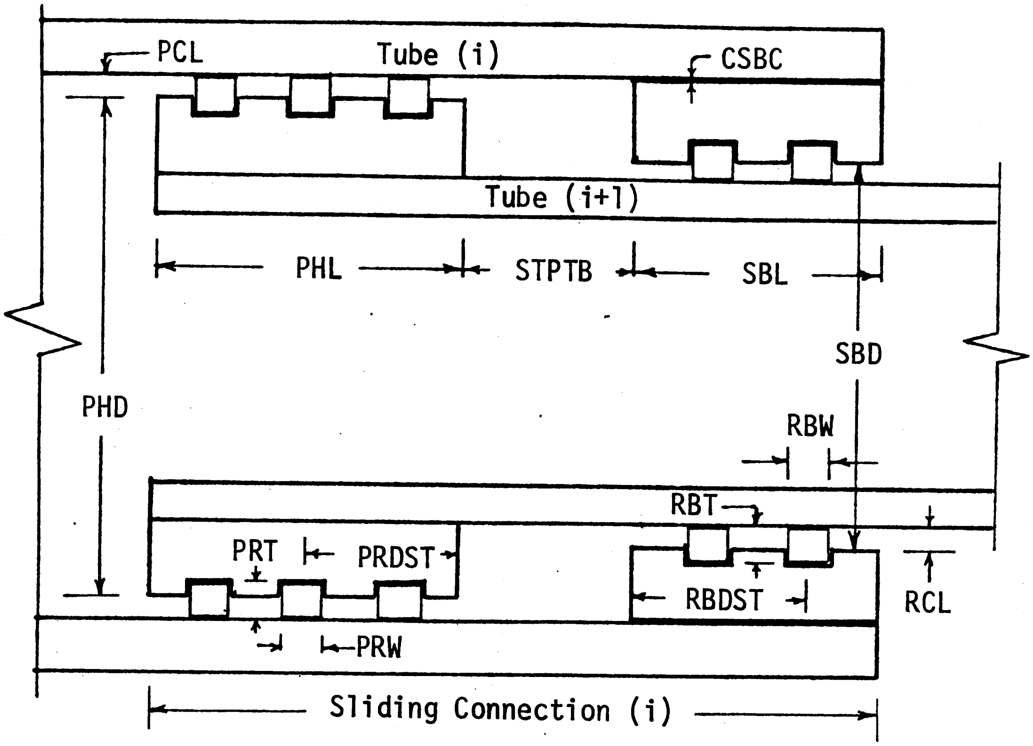


Figure 41. Dimensions at a Typical Sliding Connection (i) for SACTEL

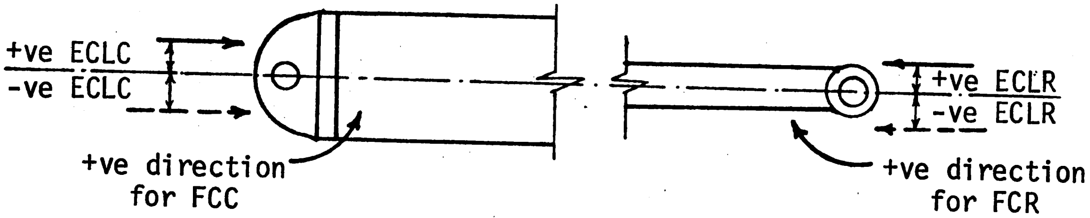
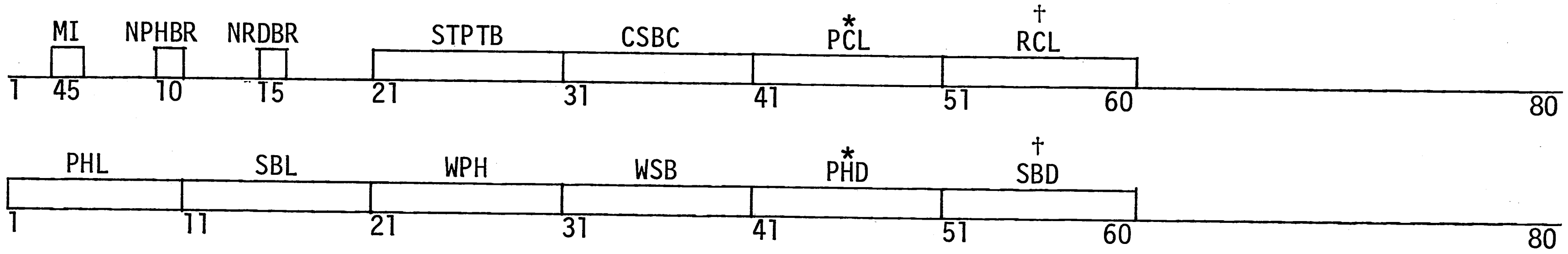


Figure 42. Sign Conventions for Eccentricities of Loading and Friction Coefficients for SACTEL

Interface Identification and Dimensions Cards:



Format--MI - I2; NPHBR and NRDBR - I1; E10.3 for the rest

MI - Number of the interface

NPHBR - Number of piston head bearings at this interface

NRDBR - Number of rod bearings at this interface

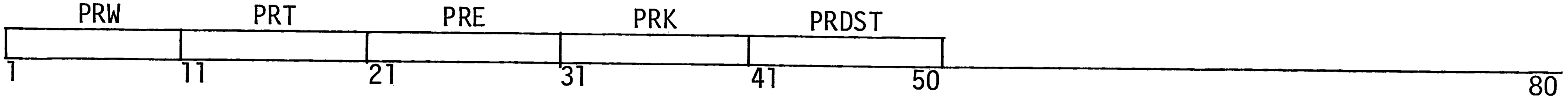
WPH - Weight of piston head

WSB - Weight of stuffing box

* Input either PHD or PCL; if both are input PCL will be used and PHD will be ignored

† Input either SBD or RCL; if both are input RCL will be used and SBD will be ignored

Piston Head Bearings Cards:



Format--E10.3 for all

Input either (PRW, PRT, and PRE) or (PRK); if PRK and some or all of PRW, PRT and PRE are input, PRK will be used and the rest ignored

Rod Bearings Cards:

RBW	RBT	RBE	RBK	RBDST	
1	11	21	31	41 50	80

Format--E10.3 for all

Input either (RBW, RBT, RBE) or (RBK); if RBK and some or all of RBW, RBT and RBE are input, RBK will be used and the rest ignored

PRE and RBE - Young's modulus of piston head bearings and rod bearings

PRK and RBK - Stiffnesses of piston head bearings and rod bearings per unit length (force required to compress a unit length of bearing by one unit)

TABLE 6: INCLINATION, FIXITY, FRICTION COEFFICIENTS, AND LOADING ECCENTRICITIES (No card if TABLE 6 is retained from previous problem)

CINCL		LCEND	LREND	FCC*	FCR*	ECLC*	ECLR*
1 10		31 33	36 38	41	51	61	71 80

Format--LCEND and LREND - A3; E10.3 for the rest

CINCL - Inclination of the cylinder with horizontal (always positive and between 0° and 90°)

LCEND - Enter FIX for fixed or PIN for pinned cylinder support

LREND - Enter FIX for fixed or PIN for pinned rod support

FCC - Friction coefficient at cylinder pin. Leave blank if LCEND is FIX

FCR - Friction coefficient at rod pin. Leave blank if LREND is FIX

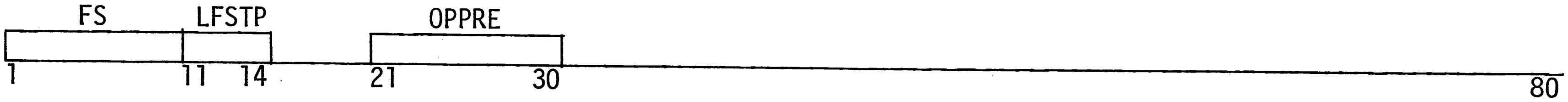
ECLC - Eccentricity of loading at cylinder end

ECLR - Eccentricity of loading at rod end

* See Figure 42 for sign convention

The direction of friction moments at the pins should be visualized by the user depending on the direction of rotation of the pins in the case of rotating pins, and depending on the predicted direction of the slopes at ends of the system for that particular loading, and accordingly proper signs should be assigned for FCC and FCR

<u>TABLE 7: FACTOR OF SAFETY OR OPERATING PRESSURE</u> (No card if TABLE 7 is retained from previous problem)



Format--LFSTP - A4; E10.3 for the rest

LPRTP = 1 - Enter only FS and LFSTP

= 2 - Enter only OPPRE

FS - Factor of safety

LFSTP - Factor of safety type (enter LOAD if FS is to be applied to the critical load obtained; enter STRS if FS is to be applied to the limiting stresses)

If only critical load analysis is required and no factored load analysis is required, leave this card blank or enter FS $\leq$ 1.0, and LFSTP--LOAD or STRS or blank

OPPRE - Particular operating pressure for which analysis is required

NEXT PROBLEM

Start from "PROBLEM IDENTIFICATION" card

END OF RUN

At the end of last problem data set, insert a blank card (only first 4 columns need to be blank, the rest of the card may be used for comments)

```
C
C  -----------------------------------------------------------------------
C |                                                                       |
C |                                                                       |
C |                                                                       |
C |           STRESS ANALYSIS OF HYDRAULIC CYLINDERS                      |
C |           ------ -------- -- --------- ---------                      |
C |                                                                       |
C |                     TELESCOPING CYLINDERS                             |
C |                                                                       |
C |                                                                       |
C |                    JANUARY 15, 1975 VERSION                           |
C |                                                                       |
C |                                                                       |
C |                        K. L. SESHASAI                                 |
C |                                                                       |
C |                  SCHOOL OF CIVIL ENGINEERING                          |
C |                  OKLAHOMA STATE UNIVERSITY                            |
C |                   STILLWATER, OK - 74074                              |
C |                                                                       |
C |                                                                       |
C |                                                                       |
C |  FACTORS CONSIDERED IN THE ANALYSIS:                                  |
C |                                                                       |
C |        1.  SELF WEIGHT                                                |
C |        2.  LOADING ECCENTRICITY AT BOTH THE ENDS                      |
C |        3.  STIFFNESSES OF THE BEARINGS                                |
C |        4.  FRICTION MOMENTS AT THE SUPPORTS                           |
C |        5.  VARYING CYLINDER SUPPORT LOCATION                          |
C |        6.  INCLINATION OF THE CYLINDER                                |
C |        7.  END CONDITIONS - PINNED OR FIXED                           |
C |        8.  SOLID ROD OR HOLLOW ROD WITH OR WITHOUT FLUID IN IT        |
C |                                                                       |
C |                                                                       |
C |  TYPES OF PROBLEMS:                                                   |
C |                                                                       |
C |        1.  DETERMINATION OF CRITICAL LOAD AND ANALYSIS FOR            |
C |            CRITICAL AND A FACTORED LOAD                               |
C |        2.  ANALYSIS FOR A PARTICULAR PRESSURE                         |
C |                                                                       |
C |                                                                       |
C |  RESULTS GIVEN BY THE COMPUTER:                                       |
C |                                                                       |
C |        1.  CRITICAL LOAD AND CORRESPONDING PRESSURE                   |
C |        2.  CROOKEDNESS ANGLES AT THE INTERFACES                       |
C |        3.  MAX DEFLECTION, MAX LONGITUDINAL AND SHEAR STRESSES,       |
C |            DISTANCE AT WHICH THEY OCCUR, FACTOR OF SAFETY'S ON        |
C |            THESE STRESSES FOR BOTH CYL AND ROD PORTIONS               |
C |        4.  MAXIMUM STRESSES AT SUPPORTS IN CASE OF FIXED              |
C |            SUPPORTS AND FACTOR OF SAFETY'S ON THESE STRESSES          |
C |        5.  MAXIMUM HOOP STRESSES IN EACH TUBE AND FACTOR OF           |
C |            SAFETY'S ON THESE STRESSES                                 |
C |        6.  FORCES ON EACH BEARING AND AT OTHER CONTACT POINTS         |
C |        7.  AXIAL TENSION AND END DEFLECTION IN OVERHANG IN            |
C |            CASE OF TRUNNION MOUNT                                     |
C |                                                                       |
C |                                                                       |
C |_______________________________________________________________________|
```

```
C
C---- >>> MAIN PROGRAM - SACTEL
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / BEARDM / PRW(9,5), PRT(9,5), PRE(9,5),
     1                  RBW(9,5), RBT(9,5), RBE(9,5)
      COMMON / BEARPR / PRKX(9), SPRK(9), RBKY(9), SRBK(9)
      COMMON / BRSTDS / PRK(9,5), RBK(9,5), PRDST(9,5), RBDST(9,5)
      COMMON / CANDDS / C( 10 ), D( 10 )
      COMMON / CKCLTW / CK( 10 ), CLT( 10 ), W( 9 )
      COMMON / CONSTS / CSBC(9), PCL1(9), RCL1(9), WPH1(9), WSB1(9),
     1                  WC1(10),PHD(9),SBD(9),CID(10),COD(10),ECYL(10)
      COMMON / CRPROP / CYZ(10), CYZI(10), BAREA(10), CAREA(10),
     1                  HSCI(10), HSCO(10)
      COMMON / CYLWT  / WC(10), EEL, FFL
      COMMON / ECCENT / ECLC, ECLR
      COMMON / ENDS   / LCEND, LREND
      COMMON / FCSSTF / FCCY, FCRD, CSSTF, RSSTF, CONM
      COMMON / GLDFOR / FX(9,5), FY(9,5), F1(9), F2(9), F3(9), F4(9)
      COMMON / GLLNTS / STPTB(9), PHL(9), SBL(9), CL(10), EPTK
      COMMON / INFRPD / CINCL, FCC, FCR, CPD, RPD
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
      COMMON / NBEARS / NPHBR(9), NRDBR(9)
      COMMON / OPFSTP / FYCYL(10), OPPRE, FS, LFSTP
      COMMON / PHSBWC / WPH(9), WSB(9), PCL(9), RCL(9), CYK(10)
      COMMON / SPRMOM / AKTHC, AKTHR
      COMMON / STRESS / TLSTO(10), HSI(10), SSU(10), SSI(10),
     1                  TLSRPO, TLSCPO, AXSOH, PRES
      COMMON / UNITS  / LNTU, LODU, LPREU, LANGU
C
      DIMENSION FYCYLT(10), BM(10), TETA(9), DEF(10), XL(10)
      DIMENSION BMG( 9 )
C
      DATA ZERO, ONE, H180 / 0.0D00, 1.0D00, 180.0D00 /
      DATA PI / 3.14159265358979300D00 /
      DATA IBLNK, LOAD, LDEG / 4H    , 4HLOAD, 4HDEG  /
C
                 NPROB  = IBLNK
  100 CALL INPECO
     O           ( NCYL, EXL, CHDS, LFLUID                                )
          DO 120 I = 1, NCYL
  120            FYCYLT(I) = FYCYL( I )
      CALL CONST
     I           ( NCYL, LANGU, CHDS, EXL                                 )
      CALL TRIALP
     I           ( ECYL(NCYL), CYZ(NCYL), COD(NCYL), EXL,
     O             P, PINCR1, PINCR2                                      )
C
C---- >>> KEY-- KWIT IS SETUP TO APPLY FACTOR OF SAFETY AND REPEAT
C          ANALYSIS FOR FACTORED LOAD
C
                 KWIT   = 1
C
C---- >>> KEY-- KEYF IS SETUP TO QUIT LOOP AT FINAL ITERATION
C
  200            KEYF   = 1
C
C---- >>> KEY-- KEYST IS SETUP TO CHECK INPUT PRESSURE AGAINST CRITICAL
```

```
C          PRESSURE.
C
                KEYST   = 1
C
C---- >>> KEY'S-- KEYT AND KEYP ARE SETUP TO MAKE PROPER LOAD INCREMENTS
C
                KEYT    = 1
                KEYP    = 1
                NM1     = NCYL - 1
C
C---- >>> INITIALIZE TETA'S AND BMG'S EQUAL TO ZERO
C
          DO 220 I = 1, NCYL
                BMG(I) = ZERO
  220           TETA(I) = ZERO
  300 CALL EQLIBM
     I          ( NCYL, CHDS, EXL, P, NM1,
     O            BMG, DEF, TETA, THC, REC                                  )
      CALL XATYMX
     I          ( NCYL, DEF, BMG, EXL, REC, P,
     O            XL                                                        )
      CALL DEFMOM
     I          ( P, EXL, REC, NCYL, 2, XL,
     O            DEF, BM, BMC, BMR                                         )
      CALL STRCHS
     I          ( NCYL, P, BM, CHDS, LFLUID, BMR, BMC, FYCYLT, CID(NCYL),
     I            PINCR1, PINCR2, KEYF, KEYST, KEYT, KEYP                   )
C
C---- >>> IS IT FINAL ITERATION? ? ?
C
          IF ( KEYF - 3 ) 300, 320, 300
  320     IF ( KEYST - 1 ) 500, 340, 500
  340     IF ( LPRTP - 1 ) 360, 500, 360
C
C---- >>> PROTECTION AGAINST INPUT OPERATING PRE. BEING > CRITICAL PRE.
C
  360           PRES    = P / BAREA( NM1 )
          IF ( OPPRE - PRES ) 380, 380, 1000
  380           P       = OPPRE * BAREA( NM1 )
                KEYST   = 2
          GO TO 300
  500 CALL OUTPUT
     I          ( P, XL, DEF, CHDS, THC, NCYL, TETA, KWIT, NM1              )
C
C---- >>> IF THIS PROBLEM IS COMPLETE GO TO NEXT PROBLEM
C
          IF ( KWIT - 1 ) 100, 520, 100
  520     IF ( LPRTP - 1 ) 100, 540, 100
  540     IF ( FS - ONE ) 100, 100, 560
C
C---- >>> FACTOR OF SAFETY IS TO BE APPLIED TO STRESS OR LOAD
C
  560           P       = P / FS
                KWIT    = 2
          IF ( LFSTP .EQ. LOAD ) GO TO 300
          DO 580 I = 1, NCYL
  580           FYCYLT(I) = FYCYL( I ) / FS
          GO TO 200
```

```
C
C---- >>> ERROR MESSAGES
C
 1000 PRINT 1100, PRES
          GO TO 100
 1100 FORMAT ( 1H1, 20(/),10(10X,21H*** *** ERROR *** ***  / ),////,
     1          10X, 38HOPERATING PRESSURE IS GREATER THAN THE     /
     2          10X, 42HCAPACITY( CRITICAL LOAD ) OF THE CYLINDER.  //
     3          10X, 37HTHE MAXIMUM PRESSURE FOR THE CYL IS =,1PD10.3,//)
      END
```

```
      SUBROUTINE INPECO
     0          ( NCYL, EXL, CHCS, LFLUID                                )
C
C---- >>> SUBROUTINE TO READ AND PRINT INPUT DATA FOR SACTEL
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / BEARDM / PRW(9,5), PRT(9,5), PRE(9,5),
     1                  RBW(9,5), RBT(9,5), RBE(9,5)
      COMMON / BRSTDS / PRK(9,5), RBK(9,5), PRDST(9,5), RBDST(9,5)
      COMMON / CONSTS / CSBC(9), PCL1(9), RCL1(9), WPH1(9), WSB1(9),
     1                  WC1(10),PHD(9),SBD(9),CID(10),COD(10),ECYL(10)
      COMMON / ECCENT / ECLC, ECLR
      COMMON / ENDS   / LCEND, LREND
      COMMON / GLLNTS / STPTB(9), PHL(9), SBL(9), CL(10), EPTK
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
      COMMON / INFRPD / CINCL, FCC, FCR, CPD, RPD
      COMMON / NBEARS / NPHBR(9), NRDBR(9)
      COMMON / OPFSTP / FYCYL(10), OPPRE, FS, LFSTP
      COMMON / UNITS  / LNTU, LCDU, LPREU, LANGU
C
      DATA ZERO, P0001, ONE / 0.0D00, 0.0001D00, 1.0D00 /
      DATA IBLNK, KEEP, LYES / 4H    , 4HKEEP, 3HYES /
C
C---- >>> FORMATS
C
   10 FORMAT ( 20A4                                                      )
   20 FORMAT ( A4, 19A4                                                  )
   30 FORMAT ( 4X, I1, 5X, 6( A4, 6X )                                   )
   40 FORMAT ( 4X, 4( 6X, A4 )                                           )
   50 FORMAT ( 5F10.0                                                    )
   60 FORMAT ( 3X, I2, 5X, 6F10.0                                        )
   70 FORMAT ( 3X, I2, 2( 4X, I1 ), 5X, 4F10.0                           )
   80 FORMAT ( 6F10.0, 10X, A3                                           )
   90 FORMAT ( F10.0, 20X, 2( A3, 2X ), 4F10.0                           )
  100 FORMAT ( F10.0, A4, 6X, F10.0                                      )
  110 FORMAT ( /, 5X, 11HINPUT DATA:, //, 5X, 8HTABLE 1:, 5X,
     1         12HCONTROL DATA                                           )
  120 FORMAT ( /, 10X, 41HPROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS,
     1         31H & ANALYSIS FOR A FACTORED LOAD, /                     )
  130 FORMAT ( /, 10X, 27HPROBLEM TYPE = 2 - ANALYSIS,
     1         26H FOR A PARTICULAR PRESSURE, /                          )
  160 FORMAT ( 18X, 37HTABLES RETAINED FROM PREVIOUS PROBLEM, //,
     1         20X, 2H 2, 4X, 2H 3, 4X, 2H 4, 4X, 2H 5, 4X, 2H 6,
     2         4X, 2H 7, /, 17X, 6( 2X, A4 )                             )
  190 FORMAT ( 23X, 25HNO KEEP OPTIONS EXERCISED, /                      )
  210 FORMAT ( /, 5X, 33HTABLE 2:      UNITS OF MEASUREMENT,//, 17X,
     1         6HLENGTH, 6X, 4HLOAD, 5X, 8HPRESSURE, 3X, 7HANGULAR,
     2         //, 11X, 4( 7X, A4 )                                      )
  220 FORMAT ( //, 5X, 32HTABLE 3:      STROKE AND EXTENDED,
     1                    27H LENGTHS AND END DIMENSIONS ,
     2       //, 15X, 35HNUMBER OF TUBES( INCLUDING ROD ) = , I2,
     3        /, 15X, 35HSTROKE LENGTH                    = , 1PD12.5,
     4        /, 15X, 35HEXTENDED LENGTH                  = , 1PD12.5,
     5       //, 15X, 35HCYL. HINGE DIST. FROM END PLATE  = , 1PD12.5,
     6        /, 15X, 35HEND PLATE THICKNESS              = , 1PD12.5,
     7       //, 15X, 35HCYLINDER PIN DIAMETER            = , 1PD12.5,
     8        /, 15X, 35HROD PIN DIAMETER                 = , 1PD12.5/)
  230 FORMAT (  /, 5X, 28HTABLE 4:      TUBE DIMENSIONS ,
     1            24H AND MATERIAL PROPERTIES , //, 10X, 3HNO.,5X,
     2            6HLENGTH, 6X, 9HOUTER DIA, 4X, 9HINNER DIA, 2X,
     3            12HWT/UNIT LNT., 2X, 10HYOUNGS MOD, 3X, 10HYIELD STRS /)
  250 FORMAT ( 10X, I3, 1X, 6( 1X, 1PD12.5 )                             )
  260 FORMAT ( 27X, 28H( HOLLOW ROD WITHOUT FLUID ), /                   )
  270 FORMAT ( 28X, 25H( HOLLOW ROD WITH FLUID ) , /                     )
  280 FORMAT ( 34X, 13H( SOLID ROD ) , /                                 )
  300 FORMAT ( 1H1,4X, 33HTABLE 5:      INTERFACE DIMENSIONS ,
     1            24H AND DETAILS OF BEARINGS , /                        )
  310 FORMAT (  10X,33HDETAILS AT INTERFACE NUMBER       = , I2,
     1       //,15X,39HNUMBER OF PISTON BEARINGS                 = , I2,
     2        /,15X,39HNUMBER OF ROD BEARINGS                    = , I2,
     3       //,15X,39HLENGTH OF STOP TUBE                       = ,1PD12.5,
     4        /,15X,39HCLEARANCE BETWEEN CYL & STUFFING BOX = ,1PD12.5/)
  320 FORMAT ( /,37X, 6HLENGTH, 7X, 8HDIAMETER, 6X, 9HCLEARANCE, 6X,
     1           6HWEIGHT, /, 48X, 27H(ONE OF THESE TWO IS INPUT), //,
     2           20X, 12HPISTON HEAD , 4( 2X, 1PD12.5 ), //, 20X,
     3           12HSTUFFING BOX, 4( 2X, 1PD12.5 )                       )
  330 FORMAT ( //, 15X, 16HPISTON BEARINGS:,  /, 77X, 13HDISTANCE FROM,
     1           /, 15X, 3HNO., 6X, 5HWIDTH, 7X, 9HTHICKNESS, 2X,
     2           14HYOUNGS MODULUS, 3X, 9HSTIFFNESS, 4X, 12HBACK FACE OF,
     3           /, 77X, 11HPISTON HEAD, /                               )
  340 FORMAT ( 5( 15X, I2, 1X, 5( 2X, 1PD12.5 ) / )                      )
  350 FORMAT (      15X, 16HROD BEARINGS   :, /, 77X, 13HDISTANCE FROM,
     1           /, 15X, 3HNO., 6X, 5HWIDTH, 7X, 9HTHICKNESS, 2X,
     2           14HYOUNGS MODULUS, 3X, 9HSTIFFNESS, 4X, 12HBACK FACE OF
     3           /, 77X, 12HSTUFFING BOX, /                              )
  360 FORMAT ( 20X, 33H(NOTE:  EITHER WIDTH, THICKNESS, ,
     1            37HYOUNGS MODULUS OR STIFFNESS IS INPUT., /, 28X,
     2            42HZERO'S INDICATE THAT THEY ARE NOT INPUT. ), /       )
  380 FORMAT ( /, 5X, 43HTABLE 6:      INCLINATION, FIXITY, FRICTION ,
     1           34HCOEFFICIENTS, LOADING ECCENTRICITY, //, 10X,
     2           34HCYL INCLINATION WITH HORIZONTAL = , 1PD12.5, //, 46X,
     3           24HCYLINDER END       ROD END, //, 10X,
     4           19HSUPPORT CONDITIONS:, 21X, A3, 12X, A3, //, 10X,
     5           36HFRICTION COEFFICIENTS AT SUPPORTS:  , 2( 1PD12.5, 2X )
     6           /, 15X, 19H(ZERO IF FIXED END), /, 10X,
     7           23HLOADING ECCENTRICITIES:, 13X, 2( 1PD12.5, 2X ), /    )
  390 FORMAT ( /, 5X, 39HTABLE 7:      FACTOR OF SAFETY, ITS TYPE,
     1            22H OR OPERATING PRESSURE, /                           )
  410 FORMAT ( /, 10X, 19HFACTOR OF SAFETY = , F6.3, 4H ON , A4, /       )
  420 FORMAT ( /, 10X, 21HOPERATING PRESSURE = , 1PD12.5, /              )
  430 FORMAT ( /, 10X, 31HCRITICAL LOAD ANALYSIS IS ASKED, /             )
  480 FORMAT ( //, 10X, 6H***** , 19HPROGRAM TERMINATED , 5H*****        )
  490 FORMAT ( 1H1                                                       )
  700 FORMAT ( 1H1, 15(/), 5( 10X, 6H***** ,
     1           28HERROR IN INPUT LENGTHS ***** , / )                   )
  720 FORMAT ( 1H1, 15(/), 10X, 6H***** ,
     1           13HERROR - PCL1(, I2, 20H ) IS NEGATIVE *****           )
  740 FORMAT ( 1H1, 15(/), 10X, 6H***** ,
     1           12HERROR - CID(, I2, 20H ) IS LESS THAN PHD(, I2,
     2           8H ) *****                                              )
  760 FORMAT ( 1H1, 15(/), 10X, 6H***** ,
     1           13HERROR - RCL1(, I2, 20H ) IS NEGATIVE *****           )
  780 FORMAT ( 1H1, 15(/), 10X, 6H***** , 12HERROR - COD(, I2,
     1           '+1 ) IS GREATER THAN SBD(', I2, 8H ) *****             )
C
C---- >>> READ AND ECHO RUN AND PROBLEM IDENTIFICATION
```

```
C
          IF ( NPROB .NE. IBLNK ) GO TO 1000
      READ ( 5, 10 ) ( IDCARD( I ), I = 1, 40 )
 1000 READ ( 5, 20 ) NPROB, ( IPROB( I ), I = 1, 19 )
C
C---- >>> TEST FOR END OF RUN
C
          IF ( NPROB .EQ. IBLNK ) GO TO 3200
      CALL TITLE
C
C---- >>> READ TABLE 1:  PROBLEM TYPE AND TABLES TO BE RETAINED FROM
C                        PREVIOUS PROBLEM
C
      READ ( 5, 30 ) LPRTP, KEEP2, KEEP3, KEEP4, KEEP5, KEEP6, KEEP7
          IF ( KEEP2 .EQ. KEEP ) GO TO 1100
C
C---- >>> READ TABLE 2:  UNITS OF MEASUREMENT
C
      READ ( 5, 40 ) LNTU, LODU, LPREU, LANGU
 1100     IF ( KEEP3 .EQ. KEEP ) GO TO 1200
C
C---- >>> READ TABLE 3:  GENERAL DIMENSIONS
C
      READ ( 5,60 ) NCYL, STROK, EXL, CHDS, EPTK, CPD, RPD
 1200     IF ( KEEP4 .EQ. KEEP ) GO TO 1300
C
C---- >>> READ TABLE 4:  DIMENSIONS AND MATERIAL PROPERTIES OF EACH TUBE
C
      READ ( 5,80 ) ( CL(I), COD(I), CID(I), WC1(I), ECYL(I), FYCYL(I),
     1                                        LFLUID, I = 1, NCYL )
 1300     IF ( KEEP5 .EQ. KEEP ) GO TO 1500
              NM1     = NCYL - 1
C
C---- >>> READ TABLE 5:  DIMENSIONS & MATERIAL PROPERTIES AT INTERFACES
C
          DO 1400 I = 1, NM1
      READ ( 5,70 ) MI, NPHBR(MI), NRDBR(MI), STPTB(MI), CSBC(MI),
     1              PCL1(MI), RCL1(MI)
      READ ( 5,80 ) PHL(MI), SBL(MI), WPH1(MI), WSB1(MI),PHD(MI),SBD(MI)
              K       = MI
              L       = NPHBR( MI )
      READ ( 5,50 ) ( PRW(K,J), PRT(K,J), PRE(K,J), PRK(K,J), PRDST(K,J)
     1                                        , J = 1, L )
              L       = NRDBR( MI )
      READ ( 5,50 ) ( RBW(K,J), RBT(K,J), RBE(K,J), RBK(K,J), RBDST(K,J)
     1                                        , J = 1, L )
 1400     CONTINUE
C
C---- >>> TEST FOR PROPER INPUT
C
              CHKEXL = CHDS + EPTK + CL( NCYL )
          DO 1450 I = 1, NM1
 1450         CHKEXL = CHKEXL + CL(I) - SBL(I) - STPTB(I) - PHL(I)
              DIFF   = DABS( CHKEXL - EXL )
          IF ( DIFF .GE. 0.01D00 ) GO TO 2500
              CHSTRK = EXL - CHDS - EPTK - CL( NCYL )  + P0001
          IF ( CHSTRK .LT. STROK ) GO TO 2500
          DO 1490 I = 1, NM1
          IF ( PCL1(I) ) 2600, 1460, 1470
 1460     IF ( CID(I) .LT. PHD(I) ) GO TO 2700
 1470     IF ( RCL1(I) ) 2800, 1480, 1490
 1480     IF ( COD(I+1) .GT. SBD(I) ) GO TO 2900
 1490     CONTINUE
 1500     IF ( KEEP6 .EQ. KEEP ) GO TO 1600
C
C---- >>> READ TABLE 6:  INCLINATION, END FIXITY, FRICTION COEFFICIENTS
C                        AND ECCENTRICITY OF LOADING
C
      READ ( 5,90 ) CINCL, LCEND, LREND, FCC, FCR, ECLC, ECLR
 1600     IF ( KEEP7 .EQ. KEEP ) GO TO 1700
C
C---- >>> READ TABLE 7:  FACTOR OF SAFETY, ITS TYPE / OPERATING PRESSURE
C
      READ ( 5,100 ) FS, LFSTP, CPPRE
 1700     CONTINUE
C
C---- >>> PRINT ALL THE TABLES READ
C
      PRINT 110
          IF ( LPRTP .EQ. 1 ) PRINT 120
          IF ( LPRTP .EQ. 2 ) PRINT 130
      PRINT 160, KEEP2, KEEP3, KEEP4, KEEP5, KEEP6, KEEP7
          IF ( KEEP2 .NE. IBLNK ) GO TO 1750
          IF ( KEEP3 .NE. IBLNK ) GO TO 1750
          IF ( KEEP4 .NE. IBLNK ) GO TO 1750
          IF ( KEEP5 .NE. IBLNK ) GO TO 1750
          IF ( KEEP6 .NE. IBLNK ) GO TO 1750
          IF ( KEEP7 .EQ. IBLNK ) PRINT 190
 1750     CONTINUE
      PRINT 210, LNTU, LODU, LPREU, LANGU
      PRINT 220, NCYL, STROK, EXL, CHDS, EPTK, CPD, RPD
      PRINT 230
          DO 1760 I = 1, NCYL
 1760 PRINT 250, I, CL(I), COD(I), CID(I), WC1(I), ECYL(I), FYCYL(I)
          IF ( CID( NCYL ) ) 1780, 1780, 1770
 1770     IF ( LFLUID .NE. LYES ) PRINT 260
          IF ( LFLUID .EQ. LYES ) PRINT 270
          GO TO 1790
 1780 PRINT 280
 1790     CONTINUE
      PRINT 300
          DO 1800 I = 1, NM1
      PRINT 310, I, NPHBR(I), NRDBR(I), STPTB(I), CSBC(I)
      PRINT 320, PHL(I), PHD(I),PCL1(I),WPH1(I), SBL(I), SBD(I),RCL1(I),
     1           WSB1(I)
      PRINT 330
              L       = NPHBR( I )
      PRINT 340, ( J, PRW(I,J), PRT(I,J), PRE(I,J), PRK(I,J), PRDST(I,J)
     1                                        , J = 1, L )
      PRINT 350
              L       = NRDBR( I )
      PRINT 340, ( J, RBW(I,J), RBT(I,J), RBE(I,J), RBK(I,J), RBDST(I,J)
     1                                        , J = 1, L )
 1800     CONTINUE
      PRINT 360
      PRINT 380, CINCL, LCEND, LREND, FCC, FCR, ECLC, ECLR
```

```
      PRINT 390
           IF ( LPRTP .EQ. 1 ) GO TO 1900
           IF ( LPRTP .EQ. 2 ) PRINT 420, UPPRE
           GO TO 1950
 1900      IF ( FS .LE. ONE ) PRINT 430
           IF ( FS .GT. ONE ) PRINT 410, FS, LFSTP
 1950 RETURN
C
C---- >>> DIAGGNOSTICS FOR ILLEGAL INPUTS
C
 2500 PRINT 700
           GO TO 3100
 2600 PRINT 720, I
           GO TO 3100
 2700 PRINT 740, I, I
           GO TO 3100
 2800 PRINT 760, I
           GO TO 3100
 2900 PRINT 780, I, I
 3100 PRINT 480
 3200 PRINT 490
C
C---- >>> END OF RUN IF ERROR IN INPUT IS ENCOUNTERED
C
      STOP
      END
```

```
      SUBROUTINE TITLE
C
C---- >>> SUBROUTINE TO PRINT TITLE, PROGRAM IDENTIFICATION, AND PROBLEM
C         IDENTIFICATION
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      REAL * 8 IDATE
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
C
  100 FORMAT ( I2, 1X, I2, 1X, I2                                        )
  110 FORMAT ( 1H1,    4X,35HPROGRAM SACTEL - STRESS ANALYSIS OF,
     1          25H CYLINDERS ( TELESCOPIC ),6X,6HDATE: ,I2,1H/,I2,1H/,
     2          I2, /                                                    )
  120 FORMAT ( /, 2( 5X, 20A4, / )                                       )
  130 FORMAT (     5X, 8HPROBLEM , A4, 1H:, //, 1X, 19A4                 )
      CALL DATE ( IDATE                                                  )
      CALL CORE ( IDATE, 8                                               )
      READ ( 99, 100 ) MONTH, IDAY, IYEAR
C
C---- >>> PRINT DATE
C
      PRINT 110, MONTH, IDAY, IYEAR
      PRINT 120, ( IDCARD( I ), I = 1, 40 )
      PRINT 130, NPROB, ( IPROB( I ), I = 1, 19 )
      RETURN
      END
```

```
      SUBROUTINE CONST
     I          ( NCYL, LANGU, CHDS, EXL                                  )
C
C---- >>> SUBROUTINE TO CALCULATE CONSTANT TERMS FOR CONVENIENCE
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / BEARDM / PRW(9,5), PRT(9,5), PRE(9,5),
     1                  RBW(9,5), RBT(9,5), RBE(9,5)
      COMMON / BEARPR / PRKX(9), SPRK(9), RBKY(9), SRBK(9)
      COMMON / BRSTDS / PRK(9,5), RBK(9,5), PRDST(9,5), RBDST(9,5)
      COMMON / CONSTS / CSBC(9), PCL1(9), RCL1(9), WPH1(9), WSB1(9),
     1                  WC1(10),PHD(9),SBD(9),CID(10),COD(10),ECYL(10)
      COMMON / CRPROP / CYZ(10), CYZI(10), BAREA(10), CAREA(10),
     1                  HSCI(10), HSCO(10)
      COMMON / CYLWT  / WC(10), EEL, FFL
      COMMON / ECCENT / ECLC, ECLR
      COMMON / ENDS   / LCEND, LREND
      COMMON / FCSSTF / FCCY, FCRD, CSSTF, RSSTF, CONM
      COMMON / INFRPD / CINCL, FCC, FCR, CPD, RPD
      COMMON / NBEARS / NPHBR(9), NRDBR(9)
      COMMON / PHSBWC / WPH(9), WSB(9), PCL(9), RCL(9), CYK(10)
C
      DATA ZERO, TWO, FOUR, SXTFOR / 0.0D00, 2.0D00, 4.0D00, 64.0D00 /
      DATA H180, AINFIN / 180.0D00, 1.0D20 /
      DATA PI / 3.141592653589793D00 /
      DATA LDEG, LFIX / 4HDEG , 3HFIX /
C
C---- >>> CALCULATE STIFFNESSES OF BEARINGS AND SEALS IF NOT INPUT
C
             NM1     = NCYL - 1
         DO 150 I = 1, NM1
             SPRK(I) = ZERO
             PRKX(I) = ZERO
             NL      = NPHBR( I )
         DO 110 J = 1, NL
         IF ( PRK( I,J ) ) 95, 95, 100
   95        PRK(I,J) = CID(I) * PRW(I,J) * PRE(I,J) / PRT(I,J)
  100        PRKX(I) = PRK( I,J ) * PRDST( I,J ) + PRKX( I )
  110        SPRK(I) = PRK( I,J ) + SPRK( I )
             SRBK(I) = ZERO
             RBKY(I) = ZERO
             NL      = NRDBR( I )
         DO 130 J = 1, NL
         IF ( RBK( I,J ) ) 115, 115, 120
  115        RBK(I,J) = COD(I+1) * RBW(I,J) * RBE(I,J) / RBT(I,J)
  120        RBKY(I) = RBK(I,J) * RBDST(I,J) + RBKY(I)
  130        SRBK(I) = RBK(I,J) + SRBK(I)
  150    CONTINUE
             TEMP    = PI / H180
             BETA    = CINCL
         IF ( LANGU .EQ. LDEG ) BETA = CINCL * TEMP
             CB      = DCOS( BETA )
C
C---- >>> CALCULATE CROSS SECTIONAL PROPERTIES
C
         DO 200 I = 1, NCYL
             COD2    = COD(I) * COD(I)
             CID2    = CID(I) * CID(I)
```

```
               COD4    = COD2 * COD2
               CID4    = CID2 * CID2
               CYI     = PI * ( COD4 - CID4 ) / SXTFOR
               CYZ(I) = CYI * TWO / COD( I )
            IF ( CID( I )  )170, 170, 160
  160          CYZI(I)= CYI * TWO / CID( I )
C
C---- >>> BORE AREAS AND CROSS SECTIONAL AREAS OF TUBES
C
  170          BAREA(I) = PI * CID2 / FOUR
               DEN      = COD2 - CID2
               CAREA(I) = PI * DEN / FOUR
C
C---- >>> CALCULATE HOOP STRESS COEFFICIENTS
C
               HSCI(I) = ( COD2 + CID2 ) / DEN
               HSCO(I) = TWO * CID2 / DEN
               CYK(I) = DSQRT( ECYL(I) * CYI )
            IF ( I - NCYL ) 190, 200, 200
C
C---- >>> CALCULATE CLEARANCES AT PISTON HEAD AND STUFFING BOX
C
  190          PCL(I) = ( CID(I) - PHD(I) ) / TWO
            IF ( PCL1(I) .GT. ZERO ) PCL(I) = PCL1(I)
               RCL(I) = ( SBD(I) - COD(I+1) ) / TWO + CSBC(I)
            IF ( RCL1(I) .GT. ZERO ) RCL(I) = RCL1(I) + CSBC(I)
C
C---- >>> CALCULATE VERTICAL COMPONENTS OF WEIGHTS
C
               WPH(I) = WPH1(I) * CB
               WSB(I) = WSB1(I) * CB
  200          WC(I)  = WC1(I) * CB
C
C---- >>> CALCULATE FRICTION MOMENT COEFFICIENTS
C
               FCCY    = FCC * CPD / TWO
               FCRD    = FCR * RPD / TWO
               FFL     = ( FCRD - FCCY ) / EXL
               EEL     = ( ECLR - ECLC ) / EXL
C
C---- >>> ESTABLISH STIFFNESSES FOR ROTATIONAL SPRINGS AT SUPPORTS AS
C         PER INPUT SUPPORT CONDITIONS
C
               CSSTF   = ZERO
               RSSTF   = ZERO
            IF ( LCEND .EQ. LFIX ) CSSTF = AINFIN
            IF ( LREND .EQ. LFIX ) RSSTF = AINFIN
C
C---- >>> MOMENT DUE TO OVER HANG
C
               CONM    = WC(1) * CHDS * CHDS / TWO
            IF ( CHDS ) 230, 230, 220
  220          CONM    = ZERO
  230       IF ( LCEND .EQ. LFIX ) CONM = ZERO
      RETURN
      END
```

```
      SUBROUTINE TRIALP
     I          ( ECYLN, CYZN, CODN, EXL,
     O            P, PINCR1, PINCR2                                  )
C
C---- >>> SUBROUTINE TO CALCULATE TRIAL LOAD AND LOAD INCREMENTS
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
C
      DATA ONEP25, TWO, FIFTY, THOSND / 1.25D00,2.D00,50.D00,1000.D00 /
      DATA PI / 3.14159265358979D00 /
      DATA LFIX / 3HFIX /
C
C---- >>> TRIAL LOAD (1) AS PER EULERS BUCKLING, CONSIDERING FULL
C         LENGTH STIFFNESS AS THAT OF ROD ONLY
C
            PI2     = PI * PI
            EXL2    = EXL * EXL
            CYIN    = CYZN * CODN / TWO
            P       = PI2 * ECYLN * CYIN / EXL2
            P       = P * ONEP25
            PINCR1  = P / FIFTY
            PINCR2  = P / THOSND
      RETURN
      END
```

```
      SUBROUTINE EQLIBM
     I          ( NCYL, CHDS, EXL, P, NM1,
     O            BM, DEF, TETA, THC, REC                                   )
C
C---- >>> SUBROUTINE TO CALCULATE CONSISTENT VALUES OF DEFLECTIONS AND
C          CROOKEDNESS ANGLES BY ITERATING, FOR A PARTICULAR LOAD
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / BEARPR / PRKX(9), SPRK(9), RBKY(9), SRBK(9)
      COMMON / BRSTDS / PRK(9,5), RBK(9,5), PRDST(9,5), RBDST(9,5)
      COMMON / CANDDS / C( 10 ), D( 10 )
      COMMON / CKCLTW / CK( 10 ), CLT( 10 ), W( 9 )
      COMMON / CYLWT  / WC(10), EEL, FFL
      COMMON / ECCENT / ECLC, ECLR
      COMMON / FCSSTF / FCCY, FCRD, CSSTF, RSSTF, CONM
      COMMON / GLDFOR / FX(9,5), FY(9,5), F1(9), F2(9), F3(9), F4(9)
      COMMON / GLLNTS / STPTB(9), PHL(9), SBL(9), CL(10), EPTK
      COMMON / NBEARS / NPHBR(9), NRDBR(9)
      COMMON / PHSBWC / WPH(9), WSB(9), PCL(9), RCL(9), CYK(10)
      COMMON / SPRMOM / AKTHC, AKTHR
      COMMON / STFDST / PRKT(5), PRDSTT(5), RBKT(5), RBDSTT(5)
C
      DIMENSION BM(NCYL), DEF(NCYL), TETA(NCYL), TETAF(9)
      DIMENSION FXX( 5 ), FYY( 5 )
      DIMENSION X(9), Y(9)
      DIMENSION S( 22, 22 ), R( 22 )
C
      DATA TWO, HUNDRD / 2.0D00, 100.0D00 /
C
                KOUNT   = 1
                SQP     = DSQRT( P )
            DO 210 I = 1, NCYL
  210           CK(I)   = SQP / CYK( I )
            GO TO 400
C
C ---- >>>CALCULATE TRANSFORMED CYLINDER AND ROD LENGTHS
C
  220           CLT(1) = CL( 1 ) + EPTK + CHDS - SBL( 1 ) - Y( 1 )
            IF ( NCYL - 2  ) 230, 250, 230
  230       DO 240 I = 2, NM1
  240           CLT(I) = CLT( I-1 ) - X( I-1 ) - PHL( I-1 )  + CL( I )
     *                   - Y( I ) - SBL( I )
  250           CLT(NCYL) = CLT( NCYL-1 ) - X( NCYL-1 ) - PHL( NCYL-1  )
     *                      + CL( NCYL )
C
C---- >>> CALCULATE LATERAL REACTION AT CYLINDER SUPPORT
C
                REC     = CONM + WC( 1 ) * CLT( 1 ) * ( EXL - CLT(1)/TWO )
            DO 300 I = 1, NM1
                W( I ) = WPH(I) + WSB(I) + WC(I) * Y(I) + WC(I+1) * X(I)
                CLC1    = CLT( I+1 ) - CLT( I )
                CLC2    = ( CLT( I+1 ) + CLT( I ) ) / TWO
                REC     = REC + W( I ) * ( EXL - CLT( I ) )
     1                    + WC( I+1 ) * CLC1 * ( EXL - CLC2 )
  300       CONTINUE
                REC     = REC / EXL
                NTEMP   = 2 * NCYL + 2
      CALL MTRXOP
     I          ( P, EXL, REC, TETA, NTEMP, NM1,
     O            THC, THR, S, R                                            )
                AKTHC   = CSSTF * THC
                AKTHR   = RSSTF * THR
      CALL DEFMOM
     I          ( P, EXL, REC, NCYL, 1, CLT,
     O            DEF, BM, BMC, BMR                                         )
  400       DO 450 I = 1, NM1
                KPHBR   = NPHBR( I )
            DO 410 J = 1, KPHBR
                PRKT(J) = PRK( I,J )
  410           PRDSTT(J) = PRDST( I,J )
                KRDBR   = NRDBR( I )
            DO 420 J = 1, KRDBR
                RBKT(J) = RBK( I,J )
  420           RBDSTT(J) = RBDST( I,J )
C
C---- >>> CALCULATE CROOKEDNESS ANGLES AT SLIDING CONNECTIONS - THETA'S
C
      CALL THETA
     I          ( KPHBR, KRDBR, STPTB(I), BM(I), PHL(I), SBL(I), PCL(I),
     I            RCL(I), PRKX(I), SPRK(I), RBKY(I), SRBK(I), X(I), Y(I),
     O            TETAF(I), F1(I), F2(I), F3(I), F4(I), FXX, FYY           )
            DO 430 J = 1, KPHBR
  430           FX( I,J ) = FXX( J )
            DO 440 J = 1, KRDBR
  440           FY( I,J ) = FYY( J )
  450       CONTINUE
                KEY     = 1
            IF ( KOUNT - 1 ) 470, 460, 470
  460           KEY     = 2
C
C---- >>> ARE INITIAL AND FINAL THETAS CLOSE?
C
  470       DO 500 I = 1, NM1
                DTETA   = DABS( TETA( I ) / HUNDRD )
                DIFF    = DABS( TETAF( I ) - TETA( I ) )
                TETA(I) = TETAF( I )
            IF ( DIFF - DTETA ) 500, 500, 490
  490           KEY     = 2
  500       CONTINUE
            IF ( KOUNT - 10 ) 520, 520, 550
  520           KOUNT   = KOUNT + 1
            IF ( KEY - 1 ) 550, 550, 220
  550       CONTINUE
      RETURN
      END
```

```
      SUBROUTINE THETA
     I          ( NPHBR, NRDBR, GC, BMG, PHL, SBL, PCL, RCL, PRKX, SPRK,
     I            RBKY, SRBK,
     O            X, Y, TETA, F1, F2, F3, F4, FX, FY                    )
C
C---- >>> SUBROUTINE TO CALCULATE CROOKEDNESS ANGLE AND FORCES AT
C         INTERFACE
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / STFDST / PRK(5), PRDST(5), RBK(5), RBDST(5)
C
      DIMENSION FX( NPHBR ), FY( NRDBR )
C
      DATA ZERO, ONE, TWO / 0.0D00, 1.0D00, 2.0D00 /
C
C---- >>> MONITOR FOR PROPER SIGN
C
            SIGN    = ONE
         IF ( BMG ) 80 , 100, 80
   80       SIGN    = BMG / DABS( BMG )
  100       SRPBK   = SRBK + SPRK
            F1      = ZERO
            F2      = ZERO
            F3      = ZERO
            F4      = ZERO
C
C---- >>> CASE 1:  NO METAL TO METAL CONTACT AT SLIDING CONNECTION
C
            X       = ( RBKY + GC * SRBK - PRKX ) / SRPBK
            Y       = GC - X
         IF ( PCL .EQ. ZERO .AND. RCL .EQ. ZERO ) GO TO 690
            CF      = ZERO
         DO 130 I = 1, NPHBR
  130       CF      = CF + PRK(I) * ( X + PRDST(I) ) * ( X + PRDST(I))
         DO 140 I = 1, NRDBR
  140       CF      = CF + RBK(I) * ( Y + RBDST(I) ) * ( Y + RBDST(I))
            TETA    = BMG / CF
            D1      = ( X + PHL ) * DABS( TETA )
            D2      = ( Y + SBL ) * DABS( TETA )
         IF ( D1 .GE. PCL .AND. D2 .GE. RCL ) GO TO 170
         IF ( D1 - PCL ) 150, 200, 200
  150    IF ( D2 - RCL ) 750, 300, 300
  170       D22     = PCL * ( Y + SBL ) / ( X + PHL )
         IF ( D22 - RCL ) 200, 300, 300
C
C---- >>> CASE 2:  CONTACT AT FRONT FACE OF PISTON HEAD
C
  200       XNUM    = ZERO
            XDEN    = ZERO
            A       = PHL + GC
            B       = DABS( BMG ) / PCL
         DO 210 I = 1, NPHBR
            TEMP    = PRK(I) * ( PHL - PRDST(I) )
            XDEN    = XDEN + TEMP
  210       XNUM    = XNUM + TEMP * PRDST(I)
            XNUM    = - XNUM
         DO 220 I = 1, NRDBR
            TEMP    = RBK(I) * ( A + RBDST(I) )
            XDEN    = XDEN + TEMP
  220       XNUM    = XNUM + TEMP * ( GC + RBDST(I) )
            XNUM    = XNUM - B * PHL
            XDEN    = B + XDEN
            X       = XNUM / XDEN
            Y       = GC - X
            TETA    = PCL / ( X + PHL ) * SIGN
            D3      = DABS( TETA * X )
            D2      = ( Y + SBL ) * DABS( TETA )
         IF ( D3 .GE. PCL .AND. D2 .GE. RCL ) GO TO 270
         IF ( D3 - PCL ) 240, 400, 400
  240    IF ( D2 - RCL ) 250, 600, 600
  250       F1      = TETA * ( RBKY + GC * SRBK - PRKX - X * SRPBK )
         GO TO 750
  270       TETA    = PCL * TWO / PHL
            D2      = ( PHL / TWO + GC + SBL ) * TETA
         IF ( D2 - RCL ) 400, 600, 600
C
C---- >>> CASE 3:  CONTACT AT FRONT FACE OF STUFFING BOX
C
  300       XNUM    = ZERO
            XDEN    = ZERO
            A       = SBL + GC
            B       = DABS( BMG ) / RCL
         DO 310 I = 1, NPHBR
            TEMP    = PRK(I) * ( A + PRDST(I) )
            XDEN    = XDEN + TEMP
  310       XNUM    = XNUM + TEMP * PRDST(I)
            XNUM    = - XNUM
         DO 320 I = 1, NRDBR
            TEMP    = RBK(I) * ( SBL - RBDST(I) )
            XDEN    = XDEN + TEMP
  320       XNUM    = XNUM + TEMP * ( GC + RBDST(I) )
            XNUM    = XNUM + B * A
            XDEN    = B + XDEN
            X       = XNUM / XDEN
            Y       = GC - X
            TETA    = RCL / ( Y + SBL ) * SIGN
            D1      = ( X + PHL ) * DABS( TETA )
            D4      = DABS( TETA * Y )
         IF ( D1 .GE. PCL .AND. D4 .GE. RCL ) GO TO 370
         IF ( D1 - PCL ) 340, 600, 600
  340    IF ( D4 - RCL ) 350, 500, 500
  350       F2      = TETA * ( X * SRPBK - RBKY - GC * SRBK + PRKX )
         GO TO 750
  370       TETA    = RCL * TWO / SBL
            D1      = ( PHL + GC + SBL / TWO ) * DABS( TETA )
         IF ( D1 - PCL ) 500, 600, 600
C
C---- >>> CASE 4:  CONTACT AT FRONT AND BACK FACES OF PISTON HEAD
C
  400       X       = - PHL / TWO
            TETA    = TWO * PCL / PHL * SIGN
            Y       = GC - X
      CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                  FX )
      CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                  FY )
         DO 470 I = 1, NPHBR
            F3      = F3 + FX(I)
```

```
  470           F1      = F1 + FX(I) * PRDST(I)
         DO 480 I = 1, NRDBR
                F3      = F3 - FY(I)
  480           F1      = F1 + FY(I) * ( GC + RBDST(I) )
                F1      = ( BMG - F1 ) / PHL
                F3      = F1 + F3
      RETURN
C
C---- >>> CASE 5:  CONTACT AT FRONT AND BACK FACES OF STUFFING BOX
C
  500           X       = GC + SBL / TWO
                TETA    = TWO * RCL / SBL * SIGN
                Y       = GC - X
      CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                 FX )
      CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                 FY )
         DO 570 I = 1, NPHBR
                F2      = - FX(I) * ( GC + PRDST(I) ) + F2
  570           F4      = - FX(I) + F4
         DO 580 I = 1, NRDBR
                F2      = F2 - FY(I) * RBDST(I)
  580           F4      = F4 + FY(I)
                F2      = ( BMG + F2 ) / SBL
                F4      = F2 + F4
      RETURN
C
C---- >>> CASE 6:  CONTACT AT FRONT FACE OF PISTON HEAD AND FRONT FACE
C                  OF STUFFING BOX
C
  600           TETA    = ( PCL + RCL ) / ( PHL + GC + SBL ) * SIGN
                X       = PCL / CABS( TETA ) - PHL
                Y       = GC - X
      CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                 FX )
      CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                 FY )
         DO 670 I = 1, NPHBR
                F1      = - FX(I) * ( SBL + GC + PRDST(I) ) + F1
  670           F2      = FX(I) + F2
         DO 680 I = 1, NRDBR
                F1      = F1 + FY(I) * ( SBL - RBDST(I) )
  680           F2      = - FY(I) + F2
                F1      = ( BMG + F1 ) / ( PHL + GC + SBL )
                F2      = F1 + F2
      RETURN
  690           TETA    = ZERO
  750 CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                 FX )
      CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                 FY )
      RETURN
      END
```

```
      SUBROUTINE GFORCE
     I                    ( AK, DST, TETA, X, N,
     O                      F )
C
C---- >>> SUBROUTINE TO CALCULATE FORCES ON EACH BEARING
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      DIMENSION AK(N), DST(N), F(N)
C
         DO 10 I = 1, N
                F(I)    = AK(I) * ( X + DST(I) ) * TETA
   10    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MTRXOP
     I          ( P, EXL, REC, TETA, NTEMP, NM1,
     O            THC, THR, S, R                                  )
C
C---- >>> SUBRCUTINE TC FURM S & R MATRICES IN S * U = R ANC SOLVE FOR U
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / CANODS / C( 10 ), D( 10 )
      COMMON / CKCLTW / CK( 10 ), CLT( 10 ), W( 9 )
      COMMON / CYLWT  / WC(10), EEL, FFL
      COMMON / ECCENT / ECLC, ECLR
      COMMON / FCSSTF / FCCY, FCRD, CSSTF, RSSTF, CONM
C
      DIMENSION S( NTEMP, NTEMP ), R( NTEMP ), TETA( NM1 )
C
      DATA ZERO, ONE, TWO / 0.0D00, 1.0D00, 2.0D00 /
C
                NCYL    = NM1 + 1
C
C---- >>> SET MATRICES INITIALLY TC ZERO
C
          DO 50 I = 1, NTEMP
                R( I ) = ZERC
          DO 50 J = 1, NTEMP
   50           S(I,J) = ZERO
C
C---- >>> FORMULATE S MATRIX
C
          DO 100 I = 1, NCYL
                A       = CK( I ) * CLT( I )
                J       = I * 2
                S(J+1,J) = DCOS( A )
                S(J+1,J+1) = DSIN( A )
          IF ( I - 1 ) 100, 100, 90
   90           A       = CK( I )  * CLT( I-1 )
                S(J-1,J) = - DCOS( A )
                S(J-1,J+1) = - DSIN( A )
                S(J,J) = CK ( I ) * DSIN( A )
                S(J,J+1) = - CK( I ) * DCOS ( A )
                A       = CK( I-1 ) * CLT( I-1  )
                S(J,J-2) = - CK( I-1 ) * DSIN( A )
                S(J,J-1) = CK( I-1 ) * DCOS( A )
  100     CONTINUE
                J       = NCYL * 2
                DEN     = P * EXL
                S(1,1) = ONE + CSSTF / DEN
                S(1,3) = - CK( 1 )
                S(1,J+2) = - RSSTF / DEN
                S(2,1) = CSSTF / P
                S(2,2) = ONE
                S(J+1,J+2) = RSSTF / P
                S(J+2,1) = CSSTF / DEN
                A       = CK( NCYL ) * CLT( NCYL )
                S(J+2,J) = CK( NCYL )  * DSIN( A )
                S(J+2,J+1) = - CK( NCYL )  * DCOS( A )
                S (J+2,J+2) = ONE - RSSTF / DEN
C
C---- >>> FORMULATE R MATRIX
C
                R( 1 ) = FFL - EEL - REC / P
                R( 2 ) = ECLC - FCCY - CONM / P + WC(1)/(P*CK(1)*CK(1) )
                R(J+1) = ECLR - FCRD - CONM / P + REC * EXL / P
     1                   -WC(1) * CLT(1) * ( EXL - CLT(1) / TWC ) / P
     2                   +WC(NCYL) / ( P * CK(NCYL) * CK(NCYL) )
                R(J+2) = FFL - EEL - REC / P + WC(1) * CLT(1) / P
          DO 200 I = 2, NCYL
                CLC1   = CLT( I ) - CLT( I-1  )
                CLC2   = EXL -  ( CLT( I ) + CLT( I-1 ) ) / TWO
                R(J+1) = R(J+1) - WC(I) * CLC1 * CLC2 / P
     1                   - W( I-1 ) * ( EXL - CLT( I-1 ) ) / P
                R(J+2) = R(J+2 ) + WC( I ) * CLC1 / P + W( I-1 ) / P
                K      = I * 2
                R( K ) = TETA( I-1 ) + W( I-1 ) / P
                R(K-1) = (WC(I-1)/(CK(I-1) *CK(I-1) )
     1                   - WC( I ) / ( CK( I ) * CK( I ) ) ) / P
  2C0     CCNTINUE
C
C---- >>> SOLVE FOR UNKNOWN VECTCR U
C
      CALL SIMSOL ( S, R, NTEMP          )
                THC    = R( 1 )
                THR    = R( J + 2 )
          DO 300 I = 1, NCYL
                K      = I * 2
                C( I ) = R( K )
                D( I ) = R( K + 1 )
  300     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SIMSOL ( S, R, N                    )
C
C---- >>> SUBROUTINE TO SOLVE FOR U VECTOR IN S * U = R
C          USING GAUSS ELIMINATION
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
C
      DIMENSION S( N, N ), R( N )
C
C---- >>> FORMULATE UPPER TRIANGULAR MATRIX
C
          DO 130 I = 1, N
               TEMP   = S( I,I )
          DO 100 J = 1, N
               S(I,J) = S( I,J ) / TEMP
  100     CONTINUE
               R( I ) = R( I ) / TEMP
          IF ( I .EQ. N ) GO TO 130
               IP1    = I + 1
          DO 120 J = IP1, N
               HOLD   = S( J,I )
          DO 110 K = I, N
               S(J,K) = S( J,K ) - HOLD * S( I,K )
  110     CONTINUE
               R( J ) = R( J ) -  HOLD * R( I )
  120     CONTINUE
  130     CONTINUE
C
C---- >>> BACK SUBSTITUTION
C
          DO 150 I = 2, N
               II     = N + 1 - I
               M      = II + 1
          DO 150 J = M, N
               R(II)  = R( II ) - S( II,J ) * R( J )
  150     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DEFMOM
     I          ( P, EXL, REC, NCYL, IDEN, XL,
     O            DEF, BM, BMC, BMR                              )
C
C---- >>> SUBROUTINE TO CALCULATE DEFLECTIONS AND BENDING MOMENTS AT
C          INPUT LENGTHS XL'S, AND BENDING MOMENTS AT SUPPORTS
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / CANDDS / C( 10 ), D( 10 )
      COMMON / CKCLTW / CK( 10 ), CLT( 10 ), W( 9 )
      COMMON / CYLWT  / WC(10), EEL, FFL
      COMMON / ECCENT / ECLC, ECLR
      COMMON / FCSSTF / FCCY, FCRD, CSSTF, RSSTF, CONM
      COMMON / SPRMOM / AKTHC, AKTHR
C
      DIMENSION DEF(NCYL), BM(NCYL), XL(NCYL)
C
      DATA ZERO, TWO / 0.0D00, 2.0D00 /
C
               YCON1  = ( EEL - FFL ) * P + ( AKTHC - AKTHR ) / EXL +REC
               YCON2  = CONM + P * ( FCCY - ECLC ) + AKTHC
               MM     = NCYL
          IF ( IDEN .EQ. 1 ) MM = NCYL - 1
          DO 200 I = 1, MM
               A      = CK( I ) * XL( I )
               A      = C( I ) * DCOS( A ) + D( I ) * DSIN( A )
          IF ( I .GT. 1 ) GO TO 100
               B      = YCON1 * XL(I) - YCON2 - WC(I)*XL(I)*XL(I) / TWO
          GO TO 150
  100          K      = I - 1
               B      = ZERO
          IF ( K .EQ. 1 ) GO TO 130
          DO 120 J = 2, K
               N      = J - 1
  120          B      = B + WC( J ) * (CLT( J ) - CLT( N ) )
     1                  *(XL(I)-(CLT(J)+CLT(N))/TWO)+W(J)*(XL(I)-CLT(J))
  130          B      = -B + YCON1 * XL( I ) - YCON2
     1                  -WC(1)*CLT(1)*(XL(I)-CLT(1)/TWO )
     2                  -WC(I)*(XL(I)-CLT(K))*(XL(I)-CLT(K))/ TWO
     3                  -W( 1 ) * ( XL( I ) - CLT( 1 ) )
  150          DEF(I) = A - B/ P - WC(I ) / ( P * CK( I ) * CK( I ) )
               BM(I)  = B + P * DEF( I )
  200     CONTINUE
               BMR    = P * ( FCRD - ECLR ) + AKTHR
          IF ( IDEN - 1 ) 300, 300, 250
  250          BMC    = YCON2
      RETURN
  300          DEF(NCYL) = ZERO
               BM(NCYL) = BMR
      RETURN
      END
```

```
      SUBROUTINE XATYMX
     I          ( NCYL, DEF, BM, EXL, REC, P,
     O            XL                                                   )
C
C---- >>> SUBROUTINE TO CALCULATE DISTANCES AT WHICH MAXIMUM BENDING
C          MOMEMTS OCCUR IN EACH TUBE
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / CANDDS / C( 10 ), D( 10 )
      COMMON / CKCLTW / CK( 10 ), CLT( 10 ), W( 9 )
      COMMON / CYLWT  / WC(10), EEL, FFL
      COMMON / SPRMOM / AKTHC, AKTHR
C
      DIMENSION DEF(NCYL), BM(NCYL), XL(NCYL)
C
      DATA ZERO, FIFTY / 0.0D00, 50.0D00 /
C
                XINCR  = EXL / ( NCYL * FIFTY )
      CALL SLOPE ( EXL, REC, P, ZERO, 1,              SB               )
          DO 600 I = 1, NCYL
          IF ( I - 1 ) 10, 20, 10
   10 CALL SLOPE ( EXL, REC, P, CLT(I-1), I,          SB               )
   20 CALL SLOPE ( EXL, REC, P, CLT(I), I,            SF               )
                XL(I)  = CLT( I )
                DF     = DEF( I )
                DB     = ZERO
          IF ( I - 1 ) 50, 50, 40
   40           DB     = DEF( I - 1 )
   50     IF ( DB .GE. ZERO .AND. DF .GE. ZERO ) GO TO 130
          IF ( DB .LE. ZERO .AND. DF .LE. ZERO ) GO TO 120
          IF ( ( SB .LE. ZERO .AND. SF .LE. ZERO ) .OR.
     1          ( SB .GE. ZERO .AND. SF .GE. ZERO ) ) GO TO 100
          GO TO 260
  100     IF ( DABS( BM(I) ) .LT. DABS( BM(I-1) ) ) XL( I ) = CLT( I-1 )
          GO TO 500
  120     IF ( SB .LE. ZERO .AND. SF .LE. ZERO ) GO TO 500
          IF ( SB .GE. ZERO .AND. SF .GE. ZERO ) GO TO 140
          GO TO 260
  130     IF ( SB .GE. ZERO .AND. SF .GE. ZERO ) GO TO 500
          IF ( SB .LE. ZERO .AND. SF .LE. ZERO ) GO TO 140
          GO TO 260
  140           XL(I)  = CLT( I-1 )
          GO TO 500
  260           XL(I)  = XL(I) - XINCR
      CALL SLOPE ( EXL, REC, P, XL(I), I,             SI               )
          IF ( ( SI .GE. ZERO .AND. SF .GE. ZERO ) .OR.
     1          ( SI .LE. ZERO .AND. SF .LE. ZERO ) ) GO TO 260
  500     CONTINUE
  600     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SLOPE
     I          ( EXL, REC, P, XL, I,                 SL               )
C
C---- >>> SUBROUTINE TO CALCULATE THE SLOPE AT INPUT DISTANCE XL FROM
C          CYLINDER SUPPORT
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / CANDDS / C( 10 ), D( 10 )
      COMMON / CKCLTW / CK( 10 ), CLT( 10 ), W( 9 )
      COMMON / CYLWT  / WC(10), EEL, FFL
      COMMON / SPRMOM / AKTHC, AKTHR
C
                YCON1  =  -EEL + FFL - (( AKTHC - AKTHR )/ EXL + REC ) /P
                A      = CK( I ) * XL
                A      = -C(I) * CK(I) * DSIN(A) + D(I) * CK(I) * DCOS(A)
          IF ( I - 2 ) 10, 20, 30
   10           SL     = A + YCON1 + WC( 1 ) * XL / P
      RETURN
   20           SL     = A + YCON1 + W( 1 ) / P
     1                   + ( WC( 1 ) *CLT( 1 ) + WC(2)*(XL-CLT(1)) ) / P
      RETURN
   30           IM1    = I - 1
                CON    = W( 1 )
          DO 60 J = 2, IM1
   60           CON    = WC( J ) * ( CLT(J) - CLT(J-1)) + W(J) + CON
                CON    = ( CON + WC(I)*( XL - CLT(I-1))+WC(1)*CLT(1)) / P
                SL     = A + YCON1 + CON
      RETURN
      END
```

```
      SUBROUTINE STRCHS
     I          ( NCYL, P, BM, CHDS, LFLUID, BMR, BMC, FYCYLT, CIDN,
     I            PINCR1, PINCR2, KEYF, KEYST, KEYT, KEYP                 )
C
C---- >>> SUBROUTINE TO CHECK THE MAXIMUM STRESSES WITH THE LIMITING
C          STRESSES
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / CRPROP / CYZ(10), CYZI(10), BAREA(10), CAREA(10),
     1                  HSCI(10), HSCO(10)
      COMMON / STRESS / TLSTO(10), HSI(10), SSO(10), SSI(10),
     1                  TLSRPO, TLSCPO, AXSOH, PRE
C
      DIMENSION BM(NCYL), FYCYLT(NCYL)
C
      DATA ZERO, TWO / 0.0D00, 2.0D00 /
      DATA LYES / 3HYES /
C
C
C---- >>> CALCULATE ALL STRESSES
C
              NM1     = NCYL - 1
              PRE     = P / BAREA( NM1 )
          DO 50 I = 1, NM1
              AXSTR   = ( BAREA(I) - BAREA(NM1) ) * PRE / CAREA( I )
              HSI(I)  = HSCI( I ) * PRE
              HSO     = HSCO( I ) * PRE
              BSTRO   = DABS( BM( I ) ) / CYZ( I )
              BSTRI   = DABS( BM( I ) ) / CYZI( I )
              TLSTO(I) = AXSTR + BSTRO
              SSO(I)  = ( HSO + BSTRO - AXSTR ) / TWO
              SSI(I)  = ( HSI( I ) + BSTRI - AXSTR ) / TWO
   50     CONTINUE
              AXSTR   =   ( P - PRE * BAREA( NCYL ) ) / CAREA( NCYL )
          IF ( CHDS ) 70, 60, 60
   60         AXSCH   = ZERO
          GO TO 80
   70         AXSOH   = PRE * BAREA( 1 ) / CAREA( 1 )
   80     IF ( LFLUID .EQ. LYES ) GO TO 90
              HSI(NCYL) = ZERO
              HSO     = ZERO
          GO TO 100
   90         HSI(NCYL) = HSCI( NCYL ) * PRE
              HSO     = HSCO( NCYL ) * PRE
  100         BSTRO   = DABS( BM( NCYL ) ) / CYZ( NCYL )
              BSTRI   = ZERO
          IF ( CIDN .GT. ZERO ) BSTRI = DABS( BM( NCYL ) ) / CYZI( NCYL)
              TLSTO(NCYL) = AXSTR + BSTRO
              SSO(NCYL) = ( HSO + BSTRO + AXSTR ) / TWO
              SSI(NCYL) = ( HSI( NCYL ) + BSTRI + AXSTR ) / TWO
              BSRPO   = DABS( BMR ) / CYZ( NCYL )
              TLSRPO = AXSTR + BSRPO
              BSCPO   = DABS( BMC ) / CYZ( 1 )
              AXSTR   = ( BAREA( 1 ) - BAREA( NM1 ) ) * PRE / CAREA( 1 )
              TLSCPO = AXSTR + BSCPO
          IF ( KEYF - 1 ) 320, 300, 320
  300     IF ( KEYST - 1 ) 320, 340, 320
  320         KEYF    = 3
      RETURN
C
C---- >>> CHECK WITH LIMITING STRESSES
C
  340     DO 500 I = 1, NCYL
              STRMX   = DMAX1( HSI(I), TLSTO(I), SSO(I)*TWO, SSI(I)*TWO)
          IF ( STRMX - FYCYLT(I) ) 500, 500, 600
  500     CONTINUE
          IF ( TLSCPO - FYCYLT( 1 ) ) 510, 510, 600
  510     IF ( TLSRPO - FYCYLT( NCYL ) ) 520, 520, 600
C
C---- >>> CHANGE THE TRIAL LOAD CORRESPONDINGLY
C
  520     IF ( KEYT - 2 ) 530, 540, 530
  530         P       = P + PINCR1
      RETURN
  540         P       = P + PINCR2
              KEYP    = 2
      RETURN
  600     IF ( KEYP - 2 ) 620, 640, 620
  620         P       = P - PINCR1
              KEYT    = 2
      RETURN
  640         P       = P - PINCR2
              KEYF    = 2
      RETURN
      END
```

```
      SUBROUTINE OUTPUT
     I          ( P, XL, DEF, CHDS, THC, NCYL, TETA, KWIT, NM1             )
C
C---- >>> SUBROUTINE TO PRINT ALL THE RESULTS
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / ENDS   / LCEND, LREND
      COMMON / GLDFOR / FX(9,5), FY(9,5), F1(9), F2(9), F3(9), F4(9)
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
      COMMON / NBEARS / NPHBR(9), NRDBR(9)
      COMMON / OPFSTP / FYCYL(10), OPPRE, FS, LFSTP
      COMMON / STRESS / TLSTO(10), HSI(10), SSO(10), SSI(10),
     1                  TLSRPO, TLSCPC, AXSOH, PRE
      COMMON / UNITS  / LNTU, LODU, LPREU, LANGU
C
      DIMENSION XL(NCYL), DEF(NCYL), TETA(NM1)
C
      DATA ZERO, TWO, H180 / 0.0D00, 2.0D00, 180.0D00 /
      DATA PI / 3.1415926535897930D00 /
      DATA LDEG, LFIX / 4HDEG , 3HFIX /
      DATA LIS, LOS / 2HIS, 2HOS /
      DATA LRAD / 4HRAD  /
C
C---- >>> FORMATS
C
  110 FORMAT ( // 5X,47HANALYSIS AFTER APPLYING GIVEN FACTOR OF SAFETY ,
     1                3HOF , F6.3, 2X, 2HON, 2X, A4, 2H: , /               )
  120 FORMAT ( // 5X,40HRESULTS:          CRITICAL LOAD ANALYSIS, /        )
  130 FORMAT ( // 5X,44HRESULTS:      ANALYSIS FOR A GIVEN OPERATING ,
     1                8HPRESSURE, /                                        )
  140 FORMAT (  /10X,33HCRITICAL LOAD FOR THE CYLINDER = ,1PD10.3,2X,A4,
     1         //10X,33HCORRESPONDING MAXIMUM PRESSURE = ,1PD10.3,2X,A4)
  160 FORMAT (  /10X,33HOP5RATING PRES OF THE CYLINDER = ,1PD10.3,2X,A4,
     1         //10X,33HCORRESPONDING LOAD             = ,1PD10.3,2X,A4)
  180 FORMAT ( // 5X,48HNOTES FOR THE FOLLOWING TABLES:
     1         //10X,48H1  THE NUMBERS IN PARENTHESES ARE FACTORS OF
     2          /10X,48H   SAFETY AGAINST CORRESPONDING STRESSES
     3         //10X,48H2  DEFLECTION, LONGITUDINAL STRESS, AND SHEAR
     4          /10X,48H   STRESS VALUES ARE AT CRITICAL SECTION
     5         //10X,48H3  MAX LONGITUDINAL STRESS IS AT OUTER SURFACE
     6          /10X,47H   AND MAX HOOP STRESS IS AT INNER SURFACE       )
  190 FORMAT (  /10X,48H4  HOOP STRESS AT ANY RADIAL DIST. IS CONSTANT
     1          /10X,48H   ALONG THE LENGTH OF THE TUBE
     2         //10X,48H5  CODE "IS" MAX SHEAR STRESS IS AT INNER FACE
     3          /10X,48H   CODE "OS" MAX SHEAR STRESS IS AT OUTER FACE
     4         //10X,48H6  ZERO METAL TO METAL CONTACT FORCES INDICATE
     5          /10X,47H   NO CONTACT                                    )
  200 FORMAT (        1H1                                                )
  240 FORMAT ( //10X,20H * * * * * * * * * *
     1               34H TABLE OF STRESSES AND DEFLECTIONS
     2               20H * * * * * * * * * *                             )
  260 FORMAT ( //10X,48HTUBE  CRIT SECTION   DEFLECTION   LONGITUDINAL
     1               48H   SHEAR   CODE      HOOP
     2          /10X,48H NO.  FROM CYL END                        STRESS
     3               47H   STRESS              STRESS                    )
  280 FORMAT (  /21X, 4( A4, 10X ), 2X, A4                               )
  300 FORMAT (  /11X, I2, 4( 4X, 1PD10.3 ), 1X, A2, 3X, 1PD10.3          )
  320 FORMAT (   44X, 2( 1H(, 1PD10.3, 1H), 2X ), 2X, 1H(, 1PD10.3, 1H))
```

```
  330 FORMAT (   44X, 2( 1H(, 1PD10.3, 1H), 2X )                         )
  340 FORMAT ( //10X,48HMAX LONGITUDINAL STRESS AT CYLINDER FIXED END =
     1                 2X, 1PD10.3, 2X, A4,
     2         //10X,48HFACTOR OF SAFETY AT THIS STRESS                 =
     3                 2X, 1PD10.3                                       )
  360 FORMAT ( //10X,48HMAX LONGITUDINAL STRESS AT ROD FIXED END        =
     1                 2X, 1PD10.3, 2X, A4,
     2         //10X,48HFACTOR OF SAFETY AT THIS STRESS                 =
     3                 2X, 1PD10.3                                       )
  380 FORMAT ( //10X,48HUNIFORM AXIAL TENSILE STRESS IN OVERHANG        =
     1                 2X, 1PD10.3, 2X, A4,
     2         //10X,48HFACTOR OF SAFETY AT THIS STRESS                 =
     3                 2X, 1PD10.3,
     4         //10X,48HEND DEFLECTION OF THE OVERHANG                  =
     5                 2X, 1PD10.3, 2X, A4, /                            )
  400 FORMAT (   10X,14H * * * * * * *
     1               46HTABLE OF CROOKEDNESS ANGLES AND BEARING FORCES
     2               14H * * * * * * *                                   )
  420 FORMAT ( //10X,43HINTERFACE  CROOKEDNESS ANGLE                 ,
     1               19HFORCES AT INTERFACE                              )
  440 FORMAT (   13X,20HNO.            DEGREES, 28X, A4                  )
  460 FORMAT (   13X,20HNO.            RADIANS, 28X, A4                  )
  480 FORMAT (  /13X, I2, 8X, 1PD12.5                                    )
  500 FORMAT (1H+40X,30HON PISTON HEAD BEARING NO.     ,
     1               10( I1, 3H = , 1PD10.3, /, 71X )                    )
  520 FORMAT (   41X,30HON ROD BEARING NO.             ,
     1               10( I1, 3H = , 1PD10.3, /, 71X )                    )
  540 FORMAT (   41X,34HMETAL TO METAL CONTACT FORCES -    ,
     1        //41X,34HF1 - AT PISTON HEAD FRONT FACE  = , 1PD10.3,
     2         /41X,34HF2 - AT STUFFING BOX FRONT FACE = , 1PD10.3,
     3         /41X,34HF3 - AT PISTON HEAD BACK FACE   = , 1PD10.3,
     4         /41X,34HF4 - AT STUFFING BOX INNER FACE = , 1PD10.3     )
C
C---- >>> PRINT ALL RESULTS
C
      CALL TITLE
          IF ( KWIT - 1 ) 1020, 1020, 1000
 1000 PRINT 110, FS, LFSTP
      PRINT 140, P, LODU, PRE, LPREU
          GO TO 1200
 1020     IF ( LPRTP - 1 ) 1060, 1060, 1100
 1060 PRINT 120
      PRINT140, P, LODU, PRE, LPREU
          GO TO 1200
 1100 PRINT 130
      PRINT 160, OPPRE, LPREU, P, LODU
 1200     CONTINUE
      PRINT 180
      PRINT 190
      PRINT 240
      PRINT 260
      PRINT 280, LNTU, LNTU, LPREU, LPREU, LPREU
          DO 1600 I = 1, NCYL
          IF ( SSO( I ) - SSI( I ) ) 1300, 1300, 1400
 1300         SS      = SSI( I )
              KODE    = LIS
          GO TO 1500
 1400         SS      = SSO( I )
```

```
                KODE    = LOS
C
C----- >>> CALCULATE THE FACTOR OF SAFETY'S ON MAXIMUM STRESSES WITH
C          LIMITING STRESSES AND PRINT
C
 1500           FSLS    = FYCYL( I ) / TLSTO( I )
                FSSS    = FYCYL( I ) / ( TWO * SS )
          IF ( HSI( I ) .LE. ZERO ) GO TO 1550
                FSHS    = FYCYL( I ) / HSI( I )
      PRINT 300, I, XL(I), DEF(I), TLSTO(I), SS, KODE, HSI(I)
      PRINT 320, FSLS, FSSS, FSHS
          GO TO 1600
 1550 PRINT 300, I, XL(I), DEF(I), TLSTO(I), SS, KODE
      PRINT 330, FSLS, FSSS
 1600     CONTINUE
          IF ( TLSCPO ) 1620, 1630, 1620
 1620           FSCP    = FYCYL( 1 ) / TLSCPO
          IF ( LCEND .EQ. LFIX ) PRINT 340, TLSCPO, LODU, FSCP
 1630     IF ( TLSRPO ) 1640, 1650, 1640
 1640           FSRP    = FYCYL( NCYL ) / TLSRPO
          IF ( LREND .EQ. LFIX ) PRINT 360, TLSRPO, LODU, FSRP
 1650     IF ( CHDS ) 1660, 1680, 1680
 1660           FCSF    = FYCYL( 1 ) / AXSOH
                ENDDF   = THC * CHDS
      PRINT 380, AXSOH, LPREU, FCSF, ENDDF, LNTU
 1680 PRINT 200
      PRINT 400
      PRINT 420
          IF ( LANGU .EQ. LDEG ) PRINT 440, LODU
          IF ( LANGU .EQ. LRAD ) PRINT 460, LODU
                TEMP    = H180 / PI
                NM1     = NCYL - 1
          DO 1700 I = 1, NM1
                THETA   = TETA( I )
          IF ( LANGU .EQ. LDEG ) THETA = TETA( I ) * TEMP
      PRINT 480, I, THETA
                NL      = NPHBR( I )
      PRINT 500, ( J, FX( I,J ), J = 1, NL )
                NL      = NRDBR( I )
      PRINT 520, ( J, FY( I,J ), J = 1, NL )
      PRINT 540, F1( I ), F2( I ), F3( I ), F4( I )
 1700     CONTINUE
      RETURN
      END
```

```
      00000000011111111112222222222333333333344444444445555555555666666666677777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
   1  EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
   2  CODED  JUNE 9, 1976   BY   K. L. SESHASAI
   3  TEL1      LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER; EQUIVALENT TO PROB. REG1
   4      1
   5            INCH      KIPS      KSI       DEG
   6      2     50.0      116.71    3.0       0.76      4.75      4.75
   7  60.57     7.0       6.0       0.0032    29000.0   125.0
   8  62.95     3.0       0.0       0.002     29000.0   125.0
   9      1    3    1     0.0       0.0       0.0       0.0
  10  6.13      4.44      0.05      0.07      5.939     3.009
  11  0.316     0.451     500.0               2.375
  12  0.365     0.25      1000.0              3.9
  13  0.316     0.451     500.0               5.45
  14  0.35      0.2       750.0               3.15
  15  0.0                           PIN  PIN  +0.025    +0.025    +0.1      +0.12
  16  2.0       LOAD
  17  TEL2      LPRTP=1; P-F; HOLLOW ROD WITH NO FLUID; VERTICAL CYLINDER.
  18      1     KEEP
  19      3     66.0      129.76    3.0       0.76      2.0       1.0
  20  46.94     7.0       6.025     0.0032    29000.0   100.0
  21  52.13     4.75      4.0       0.0022    29000.0   100.0
  22  45.5      3.0       1.5       0.002     29000.0   100.0               NO
  23      1    3    1               0.003
  24  6.13      4.44      0.04      0.06      6.014     4.76
  25                                2100.0    2.375
  26                                8800.0    3.9
  27                                2100.0    5.45
  28                                3900.0    3.15
  29      2    2    1                         0.009     0.008
  30  4.0       4.0       0.03      0.04
  31  0.316     0.3       500.0               1.0
  32  0.316     0.3       500.0               2.375
  33  0.45      0.2       500.0               2.5
  34  90.0                          PIN  FIX  -0.05               +0.1      -0.05
  35  4.0       STRS
  36  TEL3      LPRTP=1; F-F; SOLID ROD; 30 DEG INCLINED.
  37      1
  38            INCH      LBS       PSI       DEG
  39      4     90.0      144.0     4.0       1.0
  40  37.0      8.0       7.0       3.9       29000000. 75000.0
  41  42.0      6.25      5.5       2.8       29000000. 75000.0
  42  45.0      4.75      4.0       2.5       29000000. 75000.0
  43  45.0      3.0       0.0       2.0       29000000. 125000.0
  44      1    2    1     1.0       0.002     0.005     0.004
  45  5.0       5.0       30.0      40.0
  46                                2100000.0 2.375
  47                                8800000.0 3.9
  48  0.35      0.2       750000.0            1.75
  49      2    2    1     1.0       0.001     0.005     0.005
  50  4.0       4.0       25.0      35.0
  51                                2100000.0 1.75
  52                                8800000.0 2.9
  53                                4000000.0 2.0
  54      3    2    1     2.0       0.001     0.005     0.008
```

```
      00000000011111111112222222222333333333344444444445555555555666666666677777777778
      12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
  55  4.0       4.0       35.0      30.0
  56                                3000000.0 1.75
  57                                8000000.0 2.9
  58                                4000000.0 2.5
  59  30.0                          FIX  FIX                      -0.05     -0.025
  60
  61  TEL4      LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER WITH A OVERHANG.
  62      1
  63            INCH      KIPS      KSI       RAD
  64      3     64.0      101.0     -11.0     1.0       2.0       1.0
  65  40.0      6.25      5.5       0.0028    29000.0   75.0
  66  45.0      4.75      4.0       0.0025    29000.0   75.0
  67  45.0      3.0       0.0       0.002     29000.0   100.0
  68      1    2    1     1.0       0.001
  69  4.0       4.0       0.025     0.035     5.495     4.755
  70                                2100.0    1.75
  71                                8800.0    2.9
  72                                4000.0    2.0
  73      2    2    1     2.0       0.001     0.005     0.008
  74  4.0       4.0       0.035     0.03
  75                                3000.0    1.75
  76                                8000.0    2.9
  77                                4000.0    2.5
  78  0.0                           PIN  PIN  +0.05                         +0.1
  79  1.0       LOAD
  80  TEL5      LPRTP=2; F-P; HOLLOW ROD WITH FLUID; INCLINED CYL; METRIC UNITS.
  81      2
  82            CM        KGS       KSCM      RAD
  83      3     165.0     294.0     9.0       2.5                 3.0
  84  102.5     16.0      14.0      1.5       2100000.0 7050.0
  85  113.5     12.0      10.0      1.3       2100000.0 7050.0
  86  114.0     8.0       5.0       1.2       2100000.0 8800.0              YES
  87      1    2    1     2.5       0.005     0.01      0.01
  88  10.0      10.0      15.0      18.0
  89  0.8       0.25      35000.0             3.5
  90  0.8       0.25      35000.0             8.0
  91  0.8       0.25      50000.0             7.0
  92      2    2    1     5.0       0.005
  93  10.0      10.0      15.0      16.0      9.99      8.01
  94                                375000.0  3.5
  95                                375000.0  8.0
  96                                500000.0  7.0
  97  0.75                          FIX  PIN            -0.05               +0.1
  98                      175.0
  99            THIS IS A BLANK CARD
```

```
PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )       DATE:  8/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TEL1:

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER; EQUIVALENT TO PROB. REG1

INPUT DATA:

TABLE 1:     CONTROL DATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD

             TABLES RETAINED FROM PREVIOUS PROBLEM

               2     3     4     5     6     7

                 NO KEEP OPTIONS EXERCISED


TABLE 2:     UNITS OF MEASUREMENT

            LENGTH      LOAD     PRESSURE   ANGULAR

             INCH       KIPS       KSI        DEG


TABLE 3:     STROKE AND EXTENDED LENGTHS AND END DIMENSIONS

         NUMBER OF TUBES( INCLUDING ROD ) =  2
         STROKE LENGTH                    =  5.00000D 01
         EXTENDED LENGTH                  =  1.16710D 02

         CYL. HINGE DIST. FROM END PLATE  =  3.00000D 00
         END PLATE THICKNESS              =  7.60000D-01

         CYLINDER PIN DIAMETER            =  4.75000D 00
         ROD PIN DIAMETER                 =  4.75000D 00

TABLE 4:     TUBE DIMENSIONS AND MATERIAL PROPERTIES

     NO.    LENGTH      OUTER DIA    INNER DIA   WT/UNIT LNT.  YOUNGS MOD   YIELD STRS

      1   6.05700D 01  7.00000D 00  6.00000D 00  3.20000D-03  2.90000D 04  1.25000D 02
      2   6.29500D 01  3.00000D 00  0.0          2.00000D-03  2.90000D 04  1.25000D 02
                                ( SOLID ROD )
```

```
TABLE 5:     INTERFACE DIMENSIONS AND DETAILS OF BEARINGS

    DETAILS AT INTERFACE NUMBER    =  1

        NUMBER OF PISTON BEARINGS               =  3
        NUMBER OF ROD BEARINGS                  =  1

        LENGTH OF STOP TUBE                     =  0.0
        CLEARANCE BETWEEN CYL & STUFFING BOX =  0.0

                             LENGTH       DIAMETER      CLEARANCE       WEIGHT
                                        (ONE OF THESE TWO IS INPUT)

           PISTON HEAD    6.13000D 00   5.98900D 00   0.0            5.00000D-02

           STUFFING BOX   4.44000D 00   3.00900D 00   0.0            7.00000D-02

        PISTON BEARINGS:
                                                                       DISTANCE FROM
        NO.     WIDTH       THICKNESS  YOUNGS MODULUS   STIFFNESS     BACK FACE OF
                                                                       PISTON HEAD

         1   3.16000D-01  4.51000D-01   5.00000D 02   0.0             2.37500D 00
         2   3.65000D-01  2.50000D-01   1.00000D 03   0.0             3.90000D 00
         3   3.16000D-01  4.51000D-01   5.00000D 02   0.0             5.45000D 00

        ROD BEARINGS   :
                                                                       DISTANCE FROM
        NO.     WIDTH       THICKNESS  YOUNGS MODULUS   STIFFNESS     BACK FACE OF
                                                                       STUFFING BOX

         1   3.50000D-01  2.00000D-01   7.50000D 02   0.0             3.15000D 00

            (NOTE:  EITHER WIDTH, THICKNESS, YOUNGS MODULUS OR STIFFNESS IS INPUT.
                    ZERO'S INDICATE THAT THEY ARE NOT INPUT. )

TABLE 6:     INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

    CYL INCLINATION WITH HORIZONTAL =  0.0

                                             CYLINDER END     ROD END

    SUPPORT CONDITIONS:                          PIN             PIN

    FRICTION COEFFICIENTS AT SUPPORTS:    2.50000D-02   2.50000D-02
         (ZERO IF FIXED END)
    LOADING ECCENTRICITIES:               1.00000D-01   1.20000D-01

TABLE 7:     FACTOR OF SAFETY, ITS TYPE OR OPERATING PRESSURE


    FACTOR OF SAFETY =  2.000 ON LOAD
```

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PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )       DATE:  8/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TEL1:

  LPRTP=1; P-P: SOLID ROD; HORIZONTAL CYLINDER; EQUIVALENT TO PROB. REG1

RESULTS:            CRITICAL LOAD ANALYSIS


    CRITICAL LOAD FOR THE CYLINDER =  1.281D 02  KIPS

    CORRESPONDING MAXIMUM PRESSURE =  4.532D 00  KSI

NOTES FOR THE FOLLOWING TABLES:

    1  THE NUMBERS IN PARENTHESES ARE FACTORS OF
       SAFETY AGAINST CORRESPONDING STRESSES

    2  DEFLECTION, LONGITUDINAL STRESS, AND SHEAR
       STRESS VALUES ARE AT CRITICAL SECTION

    3  MAX LONGITUDINAL STRESS IS AT OUTER SURFACE
       AND MAX HOOP STRESS IS AT INNER SURFACE

    4  HOOP STRESS AT ANY RADIAL DIST. IS CONSTANT
       ALONG THE LENGTH OF THE TUBE

    5  CODE "IS" MAX SHEAR STRESS IS AT INNER FACE
       CODE "CS" MAX SHEAR STRESS IS AT OUTER FACE

    6  ZERO METAL TO METAL CONTACT FORCES INDICATE
       NO CONTACT

   * * * * * * * * * * TABLE OF STRESSES AND DEFLECTIONS * * * * * * * * * *

  TUBE  CRIT SECTION   DEFLECTION   LONGITUDINAL     SHEAR    CODE     HOOP
   NO.  FROM CYL END                   STRESS        STRESS            STRESS

            INCH          INCH          KSI           KSI               KSI

   1     5.898D 01     1.908D 00     1.671D 01     2.198D 01 IS     2.963D 01
                                   ( 7.481D 00)  ( 2.844D 00)     ( 4.218D 00)

   2     7.003D 01     2.077D 00     1.237D 02     6.184D 01 OS
                                   ( 1.011D 00)  ( 1.011D 00)
```

```
 * * * * * * *TABLE OF CROOKEDNESS ANGLES AND BEARING FORCES * * * * * * *

INTERFACE  CROOKEDNESS ANGLE                   FORCES AT INTERFACE
   NO.         DEGREES                                KIPS

   1          4.79133D-02      ON PISTON HEAD BEARING NO.     1 =   2.520D 00
                                                              2 =   2.167D 01
                                                              3 =   7.925D 00

                               ON ROD BEARING NO.             1 =   1.347D 01

                               METAL TO METAL CONTACT FORCES -

                               F1 - AT PISTON HEAD FRONT FACE  =   0.0
                               F2 - AT STUFFING BOX FRONT FACE =   1.865D 01
                               F3 - AT PISTON HEAD BACK FACE   =   0.0
                               F4 - AT STUFFING BOX INNER FACE =   0.0
```

```
PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )        DATE:  8/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976    BY    K. L. SESHASAI

PROBLEM TEL1:

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER; EQUIVALENT TO PROB. REG1

ANALYSIS AFTER APPLYING GIVEN FACTOR OF SAFETY OF  2.000  ON  LOAD:

     CRITICAL LOAD FOR THE CYLINDER =  6.407D 01  KIPS

     CORRESPONDING MAXIMUM PRESSURE =  2.266D 00  KSI

NOTES FOR THE FOLLOWING TABLES:

     1  THE NUMBERS IN PARENTHESES ARE FACTORS OF
        SAFETY AGAINST CORRESPONDING STRESSES

     2  DEFLECTION, LONGITUDINAL STRESS, AND SHEAR
        STRESS VALUES ARE AT CRITICAL SECTION

     3  MAX LONGITUDINAL STRESS IS AT OUTER SURFACE
        AND MAX HOOP STRESS IS AT INNER SURFACE

     4  HOOP STRESS AT ANY RADIAL DIST. IS CONSTANT
        ALONG THE LENGTH OF THE TUBE

     5  CODE "IS" MAX SHEAR STRESS IS AT INNER FACE
        CODE "OS" MAX SHEAR STRESS IS AT OUTER FACE

     6  ZERO METAL TO METAL CONTACT FORCES INDICATE
        NO CONTACT

     * * * * * * * * * * TABLE OF STRESSES AND DEFLECTIONS * * * * * * * * * *

     TUBE  CRIT SECTION    DEFLECTION    LONGITUDINAL      SHEAR    CODE      HOOP
     NO.   FROM CYL END                    STRESS          STRESS            STRESS

               INCH           INCH          KSI             KSI               KSI

      1     5.763D 01      1.507D-01      1.348D 00       7.986D 00 IS     1.482D 01
                                        ( 9.276D 01)   ( 7.826D 00)     ( 8.437D 00)

      2     6.886D 01      1.636D-01      1.694D 01       8.468D 00 OS
                                        ( 7.331D 00)   ( 7.381D 00)
```

```
* * * * * * *TABLE OF CROOKEDNESS ANGLES AND BEARING FORCES * * * * * * *

INTERFACE  CROOKEDNESS ANGLE                     FORCES AT INTERFACE
   NO.          DEGREES                                 KIPS

   1          7.46791D-03      ON PISTON HEAD BEARING NO.      1 =  3.152D-02
                                                               2 =  1.872D 00
                                                               3 =  8.738D-01

                               ON ROD BEARING NO.              1 =  2.777D 00

                               METAL TO METAL CONTACT FORCES -

                               F1 - AT PISTON HEAD FRONT FACE  =  0.0
                               F2 - AT STUFFING BOX FRONT FACE =  0.0
                               F3 - AT PISTON HEAD BACK FACE   =  0.0
                               F4 - AT STUFFING BOX INNER FACE =  0.0
```

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PROGRAM S[illegible]TEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )       DATE:  8/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TEL2:

  LPRTP=1; P-F; HOLLOW ROD WITH NO FLUID; VERTICAL CYLINDER.

INPUT DATA:

TABLE 1:     CONTROL DATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD

             TABLES RETAINED FROM PREVIOUS PROBLEM

               2     3     4     5     6     7
             KEEP

TABLE 2:     UNITS OF MEASUREMENT

            LENGTH      LOAD     PRESSURE   ANGULAR

             INCH       KIPS       KSI         DEG

TABLE 3:     STROKE AND EXTENDED LENGTHS AND END DIMENSIONS

          NUMBER OF TUBES( INCLUDING ROD ) =  3
          STROKE LENGTH                    =  6.60000D 01
          EXTENDED LENGTH                  =  1.29760D 02

          CYL. HINGE DIST. FROM END PLATE  =  3.00000D 00
          END PLATE THICKNESS              =  7.60000D-01

          CYLINDER PIN DIAMETER            =  2.00000D 00
          ROD PIN DIAMETER                 =  1.00000D 00

TABLE 4:     TUBE DIMENSIONS AND MATERIAL PROPERTIES

      NO.    LENGTH       OUTER DIA     INNER DIA  WT/UNIT LNT.  YOUNGS MOD   YIELD STRS

       1  4.69400D 01  7.00000D 00  6.02500D 00  3.20000D-03  2.90000D 04  1.00000D 02
       2  5.21300D 01  4.75000D 00  4.00000D 00  2.20000D-03  2.90000D 04  1.00000D 02
       3  4.55000D 01  3.00000D 00  1.50000D 00  2.00000D-03  2.90000D 04  1.00000D 02
                       ( HOLLOW ROD WITHOUT FLUID )
```

```
TABLE 5:     INTERFACE DIMENSIONS AND DETAILS OF BEARINGS

   DETAILS AT INTERFACE NUMBER    =  1

       NUMBER OF PISTON BEARINGS                =  3
       NUMBER OF ROD BEARINGS                   =  1

       LENGTH OF STOP TUBE                      =  0.0
       CLEARANCE BETWEEN CYL & STUFFING BOX =  3.00000D-03

                        LENGTH        DIAMETER        CLEARANCE         WEIGHT
                                   (ONE OF THESE TWO IS INPUT)

          PISTON HEAD   6.13000D 00   6.01400D 00   0.0              4.00000D-02

          STUFFING BOX  4.44000D 00   4.76000D 00   0.0              6.00000D-02

      PISTON BEARINGS:

      NO.      WIDTH          THICKNESS  YOUNGS MODULUS    STIFFNESS    DISTANCE FROM
                                                                        BACK FACE OF
                                                                        PISTON HEAD

       1    0.0              0.0          0.0             2.10000D 03   2.37500D 00
       2    0.0              0.0          0.0             8.80000D 03   3.90000D 00
       3    0.0              0.0          0.0             2.10000D 03   5.45000D 00

      ROD BEARINGS   :
                                                                        DISTANCE FROM
      NO.      WIDTH          THICKNESS  YOUNGS MODULUS    STIFFNESS    BACK FACE OF
                                                                        STUFFING BOX

       1    0.0              0.0          0.0             3.90000D 03   3.15000D 00

   DETAILS AT INTERFACE NUMBER    =  2

       NUMBER OF PISTON BEARINGS              =  2
       NUMBER OF ROD BEARINGS                 =  1

       LENGTH OF STOP TUBE                    =  0.0
       CLEARANCE BETWEEN CYL & STUFFING BOX =  0.0

                        LENGTH       DIAMETER       CLEARANCE        WEIGHT
                                  (ONE OF THESE TWO IS INPUT)

         PISTON HEAD   4.00000D 00   0.0            9.00000D-03   3.00000D-02

         STUFFING BOX  4.00000D 00   0.0            8.00000D-03   4.00000D-02

      PISTON BEARINGS:
                                                                       DISTANCE FROM
      NO.      WIDTH         THICKNESS  YOUNGS MODULUS   STIFFNESS     BACK FACE OF
                                                                       PISTON HEAD

       1    3.16000D-01   3.00000D-01   5.00000D 02   0.0              1.00000D 00
       2    3.16000D-01   3.00000D-01   5.00000D 02   0.0              2.37500D 00

      ROD BEARINGS   :
                                                                       DISTANCE FROM
      NO.      WIDTH         THICKNESS  YOUNGS MODULUS   STIFFNESS     BACK FACE OF
                                                                       STUFFING BOX
```

```
      1     4.500000-01    2.000000-01    5.00000D 02    0.0              2.50000D 00

            (NOTE:  EITHER WIDTH, THICKNESS, YOUNGS MODULUS OR STIFFNESS IS INPUT.
                    ZERO'S INDICATE THAT THEY ARE NOT INPUT. )

TABLE 6:      INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =  9.00000D 01

                                              CYLINDER END     ROD END

     SUPPORT CONDITIONS:                          PIN            FIX

     FRICTION COEFFICIENTS AT SUPPORTS:  -5.00000D-02   0.0
          (ZERO IF FIXED END)
     LOADING ECCENTRICITIES:                1.00000D-01  -5.00000D-02

TABLE 7:      FACTOR OF SAFETY, ITS TYPE OR OPERATING PRESSURE

     FACTOR OF SAFETY =  4.000 ON STRS
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PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )       DATE: 8/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TEL2:

  LPRTP=1; P-F; HOLLOW ROD WITH NO FLUID; VERTICAL CYLINDER.

RESULTS:             CRITICAL LOAD ANALYSIS


     CRITICAL LOAD FOR THE CYLINDER =  1.871D 02  KIPS

     CORRESPONDING MAXIMUM PRESSURE =  1.489D 01  KSI

NOTES FOR THE FOLLOWING TABLES:

     1  THE NUMBERS IN PARENTHESES ARE FACTORS OF
        SAFETY AGAINST CORRESPONDING STRESSES

     2  DEFLECTION, LONGITUDINAL STRESS, AND SHEAR
        STRESS VALUES ARE AT CRITICAL SECTION

     3  MAX LONGITUDINAL STRESS IS AT OUTER SURFACE
        AND MAX HOOP STRESS IS AT INNER SURFACE

     4  HOOP STRESS AT ANY RADIAL DIST. IS CONSTANT
        ALONG THE LENGTH OF THE TUBE

     5  CODE "IS" MAX SHEAR STRESS IS AT INNER FACE
        CODE "OS" MAX SHEAR STRESS IS AT OUTER FACE

     6  ZERO METAL TO METAL CONTACT FORCES INDICATE
        NO CONTACT


   * * * * * * * * * * TABLE OF STRESSES AND DEFLECTIONS * * * * * * * * * *

   TUBE  CRIT SECTION   DEFLECTION   LONGITUDINAL      SHEAR   CODE      HOOP
    NO.  FROM CYL END                   STRESS         STRESS            STRESS

             INCH           INCH          KSI            KSI               KSI

    1     4.398D 01     8.249D-02     2.565D 01      3.890D 01 IS      1.000D 02
                                    ( 3.899D 00)   ( 1.285D 00)      ( 1.000D 00)

    2     6.075D 01     9.351D-02     4.651D 00      4.570D 01 IS      6.746D 01
                                    ( 2.150D 01)   ( 1.094D 00)      ( 1.143D 00)

    3     8.843D 01     7.325D-02     3.470D 01      1.735D 01 OS
                                    ( 2.832D 00)   ( 2.382D 00)

  MAX LONGITUDINAL STRESS AT ROD FIXED END        =     3.726D 01  KIPS

  FACTOR OF SAFETY AT THIS STRESS                 =     2.682D 00
```

```
* * * * * * *TABLE OF CROOKEDNESS ANGLES AND BEARING FORCES * * * * * * *

INTERFACE  CROOKEDNESS ANGLE                FORCES AT INTERFACE
   NO.          DEGREES                            KIPS

   1          1.012170-02      ON PISTON HEAD BEARING NO.    1 =  3.666D-02
                                                             2 =  2.524D 00
                                                             3 =  1.177D 00

                               ON ROD BEARING NO.            1 =  3.738D 00

                               METAL TO METAL CONTACT FORCES -

                               F1 - AT PISTON HEAD FRONT FACE  =  0.0
                               F2 - AT STUFFING BOX FRONT FACE =  0.0
                               F3 - AT PISTON HEAD BACK FACE   =  0.0
                               F4 - AT STUFFING BOX INNER FACE =  0.0

   2          1.78576D-02      ON PISTON HEAD BEARING NO.    1 =  7.715D-01
                                                             2 =  1.674D 00

                               ON ROD BEARING NO.            1 =  2.446D 00

                               METAL TO METAL CONTACT FORCES -

                               F1 - AT PISTON HEAD FRONT FACE  =  0.0
                               F2 - AT STUFFING BOX FRONT FACE =  0.0
                               F3 - AT PISTON HEAD BACK FACE   =  0.0
                               F4 - AT STUFFING BOX INNER FACE =  0.0
```

```
PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )       DATE:  5/16/75

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TEL2:

  LPRTP=1; P-F; HOLLOW ROD WITH NO FLUID; VERTICAL CYLINDER.

ANALYSIS AFTER APPLYING GIVEN FACTOR OF SAFETY OF  4.000  ON  STRS:

      CRITICAL LOAD FOR THE CYLINDER =  4.677D 01  KIPS

      CORRESPONDING MAXIMUM PRESSURE =  3.722D 00  KSI

NOTES FOR THE FOLLOWING TABLES:

      1  THE NUMBERS IN PARENTHESES ARE FACTORS OF
         SAFETY AGAINST CORRESPONDING STRESSES

      2  DEFLECTION, LONGITUDINAL STRESS, AND SHEAR
         STRESS VALUES ARE AT CRITICAL SECTION

      3  MAX LONGITUDINAL STRESS IS AT OUTER SURFACE
         AND MAX HOOP STRESS IS AT INNER SURFACE

      4  HOOP STRESS AT ANY RADIAL DIST. IS CONSTANT
         ALONG THE LENGTH OF THE TUBE

      5  CODE "IS" MAX SHEAR STRESS IS AT INNER FACE
         CODE "OS" MAX SHEAR STRESS IS AT OUTER FACE

      6  ZERO METAL TO METAL CONTACT FORCES INDICATE
         NO CONTACT

   * * * * * * * * * * TABLE OF STRESSES AND DEFLECTIONS * * * * * * * * * *

   TUBE  CRIT SECTION   DEFLECTION   LONGITUDINAL     SHEAR   CODE    HOOP
   NO.   FROM CYL END                   STRESS        STRESS          STRESS

             INCH          INCH          KSI            KSI             KSI

    1     4.398D 01     1.146D-02     6.240D 00      9.650D 00 IS    2.500D 01
                                    ( 1.603D 01)   ( 5.181D 00)    ( 4.000D 00)

    2     5.816D 01     1.254D-02     6.602D-01      1.121D 01 IS    2.167D 01
                                    ( 1.515D 02)   ( 4.459D 00)    ( 4.572D 00)

    3     1.289D 02     7.586D-06     8.459D 00      4.229D 00 OS
                                    ( 1.182D 01)   ( 1.182D 01)

  MAX LONGITUDINAL STRESS AT ROD FIXED END        =     8.483D 00  KIPS

  FACTOR OF SAFETY AT THIS STRESS                 =     1.179D 01
```

```
* * * * * * *TABLE OF CROOKEDNESS ANGLES AND BEARING FORCES * * * * * * *

INTERFACE  CROOKEDNESS ANGLE              FORCES AT INTERFACE
   NO.          DEGREES                          KIPS

    1        1.58846D-03      ON PISTON HEAD BEARING NO.    1 =   5.753D-03
                                                            2 =   3.962D-01
                                                            3 =   1.848D-01

                              ON ROD BEARING NO.            1 =   5.867D-01

                              METAL TO METAL CONTACT FORCES -

                              F1 - AT PISTON HEAD FRONT FACE  =   0.0
                              F2 - AT STUFFING BOX FRONT FACE =   0.0
                              F3 - AT PISTON HEAD BACK FACE   =   0.0
                              F4 - AT STUFFING BOX INNER FACE =   0.0

    2        1.86631D-03      ON PISTON HEAD BEARING NO.    1 =   8.063D-02
                                                            2 =   1.750D-01

                              ON ROD BEARING NO.            1 =   2.556D-01

                              METAL TO METAL CONTACT FORCES -

                              F1 - AT PISTON HEAD FRONT FACE  =   0.0
                              F2 - AT STUFFING BOX FRONT FACE =   0.0
                              F3 - AT PISTON HEAD BACK FACE   =   0.0
                              F4 - AT STUFFING BOX INNER FACE =   0.0
```

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PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )       DATE:  6/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976    BY    K. L. SESHASAI

PROBLEM TEL3:

  LPRTP=1; F-F; SOLID ROD; 30 DEG INCLINED.

INPUT DATA:

TABLE 1:      CONTROL DATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD

              TABLES RETAINED FROM PREVIOUS PROBLEM

                 2      3      4      5      6      7

                   NO KEEP OPTIONS EXERCISED

TABLE 2:      UNITS OF MEASUREMENT

             LENGTH      LOAD      PRESSURE    ANGULAR

              INCH       LBS         PSI         DEG

TABLE 3:      STROKE AND EXTENDED LENGTHS AND END DIMENSIONS

           NUMBER OF TUBES( INCLUDING ROD ) =   4
           STROKE LENGTH                    =   9.00000D 01
           EXTENDED LENGTH                  =   1.44000D 02

           CYL. HINGE DIST. FROM END PLATE  =   4.00000D 00
           END PLATE THICKNESS              =   1.00000D 00

           CYLINDER PIN DIAMETER            =   0.0
           ROD PIN DIAMETER                 =   0.0

TABLE 4:      TUBE DIMENSIONS AND MATERIAL PROPERTIES

      NO.     LENGTH       OUTER DIA     INNER DIA  WT/UNIT LNT.  YOUNGS MOD   YIELD STRS

       1   3.70000D 01  8.00000D 00  7.00000D 00  3.90000D 00  2.90000D 07  7.50000D 04
       2   4.20000D 01  6.25000D 00  5.50000D 00  2.80000D 00  2.90000D 07  7.50000D 04
       3   4.50000D 01  4.75000D 00  4.00000D 00  2.50000D 00  2.90000D 07  7.50000D 04
       4.  4.50000D 01  3.00000D 00  0.0          2.00000D 00  2.90000D 07  1.25000D 05
                            ( SOLID ROD )
```

```
TABLE 5:     INTERFACE DIMENSIONS AND DETAILS OF BEARINGS

    DETAILS AT INTERFACE NUMBER     =  1

        NUMBER OF PISTON BEARINGS             =  2
        NUMBER OF ROD BEARINGS                =  1

        LENGTH OF STOP TUBE                   =  1.000000D 00
        CLEARANCE BETWEEN CYL & STUFFING BOX  =  2.000000D-03

                             LENGTH       DIAMETER       CLEARANCE      WEIGHT
                                       (ONE OF THESE TWO IS INPUT)

           PISTON HEAD    5.000000D 00   0.0            5.000000D-03   3.000000D 01

           STUFFING BOX   5.000000D 00   0.0            4.000000D-03   4.000000D 01

        PISTON BEARINGS:

        NO.      WIDTH          THICKNESS  YOUNGS MODULUS   STIFFNESS      DISTANCE FROM
                                                                           BACK FACE OF
                                                                           PISTON HEAD

         1    0.0               0.0           0.0           2.100000D 06   2.375000D 00
         2    0.0               0.0           0.0           8.800000D 06   3.900000D 00
        ROD BEARINGS    :

        NO.      WIDTH          THICKNESS  YOUNGS MODULUS   STIFFNESS      DISTANCE FROM
                                                                           BACK FACE OF
                                                                           STUFFING BOX

         1    3.500000D-01   2.000000D-01   7.500000D 05   0.0             1.750000D 00
    DETAILS AT INTERFACE NUMBER     =  2

        NUMBER OF PISTON BEARINGS             =  2
        NUMBER OF ROD BEARINGS                =  1

        LENGTH OF STOP TUBE                   =  1.000000D 00
        CLEARANCE BETWEEN CYL & STUFFING BOX  =  1.000000D-03

                             LENGTH       DIAMETER       CLEARANCE      WEIGHT
                                       (ONE OF THESE TWO IS INPUT)

           PISTON HEAD    4.000000D 00   0.0            5.000000D-03   2.500000D 01

           STUFFING BOX   4.000000D 00   0.0            5.000000D-03   3.500000D 01

        PISTON BEARINGS:

        NO.      WIDTH          THICKNESS  YOUNGS MODULUS   STIFFNESS      DISTANCE FROM
                                                                           BACK FACE OF
                                                                           PISTON HEAD

         1    0.0               0.0           0.0           2.100000D 06   1.750000D 00
         2    0.0               0.0           0.0           8.800000D 06   2.900000D 00
        ROD BEARINGS    :

        NO.      WIDTH          THICKNESS  YOUNGS MODULUS   STIFFNESS      DISTANCE FROM
                                                                           BACK FACE OF
                                                                           STUFFING BOX

         1    0.0               0.0           0.0           4.000000D 06   2.000000D 00
    DETAILS AT INTERFACE NUMBER     =  3

        NUMBER OF PISTON BEARINGS             =  2
        NUMBER OF ROD BEARINGS                =  1

        LENGTH OF STOP TUBE                   =  2.000000D 00
        CLEARANCE BETWEEN CYL & STUFFING BOX  =  1.000000D-03

                             LENGTH       DIAMETER       CLEARANCE      WEIGHT
                                       (ONE OF THESE TWO IS INPUT)

           PISTON HEAD    4.000000D 00   0.0            5.000000D-03   3.500000D 01

           STUFFING BOX   4.000000D 00   0.0            8.000000D-03   3.000000D 01

        PISTON BEARINGS:

        NO.      WIDTH          THICKNESS  YOUNGS MODULUS   STIFFNESS      DISTANCE FROM
                                                                           BACK FACE OF
                                                                           PISTON HEAD

         1    0.0               0.0           0.0           3.000000D 06   1.750000D 00
         2    0.0               0.0           0.0           8.000000D 06   2.900000D 00
        ROD BEARINGS    :

        NO.      WIDTH          THICKNESS  YOUNGS MODULUS   STIFFNESS      DISTANCE FROM
                                                                           BACK FACE OF
                                                                           STUFFING BOX

         1    0.0               0.0           0.0           4.000000D 06   2.500000D 00

            (NOTE:  EITHER WIDTH, THICKNESS, YOUNGS MODULUS OR STIFFNESS IS INPUT.
                    ZERO'S INDICATE THAT THEY ARE NOT INPUT. )

TABLE 6:     INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

    CYL INCLINATION WITH HORIZONTAL =  3.000000D 01

                                              CYLINDER END       ROD END

    SUPPORT CONDITIONS:                           FIX              FIX

    FRICTION COEFFICIENTS AT SUPPORTS:      0.0              0.0
        (ZERO IF FIXED END)
    LOADING ECCENTRICITIES:                  -5.000000D-02  -2.500000D-02

TABLE 7:     FACTOR OF SAFETY, ITS TYPE OR OPERATING PRESSURE

    CRITICAL LOAD ANALYSIS IS ASKED
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PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )       DATE:  8/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED   JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TEL3:

  LPRTP=1; F-F; SOLID ROD; 30 DEG INCLINED.

RESULTS:            CRITICAL LOAD ANALYSIS

     CRITICAL LOAD FOR THE CYLINDER =  1.198D 05  LBS

     CORRESPONDING MAXIMUM PRESSURE =  9.532D 03  PSI

NOTES FOR THE FOLLOWING TABLES:

     1  THE NUMBERS IN PARENTHESES ARE FACTORS OF
        SAFETY AGAINST CORRESPONDING STRESSES

     2  DEFLECTION, LONGITUDINAL STRESS, AND SHEAR
        STRESS VALUES ARE AT CRITICAL SECTION

     3  MAX LONGITUDINAL STRESS IS AT OUTER SURFACE
        AND MAX HOOP STRESS IS AT INNER SURFACE

     4  HOOP STRESS AT ANY RADIAL DIST. IS CONSTANT
        ALONG THE LENGTH OF THE TUBE

     5  CODE "IS" MAX SHEAR STRESS IS AT INNER FACE.
        CODE "OS" MAX SHEAR STRESS IS AT OUTER FACE.

     6  ZERO METAL TO METAL CONTACT FORCES INDICATE
        NO CONTACT

     * * * * * * * * * * TABLE OF STRESSES AND DEFLECTIONS * * * * * * * * * *

    TUBE  CRIT SECTION   DEFLECTION   LONGITUDINAL      SHEAR    CODE      HOOP
    NO.   FROM CYL END                  STRESS          STRESS             STRESS

              INCH          INCH          PSI             PSI               PSI

     1     3.512D 01     2.780D-03     2.115D 04       2.549D 04 IS      7.181D 04
                                     ( 3.547D 00)    ( 1.471D 00)      ( 1.044D 00)

     2     6.685D 01     8.492D-03     1.560D 04       2.986D 04 IS      7.497D 04
                                     ( 4.809D 00)    ( 1.256D 00)      ( 1.000D 00)

     3     9.078D 01     1.054D-02     5.199D 02       2.822D 04 IS      5.601D 04
                                     ( 1.443D 02)    ( 1.329D 00)      ( 1.339D 00)

     4     1.433D 02     7.912D-06     1.825D 04       9.123D 03 OS
                                     ( 6.851D 00)    ( 6.851D 00)

   MAX LONGITUDINAL STRESS AT CYLINDER FIXED END =    2.169D 04  LBS

   FACTOR OF SAFETY AT THIS STRESS               =    3.458D 00

   MAX LONGITUDINAL STRESS AT ROD FIXED END      =    1.829D 04  LBS

   FACTOR OF SAFETY AT THIS STRESS               =    6.835D 00
```

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* * * * * * *TABLE OF CROOKEDNESS ANGLES AND BEARING FORCES * * * * * * *

INTERFACE  CROOKEDNESS ANGLE                   FORCES AT INTERFACE
   NO.         DEGREES                                LBS

   1        -1.08475D-03      ON PISTON HEAD BEARING NO.     1 = -5.957D 01
                                                             2 = -5.037D 02

                              ON ROD BEARING NO.             1 = -5.633D 02

                              METAL TO METAL CONTACT FORCES -

                              F1 - AT PISTON HEAD FRONT FACE  =  0.0
                              F2 - AT STUFFING BOX FRONT FACE =  0.0
                              F3 - AT PISTON HEAD BACK FACE   =  0.0
                              F4 - AT STUFFING BOX INNER FACE =  0.0

   2         1.04219D-03      ON PISTON HEAD BEARING NO.     1 =  2.277D 01
                                                             2 =  2.795D 02

                              ON ROD BEARING NO.             1 =  3.022D 02

                              METAL TO METAL CONTACT FORCES -

                              F1 - AT PISTON HEAD FRONT FACE  =  0.0
                              F2 - AT STUFFING BOX FRONT FACE =  0.0
                              F3 - AT PISTON HEAD BACK FACE   =  0.0
                              F4 - AT STUFFING BOX INNER FACE =  0.0

   3         9.78226D-04      ON PISTON HEAD BEARING NO.     1 =  5.395D 01
                                                             2 =  3.009D 02

                              ON ROD BEARING NO.             1 =  3.549D 02

                              METAL TO METAL CONTACT FORCES -

                              F1 - AT PISTON HEAD FRONT FACE  =  0.0
                              F2 - AT STUFFING BOX FRONT FACE =  0.0
                              F3 - AT PISTON HEAD BACK FACE   =  0.0
                              F4 - AT STUFFING BOX INNER FACE =  0.0
```

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PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )        DATE:  8/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PRCBLEM TEL4:

 LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER WITH A OVERHANG.

INPUT DATA:

TABLE 1:     CCNTRUL DATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD

            TABLES RETAINED FROM PREVIOUS PROBLEM

              2     3     4     5     6     7

               NO KEEP CPTIONS EXERCISED

TABLE 2:     UNITS OF MEASUREMENT

            LENGTH      LOAD      PRESSURE     ANGULAR

             INCH       KIPS        KSI          RAC

TABLE 3:     STROKE AND EXTENDED LENGTHS AND END DIMENSIONS

          NUMBER OF TUBES( INCLUDING ROD ) =  3
          STROKE LENGTH                    =  6.40000D 01
          EXTENDED LENGTH                  =  1.01000D 02

          CYL. HINGE DIST. FROM END PLATE  = -1.10000D 01
          END PLATE THICKNESS              =  1.00000D 00

          CYLINDER PIN DIAMETER            =  2.00000D 00
          ROD PIN DIAMETER                 =  1.00000D 00

TABLE 4:     TUBE DIMENSIONS AND MATERIAL PROPERTIES

   NO.     LENGTH      OUTER DIA    INNER DIA   WT/UNIT LNT.  YOUNGS MOD   YIELD STRS

    1   4.00000D 01  6.25000D 00  5.50000D 00  2.80000D-03  2.90000D 04  7.50000D 01
    2   4.50000D 01  4.75000D 00  4.00000D 00  2.50000D-03  2.90000D 04  7.50000D 01
    3   4.50000D 01  3.00000D 00  0.0          2.00000D-03  2.90000D 04  1.00000D 02
                            ( SOLID ROD )
```

```
TABLE 5:     INTERFACE DIMENSIONS AND DETAILS OF BEARINGS

    DETAILS AT INTERFACE NUMBER    =  1

        NUMBER OF PISTON BEARINGS             =  2
        NUMBER OF ROD BEARINGS                =  1

        LENGTH CF STOP TUBE                   =  1.00000D 00
        CLEARANCE BETWEEN CYL & STUFFING BOX =  1.00000D-03

                         LENGTH        DIAMETER      CLEARANCE        WEIGHT
                                    (ONE OF THESE TWO IS INPUT)

          PISTON HEAD  4.00000D 00  5.49500D 00   0.0              2.50000D-02

          STUFFING BOX 4.00000D 00  4.75500D 00   0.0              3.50000D-02

        PISTON BEARINGS:

        NO.      WIDTH       THICKNESS  YOUNGS MODULUS   STIFFNESS    DISTANCE FROM
                                                                      BACK FACE OF
                                                                      PISTON HEAD

         1    0.0           0.0          0.0            2.10000D 03  1.75000D 00
         2    0.0           0.0          0.0            8.80000D 03  2.90000D 00
        ROD BEARINGS   :

        NO.      WIDTH       THICKNESS  YOUNGS MODULUS   STIFFNESS    DISTANCE FROM
                                                                      BACK FACE OF
                                                                      STUFFING BOX

         1    0.0           0.0          0.0            4.00000D 03  2.00000D 00
    DETAILS AT INTERFACE NUMBER    =  2

        NUMBER OF PISTON BEARINGS             =  2
        NUMBER OF ROD BEARINGS                =  1

        LENGTH OF STOP TUBE                   =  2.00000D 00
        CLEARANCE BETWEEN CYL & STUFFING BOX =  1.00000D-03

                         LENGTH        CIAMETER      CLEARANCE        WEIGHT
                                    (ONE OF THESE TWO IS INPUT)

          PISTON HEAD  4.00000D 00  0.0             5.00000D-03   3.50000D-02

          STUFFING BOX 4.00000D 00  0.0             8.00000D-03   3.00000D-02

        PISTCN BEARINGS:

        NO.      WIDTH       THICKNESS  YOUNGS MODULUS   STIFFNESS    DISTANCE FROM
                                                                      BACK FACE OF
                                                                      PISTON HEAD

         1    0.0           0.0          0.0            3.00000D 03  1.75000D 00
         2    0.0           0.0          0.0            8.00000D 03  2.90000D 00

        ROD BEARINGS   :

        NO.      WIDTH       THICKNESS  YOUNGS MODULUS   STIFFNESS    DISTANCE FROM
                                                                      BACK FACE OF
                                                                      STUFFING BOX
```

```
     1    0.0           0.0           0.0             4.00000D 03   2.50000D 00

          (NOTE:  EITHER WIDTH, THICKNESS, YOUNGS MODULUS OR STIFFNESS IS INPUT.
                  ZERO'S INDICATE THAT THEY ARE NOT INPUT. )


TABLE 6:      INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =  0.0

                                          CYLINDER END     ROD END

     SUPPORT CONDITIONS:                      PIN             PIN

     FRICTION COEFFICIENTS AT SUPPORTS:   5.00000D-02   0.0
         (ZERO IF FIXED END)
     LOADING ECCENTRICITIES:              0.0           1.00000D-01

TABLE 7:      FACTOR OF SAFETY, ITS TYPE OR OPERATING PRESSURE


     CRITICAL LOAD ANALYSIS IS ASKED
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PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )      DATE:  8/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TEL4:

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER WITH A OVERHANG.

RESULTS:             CRITICAL LOAD ANALYSIS


     CRITICAL LOAD FOR THE CYLINDER =  1.198D 02  KIPS

     CORRESPONDING MAXIMUM PRESSURE =  9.532D 00  KSI

NOTES FOR THE FOLLOWING TABLES:

     1  THE NUMBERS IN PARENTHESES ARE FACTORS OF
        SAFETY AGAINST CORRESPONDING STRESSES

     2  DEFLECTION, LONGITUDINAL STRESS, AND SHEAR
        STRESS VALUES ARE AT CRITICAL SECTION

     3  MAX LONGITUDINAL STRESS IS AT OUTER SURFACE
        AND MAX HOOP STRESS IS AT INNER SURFACE

     4  HOOP STRESS AT ANY RADIAL DIST. IS CONSTANT
        ALONG THE LENGTH OF THE TUBE

     5  CODE "IS" MAX SHEAR STRESS IS AT INNER FACE
        CODE "CS" MAX SHEAR STRESS IS AT OUTER FACE

     6  ZERO METAL TO METAL CONTACT FORCES INDICATE
        NO CONTACT


     * * * * * * * * * * TABLE OF STRESSES AND DEFLECTIONS * * * * * * * * * *

     TUBE  CRIT SECTION   DEFLECTION   LONGITUDINAL     SHEAR    CODE     HOOP
      NO.  FROM CYL END                   STRESS        STRESS            STRESS

               INCH          INCH          KSI            KSI               KSI

      1     2.385D 01     8.775D-02     1.674D 01     3.036D 01 IS     7.497D 01
                                      ( 4.480D 00)  ( 1.235D 00)     ( 1.000D 00)

      2     5.930D 01     1.758D-01     5.882D 00     3.048D 01 IS     5.601D 01
                                      ( 1.275D 01)  ( 1.230D 00)     ( 1.339D 00)

      3     6.262D 01     1.777D-01     2.875D 01     1.438D 01 OS
                                      ( 3.478D 00)  ( 3.478D 00)

     UNIFORM AXIAL TENSILE STRESS IN OVERHANG       =    3.272D 01  KSI

     FACTOR OF SAFETY AT THIS STRESS                =    2.292D 00

     END DEFLECTION OF THE OVERHANG                 =   -4.052D-02  INCH
```

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* * * * * * *TABLE OF CROOKEDNESS ANGLES AND BEARING FORCES * * * * * * *

INTERFACE  CROOKEDNESS ANGLE                 FORCES AT INTERFACE
   NO.          RADIANS                              KIPS

    1          1.316900D-04      ON PISTCN HEAD BEARING NO.     1 =   1.651D-01
                                                                2 =   2.026D 00

                                 ON ROD BEARING NO.             1 =   2.191D 00

                                 METAL TC METAL CONTACT FORCES -

                                 F1 - AT PISTCN HEAD FRONT FACE  =   0.0
                                 F2 - AT STUFFING BOX FRONT FACE =   0.0
                                 F3 - AT PISTCN HEAD BACK FACE   =   0.0
                                 F4 - AT STUFFING BOX INNER FACE =   0.0
    2          2.048380D-04      ON PISTCN HEAD BEARING NO.     1 =   6.473D-01
                                                                2 =   3.611D 00

                                 ON ROD BEARING NO.             1 =   4.258D 00

                                 METAL TC METAL CONTACT FORCES -

                                 F1 - AT PISTCN HEAD FRONT FACE  =   0.0
                                 F2 - AT STUFFING BOX FRONT FACE =   0.0
                                 F3 - AT PISTCN HEAD BACK FACE   =   0.0
                                 F4 - AT STUFFING BOX INNER FACE =   0.0
```

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PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )      DATE:  8/16/76

EXAMPLE PROBLEMS TO DEMCNSTRATE ALL THE OPTIONS AND VARIATICNS IN INPUT DATA
CCDED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TEL5:

  LPRTP=2; F-P; HOLLCW ROD WITH FLUID; INCLINED CYL; METRIC UNITS.

INPUT DATA:

TABLE 1:     CCNTRCL DATA

     PROBLEM TYPE = 2 - ANALYSIS FOR A PARTICULAR PRESSURE

             TABLES RETAINED FRCM PREVICUS PRCBLEM

                 2      3      4      5      6      7

                    NO KEEP OPTIONS EXERCISED


TABLE 2:     UNITS OF MEASUREMENT

           LENGTH      LOAD      PRESSURE   ANGULAR

            CM         KGS        KSCM        RAD


TABLE 3:     STROKE AND EXTENDED LENGTHS AND END DIMENSICNS

         NUMBER OF TUBES( INCLUDING ROD ) =  3
         STROKE LENGTH                    =  1.650000D 02
         EXTENDED LENGTH                  =  2.940000D 02

         CYL. HINGE DIST. FROM END PLATE  =  9.000000D 00
         END PLATE THICKNESS              =  2.500000D 00

         CYLINDER PIN DIAMETER            =  0.0
         ROD PIN DIAMETER                 =  3.000000D 00


TABLE 4:     TUBE DIMENSIONS AND MATERIAL PROPERTIES

      NC.     LENGTH       OUTER DIA     INNER DIA   WT/UNIT LNT.   YOUNGS MOD    YIELD STRS

       1   1.025000D 02  1.600000D 01  1.400000D 01  1.500000D 00  2.100000D 06  7.050000D 03
       2   1.135000D 02  1.200000D 01  1.000000D 01  1.300000D 00  2.100000D 06  7.050000D 03
       3   1.140000D 02  8.000000D 00  5.000000D 00  1.200000D 00  2.100000D 06  8.800000D 03
       .            ( HOLLOW ROD WITH FLUID )
```

```
TABLE 5:     INTERFACE DIMENSIONS AND DETAILS OF BEARINGS

    DETAILS AT INTERFACE NUMBER     =  1

        NUMBER OF PISTON BEARINGS               =  2
        NUMBER OF ROD BEARINGS                  =  1

        LENGTH OF STOP TUBE                     =  2.500000 00
        CLEARANCE BETWEEN CYL & STUFFING BOX =  5.000000-03

                          LENGTH        DIAMETER       .CLEARANCE      WEIGHT
                                      (ONE OF THESE TWO IS INPUT)

           PISTON HEAD    1.000000D 01  0.0            1.000000D-02  1.500000D 01

           STUFFING BOX   1.000000D 01  0.0            1.000000D-02  1.800000D 01

        PISTON BEARINGS:

        NO.      WIDTH         THICKNESS  YOUNGS MODULUS   STIFFNESS     DISTANCE FROM
                                                                         BACK FACE OF
                                                                         PISTON HEAD

         1    8.000000D-01   2.500000D-01   3.500000D 04   0.0          3.500000D 00
         2    8.000000D-01   2.500000D-01   3.500000D 04   0.0          8.000000D 00
        ROD BEARINGS    :

        NO.      WIDTH         THICKNESS  YOUNGS MODULUS   STIFFNESS     DISTANCE FROM
                                                                         BACK FACE OF
                                                                         STUFFING BOX

         1    8.000000D-01   2.500000D-01   5.000000D 04   0.0          7.000000D 00
    DETAILS AT INTERFACE NUMBER     =  2

        NUMBER OF PISTON BEARINGS               =  2
        NUMBER OF ROD BEARINGS                  =  1

        LENGTH OF STOP TUBE                     =  5.000000D 00
        CLEARANCE BETWEEN CYL & STUFFING BOX =  5.000000D-03

                          LENGTH        DIAMETER       CLEARANCE      WEIGHT
                                      (ONE OF THESE TWO IS INPUT)

           PISTON HEAD    1.000000D 01  9.990000D 00  0.0           1.500000D 01

           STUFFING BOX   1.000000D 01  8.010000D 00  0.0           1.600000D 01

        PISTON BEARINGS:

        NO.      WIDTH         THICKNESS  YOUNGS MODULUS   STIFFNESS     DISTANCE FROM
                                                                         BACK FACE OF
                                                                         PISTON HEAD

         1    0.0            0.0            0.0            3.750000D 05  3.500000D 00
         2    0.0            0.0            0.0            3.750000D 05  8.000000D 00
        ROD BEARINGS    :

        NO.      WIDTH         THICKNESS  YOUNGS MODULUS   STIFFNESS     DISTANCE FROM
                                                                         BACK FACE OF
                                                                         STUFFING BOX
```

```
         1     0.0            0.0            0.0            5.000000D 05   7.000000D 00

             (NOTE:  EITHER WIDTH, THICKNESS, YOUNGS MODULUS OR STIFFNESS IS INPUT.
                     ZERO'S INDICATE THAT THEY ARE NOT INPUT. )

TABLE 6:     INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

    CYL INCLINATION WITH HORIZONTAL =  7.500000D-01

                                              CYLINDER END     ROD END

    SUPPORT CONDITIONS:                           FIX             PIN

    FRICTION COEFFICIENTS AT SUPPORTS:   0.0              -5.000000D-02
         (ZERO IF FIXED END)
    LOADING ECCENTRICITIES:               0.0               1.000000D-01

TABLE 7:     FACTOR OF SAFETY, ITS TYPE OR OPERATING PRESSURE


    OPERATING PRESSURE =  1.75000D 02
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PROGRAM SACTEL - STRESS ANALYSIS OF CYLINDERS ( TELESCOPIC )      DATE: 6/16/76

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TFL5:

  LPRTP=2; F-P; HOLLOW ROD WITH FLUID; INCLINED CYL; METRIC UNITS.

RESULTS:     ANALYSIS FOR A GIVEN OPERATING PRESSURE

     OP5RATING PRES OF THE CYLINDER =  1.750D 02  KSCM

     CORRESPONCING LOAD             =  1.374D 04  KGS

NOTES FOR THE FOLLOWING TABLES:

     1  THE NUMBERS IN PARENTHESES ARE FACTORS OF
        SAFETY AGAINST CORRESPONDING STRESSES

     2  DEFLECTION, LONGITUDINAL STRESS, AND SHEAR
        STRESS VALUES ARE AT CRITICAL SECTION

     3  MAX LONGITUDINAL STRESS IS AT OUTER SURFACE
        AND MAX HOOP STRESS IS AT INNER SURFACE

     4  HOOP STRESS AT ANY RADIAL DIST. IS CONSTANT
        ALONG THE LENGTH OF THE TUBE

     5  CODE "IS" MAX SHEAR STRESS IS AT INNER FACE
        CODE "CS" MAX SHEAR STRESS IS AT OUTER FACE

     6  ZERO METAL TO METAL CONTACT FORCES INDICATE
        NO CONTACT

     * * * * * * * * * * TABLE OF STRESSES AND DEFLECTIONS * * * * * * * * * *

    TUBE  CRIT SECTION   DEFLECTION   LONGITUDINAL      SHEAR    CODE      HOOP
     NO.  FROM CYL END                   STRESS         STRESS             STRESS

              CM             CM           KSCM            KSCM              KSCM

     1     1.015D 02     2.970D-02     2.937D 02      5.252D 02 IS      1.318D 03
                                     ( 2.400D 01)   ( 6.712D 00)      ( 5.348D 00)

     2     1.914D 02     6.665D-02     6.962D 01      5.142D 02 IS      9.705D 02
                                     ( 1.013D 02)   ( 6.855D 00)      ( 7.265D 00)

     3     2.019D 02     6.767D-02     4.837D 02      4.139D 02 IS      3.994D 02
                                     ( 1.819D 01)   ( 1.063D 01)      ( 2.204D 01)

    MAX LONGITUDINAL STRESS AT CYLINDER FIXED END =    4.263D 02  KGS

    FACTOR OF SAFETY AT THIS STRESS               =    1.654D 01
```

```
* * * * * * *TABLE OF CROOKEDNESS ANGLES AND BEARING FORCES * * * * * * *

INTERFACE  CROOKEDNESS ANGLE
   NO.          RADIANS                      FORCES AT INTERFACE
                                                    KGS

   1         -7.81018D-06     ON PISTON HEAD BEARING NO.      1 = -4.337D 01
                                                              2 = -9.647D 01

                              ON ROD BEARING NO.              1 = -1.416D 02

                              METAL TO METAL CONTACT FORCES -

                              F1 - AT PISTON HEAD FRONT FACE   =  0.0
                              F2 - AT STUFFING BOX FRONT FACE  =  0.0
                              F3 - AT PISTON HEAD BACK FACE    =  0.0
                              F4 - AT STUFFING BOX INNER FACE  =  0.0

   2          6.21991D-05     ON PISTON HEAD BEARING NO.      1 =  1.131D 02
                                                              2 =  2.181D 02

                              ON ROD BEARING NO.              1 =  3.312D 02

                              METAL TO METAL CONTACT FORCES -

                              F1 - AT PISTON HEAD FRONT FACE   =  0.0
                              F2 - AT STUFFING BOX FRONT FACE  =  0.0
                              F3 - AT PISTON HEAD BACK FACE    =  0.0
                              F4 - AT STUFFING BOX INNER FACE  =  0.0
```

APPENDIX C

COMPUTER PROGRAM FOR TIE ROD CYLINDERS--SACTIE

Program SACTIE

The analytical procedure for tie rod cylinders developed in Chapter VIII has been programmed for solution on a digital computer. The program is written in FORTRAN IV language and should require only minor revisions to be operable on other computers. Double precision (16 digits accuracy) arithmetic is used, and the program can be run on any computer which has a storage capacity of 80 K bytes. A summary flow diagram is shown in Figure 43. Details of all the Subprogram Operations, Guide for Data Input, Example Problems, Listings of Input Data and Program Output are given in the following sections.

Subprogram Operation

MAIN

MAIN is a driver subroutine for the complete program. MAIN sets up keys to perform different operations and calls all the major subroutines to perform the major operations in the program. For all three problem types, MAIN first goes through critical load analysis. Then, for first problem type it sets up factored load analysis, and for second and third problem types it checks for input pressure being greater than critical pressure; if not, it goes through corresponding type of analysis.

INPECO

Subroutine INPECO reads all the input data; checks problem name being blank for end of run; checks the input data at several stages for proper input. If any error is observed the error is printed out and the program terminates. Echo prints out all the input tables.

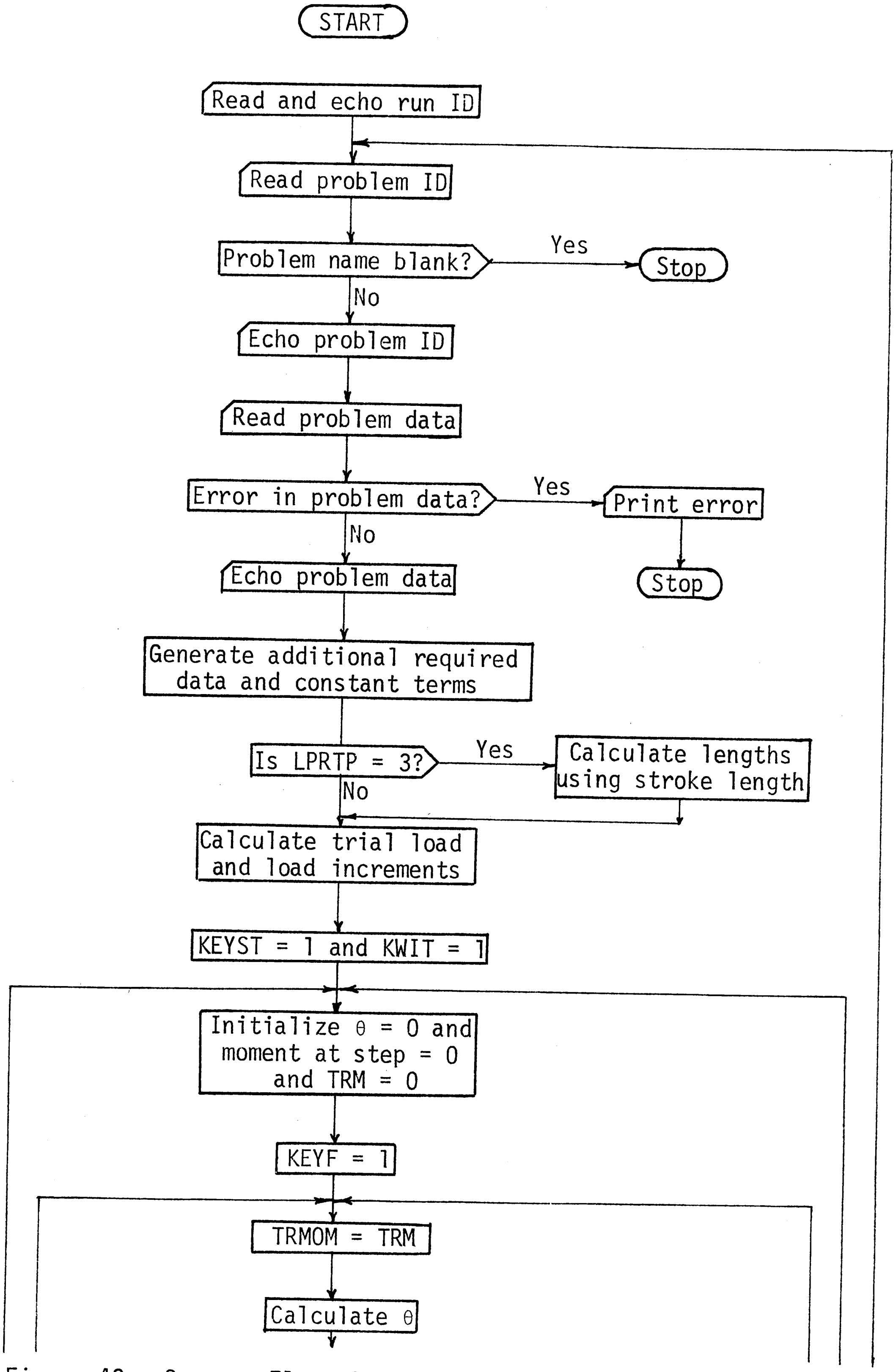


Figure 43. Summary Flow Diagram of Program SACTIE

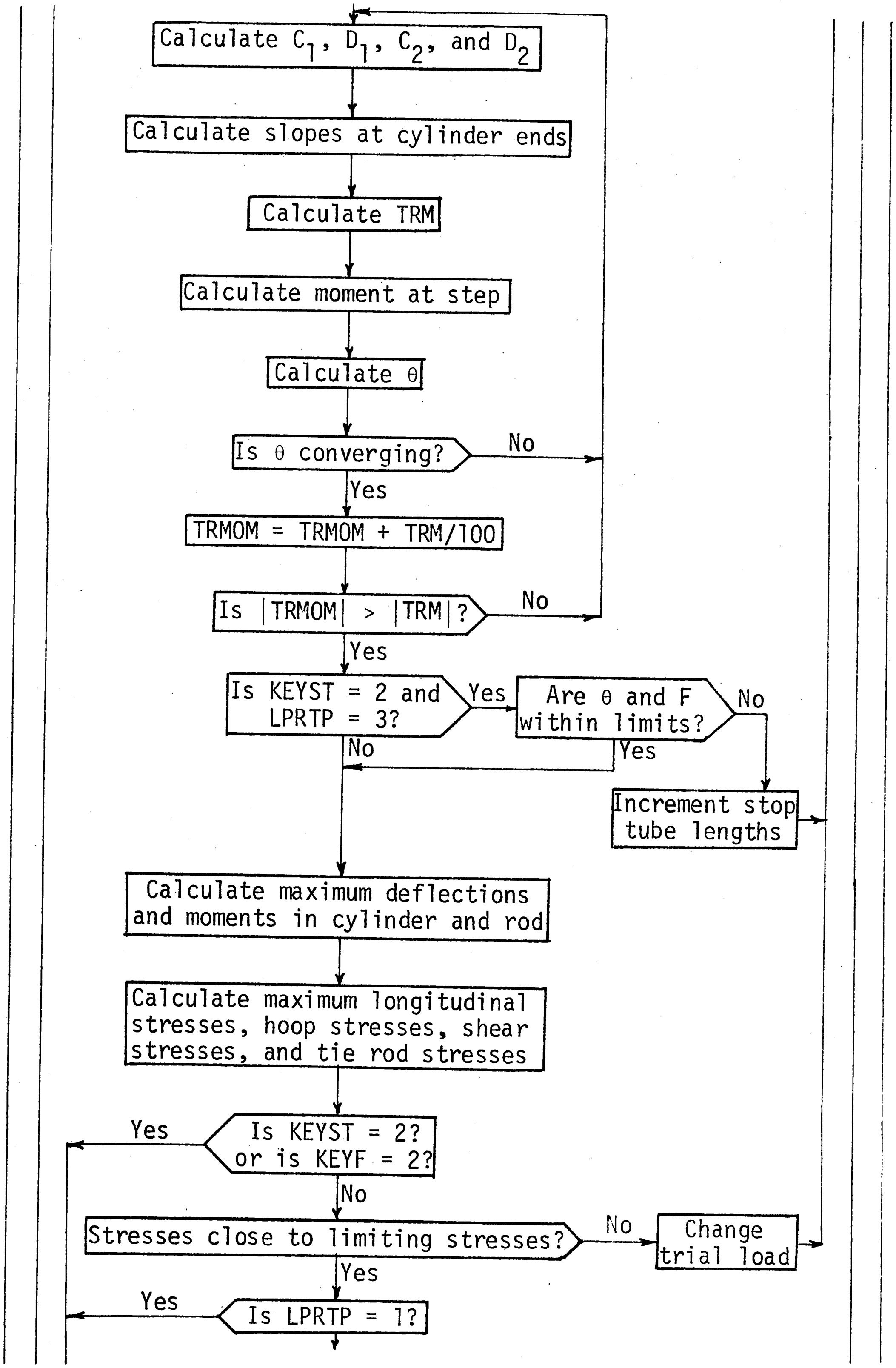


Figure 43. (Continued)

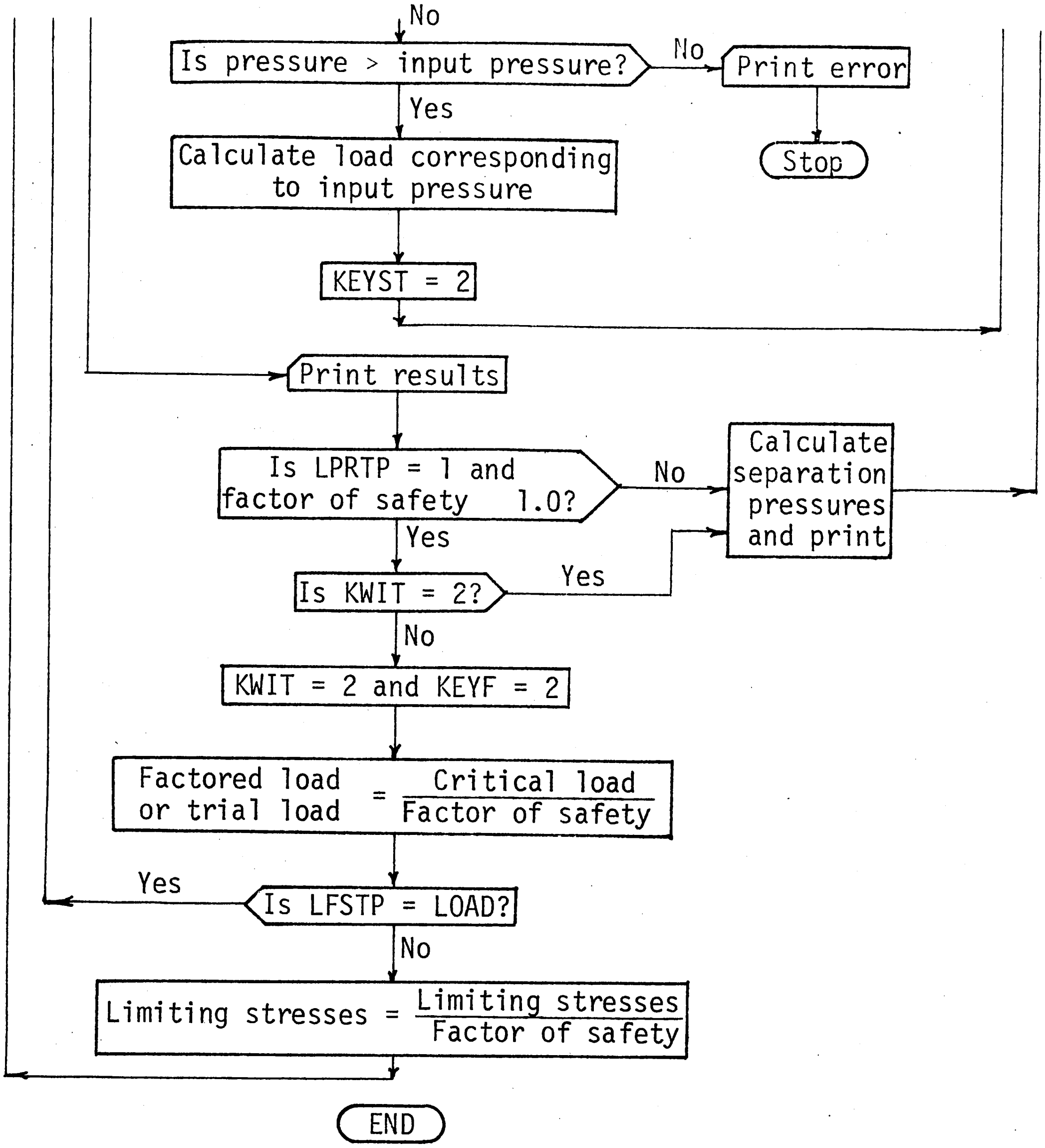


Figure 43. (Continued)

CONST1

Subroutine CONST1 calculates all the constant quantities which do not vary throughout the program. The constant quantities are: stiffnesses of bearings and seals; cross sectional properties of cylinder and rod; hoop stress coefficients; self weight reactions at supports; friction moment coefficients; and moment due to overhang in the case of cylinders with overhang.

CONST2

Subroutine CONST2 calculates the constant terms involved in tie rod stress and separation pressures calculation.

TRIALP

Subroutine TRIALP calculates a trial load and two load increments required for the iteration process in evaluating the critical load for the cylinder. The trial load is the smallest of critical load by Euler's buckling criteria considering the full length stiffness as that of rod only, critical load by hoop stress criteria for the cylinder part, and critical load by hoop stress criteria for the rod part in the case of hollow pressurized rods. The first load increment is one-fiftieth of the trial load and the second is one-thousandth. The larger load increment is for faster convergence and the smaller load increment is for better accuracy.

EQBRIM

Subroutine EQBRIM determines the equilibrium position of the system for any particular load. The equilibrium position is determined by repeating the calculation of deflections, bending moments, tie rod moment, and the crookedness angle until two consecutive values of tie rod moment and two consecutive values of crookedness angle are in close agreement. This subroutine calls subroutine THCDS for calculating the values of constant terms in the deflection equations and calls subroutine THETA for calculating the crookedness angle at a particular value of moment at the sliding connection.

THETA

Subroutine THETA calculates the crookedness angle at the sliding connection for any particular value of the moment at the sliding connection. This subroutine also calculates the forces on the bearings by calling subroutine GFORCE and the metal-to-metal contact forces at the sliding connection.

GFORCE

Subroutine GFORCE calculates the forces on the bearings for a particular value of crookedness angle at the sliding connection.

THCDS

Subroutine THCDS calculates the slopes at the supports and the constants in the deflection and moment equations at particular values of load and crookedness angle.

STOPTB

Subroutine STOPTB determines the required length of stop tube by incrementing the length of the stop tube by small quantities and checking the crookedness angle and lateral forces against the limiting values at each length.

XATYMX

Subroutine XATYMX determines the distances at which the maximum deflections occur in cylinder and rod parts.

YMAXS

Subroutine YMAXS calculates the maximum deflections in cylinder and rod parts at the places determined by the subroutine XATYMX.

STRCHS

Subroutine STRCHS calculates the maximum bending moments and, hence, maximum longitudinal stresses, maximum hoop stresses, and maximum shear stresses in the cylinder and rod parts, and calculates the tie rod stresses; it checks these stresses against the limiting stresses and makes corresponding change in the trial load using load increments. This process is repeated until any one of the maximum stress values exceeds the limiting stress. The analysis is repeated for previous load value.

SEPPRE

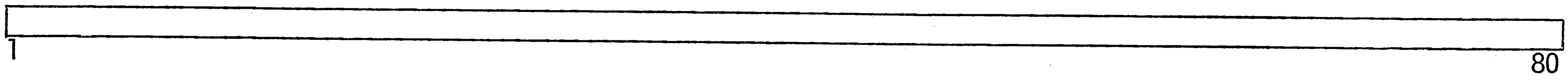
Subroutine SEPPRE calculates the separation pressures for all piston head positions in a cycle of operation.

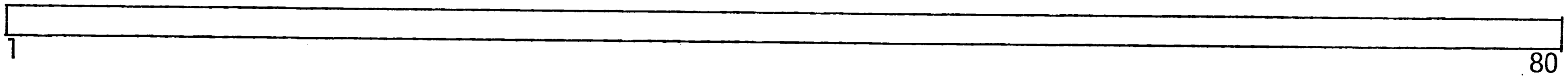
OUTPUT

Subroutine OUTPUT prints out all the results: the maximum deflections, the maximum stresses, the factor of safety existing on these stresses, and the distance from the cylinder support at which the above quantities occur in the cylinder and rod parts; the stresses in tie rods, and the factor of safety existing on these stresses; the crookedness angle; and the forces on the bearings.

Program SACTIE--Guide for Data Input

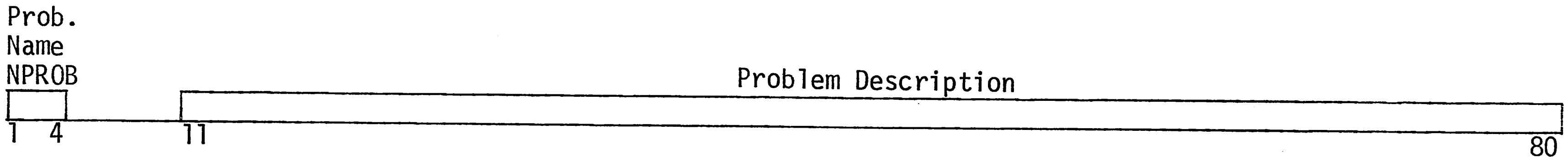
PROGRAM IDENTIFICATION (Two alphanumeric cards at the beginning of run)





Format--20A4

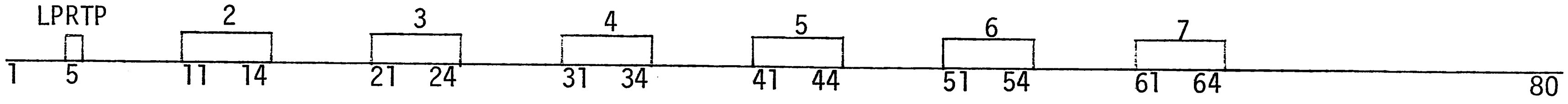
PROBLEM IDENTIFICATION (One card at the beginning of each problem)



Format--20A4

Program stops if NPROB is blank

TABLE 1: CONTROL DATA (One card for each problem)



Format--LPRTP - I1; 2 to 7 - A4

LPRTP = 1--Critical load analysis and analysis for a factored load using given factor of safety

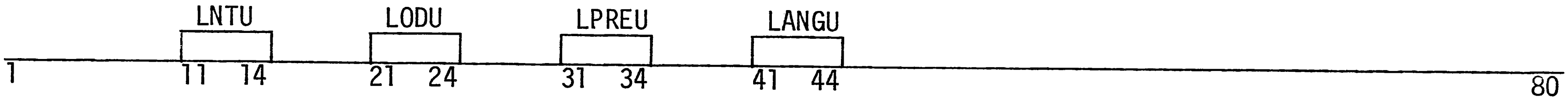
2--Analysis for a particular fluid pressure

3--Analysis to determine a stop tube length for given limiting values of crookedness angle and lateral force at the sliding connection at a given fluid pressure

If any of the following tables are same as in the previous problem and are to be retained for this problem, enter "KEEP" in the corresponding blocks 2 to 7

Enter only LPRTP for the first problem

TABLE 2: UNITS OF MEASUREMENTS (No card if TABLE 2 is retained from previous problem)



Format--A4 for all

LNTU - Unit of lengths (ex: INCH, FEET, CM, MET, etc.)

LODU - Unit of loads (ex: LBS, KIPS, KGS, etc.)

LPREU - Unit of pressures (ex: KSI, PSI, KSCM, etc.)

LANGU - Unit of angles (enter DEG or RAD starting in column 41)

TABLE 3: CYLINDER DIMENSIONS (No cards if TABLE 3 is retained from previous problem; see Figure 44 for details)

Card No. 1--Lengths

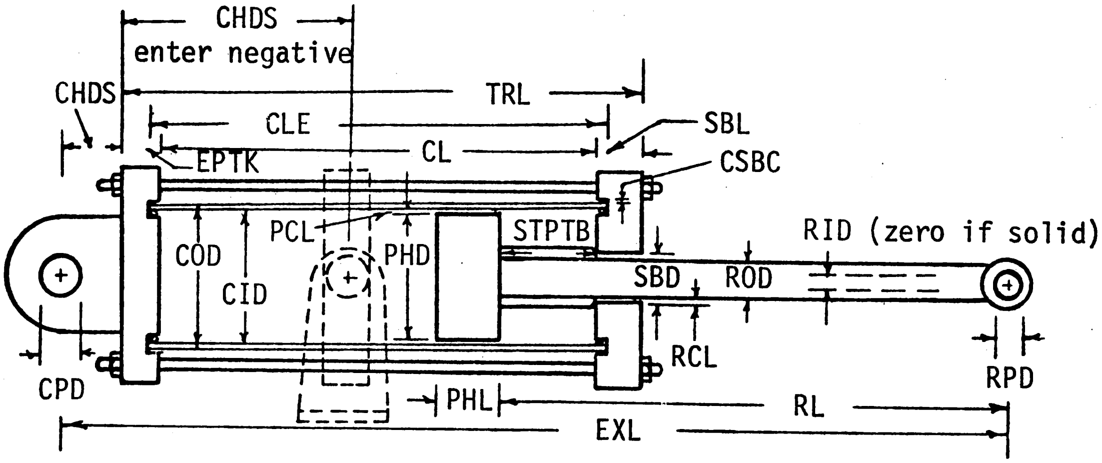


Figure 44. Cylinder Dimensions for SACTIE

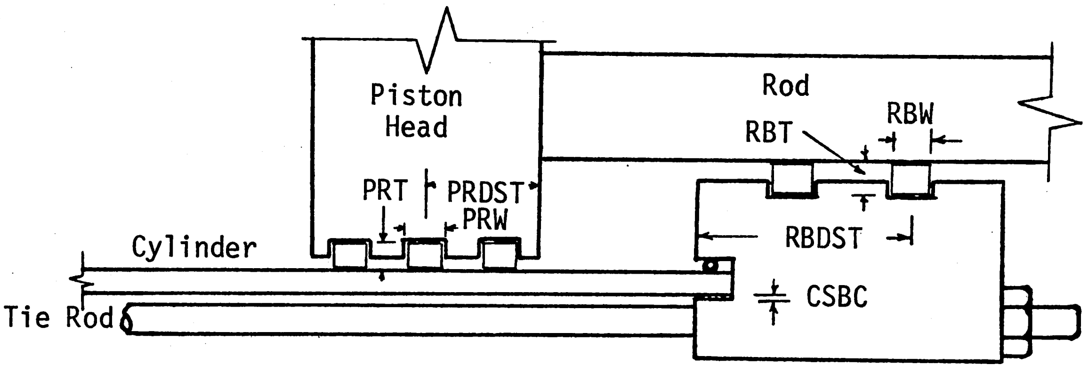


Figure 45. Dimensions of Bearings and Seals for SACTIE

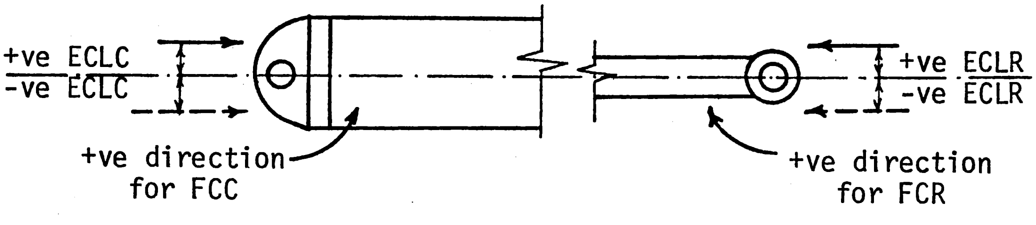
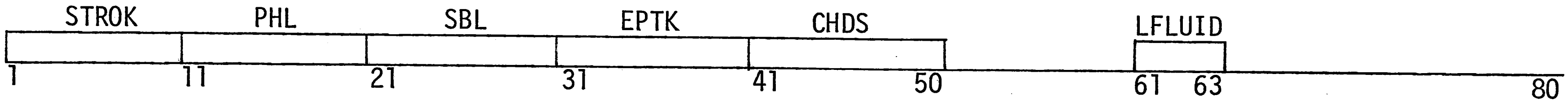


Figure 46. Sign Convention for Eccentricities of Loading and Friction Coefficients for SACTIE

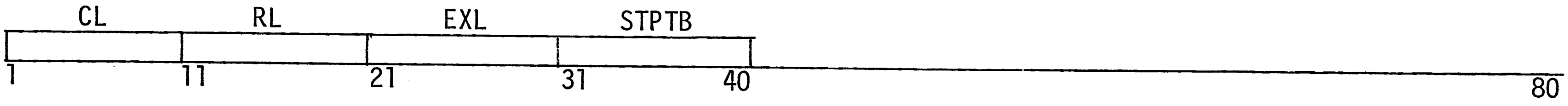


Format--LFLUID - A3; E10.3 for the rest

LFLUID - Enter "YES", for hollow rod with fluid

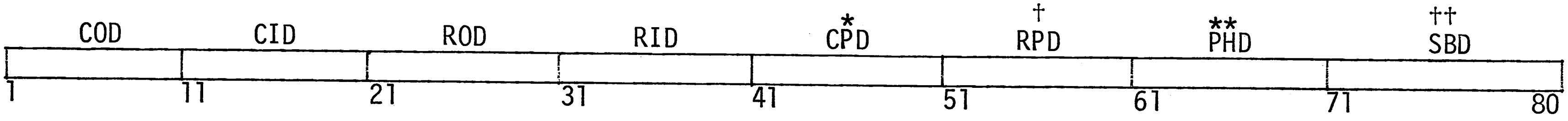
- Enter "NO" or blank, for hollow rod without fluid or solid rod

Card No. 2--Lengths (card No. 2 is not input for LPRTP = 3)



Format--E10.3 for all

Card No. 3--Diameters



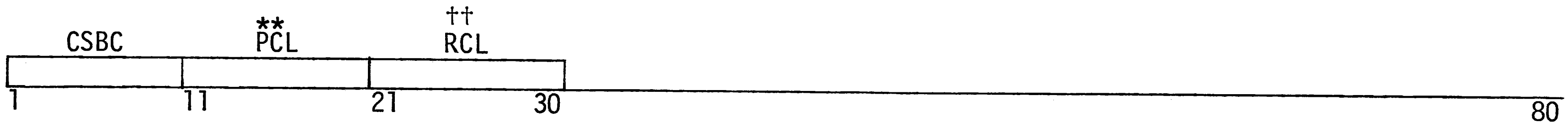
Format--E10.3 for all

* CPD - Leave blank if cylinder support is fixed

† RPD - Leave blank if rod support is fixed

** and †† - See next card

Card No. 4--Clearances

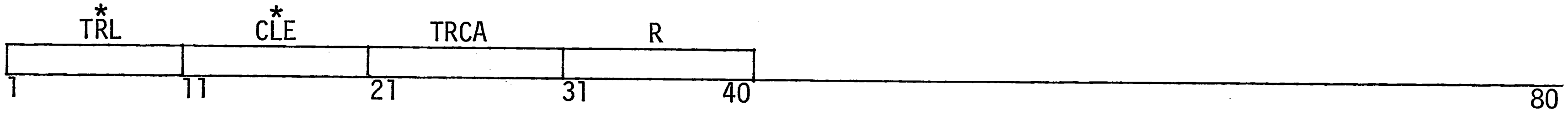


Format--E10.3 for all

** Input either PHD or PCL; if both are input, PCL will be used and PHD will be ignored

†† Input either SBD or RCL; if both are input, RCL will be used and SBD will be ignored

Card No. 5: Tie Rods Details



Format--E10.3 for all

TRL - Tie rod length

CLE - Exact cylinder length

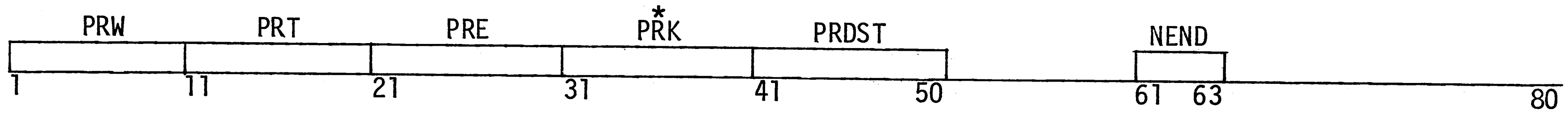
TRCA - Tie rods total cross sectional area

R - Distance of tie rods from cylinder axis in the plane of bending

* TRL and CLE are not input if LPRTP = 3

TABLE 4: BEARINGS AND SEALS (No cards if TABLE 4 is retained from previous problem; see Figure 45 for details

Piston Head Bearing Cards: (one card for each bearing)

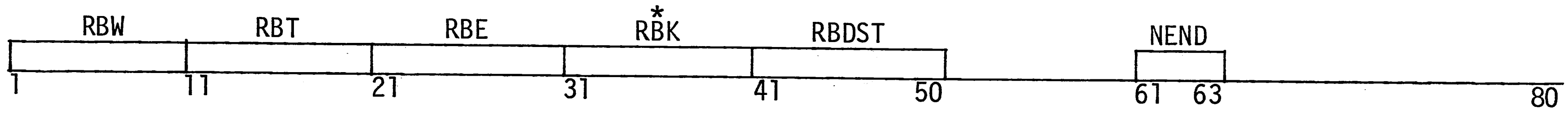


Format--NEND - A3; E10.3 for the rest

NEND - Enter "END" on the last piston head bearing card

* Input either (PRW, PRT and PRE) or (PRK); if PRK and some or all of PRW, PRT, and PRE are input, PRK will be used and the rest ignored

Rod Bearing Cards: (one card for each bearing)



Format--NEND - A3; E10.3 for the rest

NEND - Enter "END" on the last rod bearing card

* Input either (RBW, RBT, and RBE) or (RBK); if RBK and some or all of RBW, RBT and RBE are input, RBK will be used and the rest ignored

PRE and RBE - Young's modulus of piston head bearings and rod bearings

PRK and RBK - Stiffnesses of piston head bearings and rod bearings per unit length (force required to compress a unit length of bearing by one unit)

<u>TABLE 5: WEIGHTS AND MATERIAL PROPERTIES</u> (No cards if TABLE 5 is retained from previous problem)

Card No. 1: For Cylinder and Rod

WC	WR	WPH	WSB	ECYL	EROD	FYCYL	FYROD
1	11	21	31	41	51	61	71 80

Format--E10.3 for all

Card No. 2: For Tie Rods

PRC	ETR	FYTR	TRIF	
1	11	21	31 40	80

Format--E10.3 for all

WC and WR - Weight of cylinder and rod per unit length

WPH - Weight of piston head

WSB - Weight of stuffing box

ECYL, EROD and ETR - Modulus of elasticity of cylinder, rod and tie rods, respectively

FYCYL, FYROD and FYTR - Yield stresses of cylinder, rod and tie rods, respectively

PRC - Poisson's ratio for cylinder material

TRIF - Initial force in tie rods (total of all tie rods)

<u>TABLE 6: INCLINATION, FIXITY, FRICTION COEFFICIENTS, AND LOADING ECCENTRICITIES</u> (No card if TABLE 6 is retained from previous problem)

CINCL		LCEND	LREND	FCC*	FCR*	ECLC*	ECLR*
1 10		31 33	36 38	41	51	61	71 80

Format--LCEND and LREND - A3; E10.3 for the rest

CINCL - Inclination of the cylinder with horizontal (always positive and between 0° and 90°)

LCEND - Enter FIX for fixed or PIN for pinned cylinder support

LREND - Enter FIX for fixed or PIN for pinned rod support

FCC - Friction coefficient at cylinder pin. Leave blank if LCEND is FIX

FCR - Friction coefficient at rod pin. Leave blank if LREND is FIX

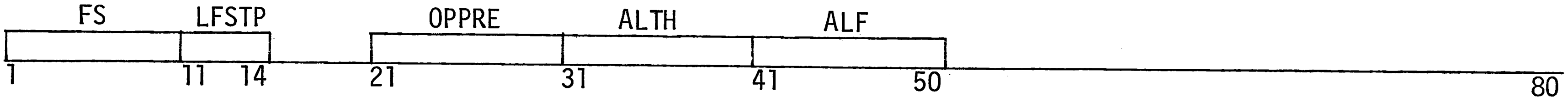
ECLC - Eccentricity of loading at cylinder end

ECLR - Eccentricity of loading at rod end

* See Figure 46 for sign convention

The direction of friction moments at the pins should be visualized by the user depending on the direction of rotation of the pins in the case of rotating pins, and depending on the predicted direction of the slopes at ends of the system for that particular loading, and accordingly proper signs should be assigned for FCC and FCR

TABLE 7: FACTOR OF SAFETY, OPERATING PRESSURE, ALLOWABLE θ and F (No card if TABLE 7 is retained from previous problem)



Format--LFSTP - A4; E10.3 for the rest

If LPRTP = 1 - enter only FS and LFSTP

= 2 - enter only OPPRE

= 3 - enter only OPPRE, ALTH and ALF

FS - Factor of safety

LFSTP - Factor of safety type (enter LOAD if FS is to be applied to the critical load obtained; enter STRS if FS is to be applied to the limiting stresses)

If only critical load analysis is required and no factored load analysis is required, leave this card blank or enter FS $\leq$ 1.0, and LFSTP--LOAD or STRS or blank

OPPRE - Particular operating pressure for which analysis is required

ALTH - Allowable crookedness angle at the sliding connection

ALF - Allowable total lateral force on bearings (total force on piston head bearings or total force on rod bearings which are equal to each other)

NEXT PROBLEM

Start from "PROBLEM IDENTIFICATION" card

END OF RUN

At the end of last problem data set, insert a blank card (only first 4 columns need to be blank, the rest of the card may be used for comments)

```
C     ------------------------------------------------------------------
C     |                                                                |
C     |                                                                |
C     |             STRESS ANALYSIS OF HYDRAULIC CYLINDERS             |
C     |             ------ -------- -- --------- ---------             |
C     |                                                                |
C     |            SIMPLE, REGULAR CYLINDERS WITH TIE RODS             |
C     |                                                                |
C     |                    JANUARY 30, 1976 VERSION                    |
C     |                                                                |
C     |                         K. L. SESHASAI                         |
C     |                                                                |
C     |                  SCHOOL CF CIVIL ENGINEERING                   |
C     |                   OKLAHOMA STATE ONIVERSITY                    |
C     |                     STILLWATER, OK - 74074                     |
C     |                                                                |
C     |                                                                |
C     |   FACTORS CONSIDERED IN THE ANALYSIS:                          |
C     |                                                                |
C     |        1.  SELF WEIGHT                                         |
C     |        2.  LOADING ECCENTRICITY AT BOTH ENDS                   |
C     |        3.  STIFFNESSES OF BEARINGS                             |
C     |        4.  FRICTION MOMENTS AT SUPPORTS                        |
C     |        5.  VARYING CYLINDER SUPPORT LOCATION                   |
C     |        6.  INCLINATICN OF CYLINDER                             |
C     |        7.  END CONDITIONS - PINNED OR FIXED                    |
C     |        8.  SOLID ROD OR HALLOW ROD WITH OR WITHOUT FLUID IN IT |
C     |        9.  TIE ROD FORCES AND MOMENTS PRODUCED BY THEM WHEN    |
C     |            THE CYLINDER IS DEFLECTED                           |
C     |                                                                |
C     |                                                                |
C     |   TYPES OF PROBLEMS:                                           |
C     |                                                                |
C     |        1.  DETERMINATION OF CRITICAL LOAD AND ANALYSIS FOR     |
C     |            CRITICAL AND A FACTORED LOAD                        |
C     |        2.  ANALYSIS FOR A PARTICULAR PRESSURE                  |
C     |        3.  ANALYSIS TO DETERMINE REQUIRED LENGTH OF STOP-TUBE  |
C     |                                                                |
C     |                                                                |
C     |   RESULTS GIVEN BY THE CCMPUTER:                               |
C     |                                                                |
C     |        1.  CRITICAL LOAC AND CORRESPONDING PRESSURE            |
C     |        2.  CROOKEDNESS ANGLE                                   |
C     |        3.  MAX DEFLECTION, MAX LONGITUDINAL AND SHEAR STRESSES,|
C     |            DISTANCE AT WHICH THEY OCCUR, FACTOR OF SAFETY'S ON |
C     |            THESE STRESSES FOR BOTH CYL AND ROD PORTIONS        |
C     |        4.  MAXIMUM STRESSES AT SUPPORTS IN CASE OF FIXED       |
C     |            SUPPORTS ANC FACTOR OF SAFETY ON THIS STRESS        |
C     |        5.  MAXIMUM HOOP STRESS IN CYLINDER, AND ROD ALSO IF    |
C     |            THE ROD IS HALLOW , AND FACTOR OF SAFETY ON THIS    |
C     |        6.  LOAD ON EACH BEARING AND AT OTHER CONTACT POINTS    |
C     |        7.  AXIAL TENSION AND END DEFLECTION IN OVERHANG IN     |
C     |            CASE OF TRUNNICN MCUNT                              |
C     |        8.  REQUIRED LENGTH OF STOP-TUBE ANC CORRESPONDING      |
C     |            EXTENDED LENGTH ( IN ANALYSIS OF TYPE 3. )          |
C     |        9.  TIE ROD FORCES IN CEFLECTED CYLINDER                |
C     |       10.  SEPARATION PRESSURES WITH CYL REMAINING STRAIGHT    |
C     |----------------------------------------------------------------|
```

```
C
C---- >>> MAIN PROGRAM - SACTIE
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / BRGSTF / PRKX, SPRK, RBKY, SRBK
      COMMON / CANDDS / C1, C2, D1, D2
      COMMON / CAREAS / BAREAC, BAREAR, CAREAC, CAREAR, RAREAC
      COMMON / CLEAR  / PCL, RCL
      COMMCN / CLERNC / CSBC, PCL1, RCL1
      COMMON / CONSTS / EEL, FFL, AKTHC, AKTHR
      COMMON / CRPROP / RDZ, CYZ, RDZI, CYZI, HSCCI, HSCCO, HSCRI, HSCRO
      COMMON / DIAMTS / COD, CID, RCD, RID, CPD, RPD, PHD, SBD
      COMMON / ECCTRI / ECLC, ECLR
      COMMON / ENDS   / LCEND, LREND
      COMMON / FRCONS / FCCY, FCRD, CCNM
      COMMON / FSOPTF / OPPRE, ALTH, ALF, FS, LFSTP
      COMMON / GLDFOR / FX(5), FY(5), F1, F2, F3, F4
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
      COMMON / INCLFR / CINCL, FCC, FCR
      COMMCN / LENGTS / STRCK, PHL, SBL, EPTK, CHDS, LFLUID
      COMMON / PISTON / PRW(5), PRT(5), PRE(5), PRK(5), PRDST(5), NPHBR
      COMMON / PROPTS / ECYL, EROD, FYCYL, FYROD
      COMMCN / RODBRS / RBW(5), RBT(5), RBE(5), RBK(5), RBDST(5), NRDBR
      COMMON / STPTBS / CL, RL, STPTB
      COMMCN / TIEROD / TRL, CLE, TRCA, R, PRC, ETR, FYTR, TRIF
      COMMCN / UNITS  / LNTU, LCDU, LPREU, LANGU
      COMMON / WGTCON / WPH, WSB
      COMMON / WGTINI / WC1, WR1, WPH1, WSB1
      COMMON / WGTVER / WC, WR
C
      DATA ZERO, ONE, H180 / 0.0D00, 1.0D00, 180.0D00 /
      DATA PI / 3.141592653589793D00 /
      DATA IBLNK, LOAD, LDEG / 4H    , 4HLOAD, 4HDEG  /
C
              NPROB  = IBLNK
   10 CALL INPECO ( IBLNK, .GC                                         )
              FYCYLT = FYCYL
              FYRODT = FYRCD
      CALL CONST1
     I         ( ECYL, EROD, CHDS, LANGU,
     O          RDI, CYK, RDK, CSSTF, RSSTF                            )
          IF ( LPRTP .EQ. 3 ) GO TO 15
      CALL CONST2 ( FCCN )
   15     CONTINUE
      CALL TRIALP
     I         ( EROD, LPRTP, RDI, FYCYL, BAREAC, HSCCI, LCEND, FYROD,
     I          BAREAR, HSCRI,
     O          PINCR1, PINCR2                                         )
C
C---- >>> KEY-- KWIT IS SETUP TG APPLY FACTOR OF SAFETY AND REPEAT
C         ANALYSIS FOR FACTORED LOAD
C
              KWIT   = 1
C
C---- >>> KEY-- KEYF IS SETUP TO QUIT LOOP AT FINAL ITERATICN
C
   20         KEYF   = 1
```

```
C
C---- >>> KEYST IS SETUP TO CHECK INPUT PRESSURE AGAINST CRITICAL PRE.
C
                KEYST  = 1
C
C---- >>> KEY'S-- KEYT AND KEYP ARE SETUP TO MAKE PROPER LOAD INCREMENTS
C
                KEYT   = 1
                KEYP   = 1
C
C---- >>> INITIALIZE TETA, BMG, AND TRM = ZERO
C
                TETA   = ZERO
                BMG    = ZERO
                TRM    = ZERO
   30 CALL EQBRIM
     I          ( PRK, PRDST, RBK, RBDST, NPHBR, NRDBR, CYK, RDK, LPRTP,
     I           GC, RPD, BMG, CSSTF, RSSTF,
     O           CLT, RLT, CK, RK, BB1, BB2, TETA, DEFG, THC, TRM )
         IF ( LPRTP .NE. 3 ) GO TO 40
         IF ( KEYST .EQ. 1 ) GO TO 40
C
C---- >>> CONVERT ALLOWABLE THETA TO RADIANS, IF INPUT IN DEGREES
C
                ALTH1  = ALTH
                TEMP   = PI / H180
         IF ( LANGU .EQ. LDEG ) ALTH1 = ALTH * TEMP
                ITERAT = 1
      CALL STOPTB
     I          ( TETA, NPHBR, NRDBR, ALTH1, ALF, STROK, ITERAT,      GC )
         IF ( ITERAT .NE. 1 ) GO TO 30
   40 CALL XATYMX
     I          ( CLT, CK, RK, DEFG,
     O           XCY, XRD, CSLPC, CSLPR                                  )
      CALL YMAXS
     I          ( XCY, XRD, CK, RK, CSLPC, CSLPR, BB1, BB2,
     O           YCMAX, YRMAX                                            )
         IF ( LPRTP .NE. 3 ) GO TO 45
      CALL CONST2 ( FCON )
   45    CONTINUE
C
C---- >>> KEY-- KEYTR IS TO QUIT LOOP AND PRINT RESULTS WHEN SEPARATION
C        OCCURS DUE TO LOSS OF TENSION IN TIE RODS
C
                KEYTR  = 1
      CALL STRCHS
     I          ( KEYF, KEYT, KEYP, XCY, XRD, YCMAX, YRMAX, RID, CHDS,
     I           OPPRE, FYRODT, FYCYLT, PINCR1, PINCR2, KEYST, LFLUID,
     I           TRM, FCON, TSTRT, TSTRB, KEYTR,
     O           HSC, HSR, CSTR, CSTRP, RSTR, RSTRP, CSS, NCSS, RSS,NRSS)
C
C---- >>> IS IT FINAL ITERATION? ? ?
C
         IF ( KEYF .NE. 3 ) GO TO 30
         IF ( KEYST .NE. 1 ) GO TO 50
         IF ( LPRTP .EQ. 1 ) GO TO 50
C
C---- >>> PROTECTION AGAINST INPUT OPERATING PRE. BEING > CRITICAL PRE.
```

```
C
                PRES   = P / BAREAC
         IF ( OPPRE .GT. PRES ) GO TO 100
                P      = OPPRE * BAREAC
                KEYST  = 2
                TRM    = ZERO
                TETA   = ZERO
      GO TO 30
   50    IF ( KWIT .NE. 1 ) GO TO 60
      CALL SEPPRE ( CLE                                                  )
   60 CALL OUTPUT
     I          ( KWIT, BAREAC, XCY, XRD, YCMAX, YRMAX, CHDS, GC, TETA,
     I           FYCYL, FYROD, CSTR, CSTRP, RSTR, RSTRP, HSC, HSR, EPTK,
     I           FYTR, KEYTR, NPHBR, NRDBR, THC, CSS, NCSS, RSS, NRSS,
     I           TSTRT, TSTRB                                            )
C
C---- >>> IF THIS PROBLEM IS COMPLETE GO TO NEXT PROBLEM
C
         IF ( KWIT .NE. 1 ) GO TO 10
         IF ( LPRTP .NE. 1 ) GO TO 10
         IF ( FS .LE. ONE ) GO TO 10
C
C---- >>> FACTOR OF SAFETY IS TO BE APPLIED TO STRESS OR LOAD
C
                P      = P / FS
                KWIT   = 2
                TRM    = ZERO
                TETA   = ZERO
         IF ( LFSTP .EQ. LOAD ) GO TO 30
                FYCYLT = FYCYL / FS
                FYRODT = FYROD / FS
         GO TO 20
C
C---- >>> ERROR MESSAGES
C
  100 PRINT 210, PRES
      GO TO 10
  210 FORMAT ( 1H1, 20(/),10(10X,21H*** *** ERROR *** ***  / ),////,
     1          10X, 38HOPERATING PRESSURE IS GREATER THAN THE    /
     2          10X, 42HCAPACITY( CRITICAL LOAD ) OF THE CYLINDER.  //
     3          10X, 37HTHE MAXIMUM PRESSURE FOR THE CYL IS =,1PD10.3,//)
      END
```

```
      SUBRCUTINE INPECC ( IBLNK, GC )
C
C---- >>> SUBROUTINE TO READ AND ECHO INPUT DATA FOR SACREG
C
      IMPLICIT REAL * 8 ( A - H, C - Z )
      COMMON EXL, P
      COMMCN / CLERNC / CSBC, PCL1, RCL1
      COMMON / DIAMTS / COD, CID, RCD, RID, CPD, RPD, PHD, SBD
      COMMCN / ECCTRI / ECLC, ECLR
      COMMON / ENDS   / LCENC, LREND
      COMMON / FSOPTF / OPPRE, ALTH, ALF, FS, LFSTP
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
      COMMCN / INCLFR / CINCL, FCC, FCR
      COMMON / LENGTS / STROK, PHL, SBL, EPTK, CHDS, LFLUID
      COMMON / PISTON / PRW(5), PRT(5), PRE(5), PRK(5), PRDST(5), NPHBR
      COMMCN / PROPTS / ECYL, ERCD, FYCYL, FYROD
      COMMON / RODBRS / RBW(5), RBT(5), RBE(5), RBK(5), RBDST(5), NRDBR
      COMMON / STPTBS / CL, RL, STPTB
      COMMCN / TIEROD / TRL, CLE, TRCA, R, PRC, ETR, FYTR, TRIF
      COMMON / UNITS  / LNTU, LODU, LPREU, LANGU
      CCMMCN / WGTINI / WC1, WR1, WPH1, WSB1
C
      DIMENSION PRK1(5), RBK1(5)
C
      DATA ZERO, ONE, TWO / 0.0D00, 1.0D00, 2.0D00 /
      DATA KEEP, IEND, LYES / 4HKEEP, 3HEND, 3HYES /
C
C---- >>> FORMATS
C
   10 FCRMAT ( 20A4                                                        )
   20 FORMAT ( A4, 19A4                                                    )
   30 FORMAT ( 4X, I1, 5X, 6( A4, 6X )                                     )
   40 FORMAT ( 4X, 4( 6X, A4 )                                             )
   50 FORMAT ( 8F10.0                                                      )
   60 FORMAT ( 5F10.0, 10X, A3                                             )
   70 FORMAT ( F10.0, 20X, A3, 2X, A3, 2X, 4F10.0                          )
   80 FORMAT ( F10.0, A4, 6X, 3F10.0                                       )
   90 FORMAT ( 1H1, 4X, 36HPROGRAM SACTIE - STRESS ANALYSIS OF ,
     1          23HCYLINDERS WITH TIE RODS, //, 2( 5X, 20A4, / ), /        )
  100 FORMAT ( 5X, 8HPROBLEM , A4, //, 1X, 19A4                            )
  110 FORMAT ( /, 5X, 11HINPUT DATA:, //, 5X, 8HTABLE 1:, 5X,
     1          12HCONTROL DATA                                            )
  120 FORMAT ( /, 10X, 41HPROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS,
     1          31H & ANALYSIS FOR A FACTORED LOAD, /                      )
  130 FORMAT ( /, 10X, 27HPRCBLEM TYPE = 2 - ANALYSIS,
     1          26H FOR A PARTICULAR PRESSURE, /                           )
  140 FORMAT ( /, 10X, 27HPRCBLEM TYPE = 3 - ANALYSIS,
     1          39H TO DETERMINE SUITABLE STOP-TUBE LENGTH, /              )
  160 FCRMAT ( /, 18X, 37HTABLES RETAINED FROM PREVIOUS PROBLEM, //,
     1          20X, 2H 2, 4X, 2H 3, 4X, 2H 4, 4X, 2H 5, 4X, 2H 6,
     2          4X, 2H 7, /, 17X, 6( 2X, A4 )                              )
  190 FORMAT ( 23X, 25HNO KEEP OPTIONS EXERCISED, /                        )
  210 FORMAT ( /, 5X, 33HTABLE 2:     UNITS OF MEASUREMENT,//, 17X,
     1          6HLENGTH, 6X, 4HLOAD, 5X, 8HPRESSURE, 3X, 7HANGULAR,
     2          //, 11X, 4( 7X, A4 )                                       )
  220 FORMAT ( //, 5X, 32HTABLE 3:     CYLINDER DIMENSIONS, //, 10X,
     1          8HLENGTHS:, //, 19X, 23HSTROKE       PISTON HEAD, 2X,
     2          40HSTUFFING BCX    ENC PLATE    HINGE DIST., //, 14X,
     3          5( 2X, 1PD12.5 )                                           )
  230 FORMAT ( //, 18X, 20HCYLINDER          ROD, 8X,
     1          23HEXTENDED       STOP TUBE                                )
  240 FORMAT ( /, 14X, 4( 2X, 1PC12.5 )                                    )
  250 FORMAT ( /, 15X, 23HTHESE NOT INPUT BECAUSE,
     1          35H STOP TUBE LENGTH ANALYSIS IS ASKED, /                  )
  260 FORMAT ( /, 10X, 10HDIAMETERS:, //, 17X, 10HCYL. OUTER, 4X,
     1          38HCYL. INNER     ROD OUTER      RCD INNER, /              )
  270 FORMAT (    14X, 4( 2X, 1PD12.5 ), 2X, 9HSOLID ROD, /                )
  280 FORMAT (    14X, 4( 2X, 1PD12.5 ), 2X, 10HHOLLOW ROD                 )
  282 FORMAT (    72X, 10HWITH FLUID                                       )
  284 FORMAT (    72X, 13HWITH NC FLUID                                    )
  290 FORMAT ( /, 18X, 23HCYL. PIN *    ROD PIN *, 3X,
     1          26HPISTON HEAD @  STUF. BOX @,//, 14X, 4( 2X, 1PD12.5 ),
     2          /, 16X, 26H(* ZERC, THE END IS FIXED),
     3          32H (@ ZERO, OTHER OPTION IS INPUT)                        )
  310 FORMAT ( /, 10X, 19HCLEARANCES BETWEEN:, //, 12X,
     1          2( 6X, 8HCYLINDER ), 8X, 3HROD, /, 9X, 3( 11X, 3HAND ),
     2          /, 16X, 12HSTUFFING BOX, 2X, 13HPISTCN HEAD @, 2X,
     3          11HSTUF. BOX @,  //, 14X, 3( 2X, 1PD12.5 ), /, 29X,
     4          31H(@ ZERO, OTHER CPTICN IS INPUT)                         )
  315 FORMAT ( /, 10X,17HTIE RODS DETAILS:,
     1         //, 15X,38HCLEAR TIE ROC LENGTH                = ,1PD12.5,
     2          /, 15X,38HEXACT CYLINDER LENGTH               = ,1PD12.5,
     3          /, 15X,38HTOTAL TIERODS CROSS SECTIONAL AREA  = ,1PD12.5,
     4          /, 15X,38HDIST OF TIE RODS FROM CYL AXIS      = ,1PD12.5,
     5          /, 20X,23H( IN PLANE OF BENDING ), /                       )
  320 FORMAT ( 1H1, 4X, 31HTABLE 4:     BEARINGS AND SEALS, //, 10X,
     1          16HPISTON BEARINGS:, /                                     )
  330 FORMAT (    21X, 3( 2H A, 12X ), 2H B, 7X, 13HDISTANCE FROM, /,
     1          20X, 5HWIDTH, 7X, 9HTHICKNESS, 2X, 14HYOUNGS MODULUS, 3X,
     2          9HSTIFFNESS, 5X, 9HBACK FACE, //,
     3          5( 14X, 5( 2X, 1PD12.5 ), / )                              )
  340 FORMAT (    10X, 13HROC BEARINGS:, /                                 )
  350 FORMAT (    15X, 48H(A IS LSED TO CALCULATE B - HENCE, EITHER A OR
     1          , 10HB IS INPUT, /, 28X,
     2          46HZERO'S ABOVE INCICATE THAT THEY ARE NOT INPUT), /       )
  360 FORMAT ( /, 5X, 44HTABLE 5:     WEIGHTS AND MATERIAL PRCPERTIES,
     1          //, 10X, 17HWEIGHTS OF PARTS:, //, 18X, 8HCYLINDER, 9X,
     2          3HROD, 7X, 11HPISTCN HEAD, 2X, 12HSTUFFING BOX, /, 21X,
     3          17H(PER UNIT LENGTH), //, 14X, 4( 2X, 1PD12.5 ), /         )
  370 FORMAT ( /, 10X,20HMATERIAL PROPERTIES:,
     1         //, 34X,35HCYLINDER         ROD           TIERODS,
     2         //, 15X,15HYOUNGS MODULLS , 3( 2X, 1PD12.5 ) ,
     3         //, 15X,15HYIELD STRESS   , 3( 2X, 1PD12.5 ) ,
     4         //, 15X,15HPOISSCNS RATIO ,    2X, 1PD12.5    ,
     5        ///, 10X,34HTOTAL INITIAL FORCE IN TIE RODS = , 1PD12.5,/ )
  380 FORMAT ( /, 5X, 43HTABLE 6:     INCLINATION, FIXITY, FRICTION ,
     1          34HCOEFFICIENTS, LOADING ECCENTRICITY, //, 10X,
     2          34HCYL INCLINATION WITH HORIZONTAL = , 1PD12.5, //, 46X,
     3          24HCYLINDER END     RCD END, //, 10X,
     4          19HSUPPORT CONDITIONS:, 21X, A3, 12X, A3, //, 10X,
     5          36HFRICTION COEFFICIENTS AT SUPPORTS:  , 2( 1PD12.5, 2X )
     6          /, 15X, 19H(ZERG IF FIXED END), /, 10X,
     7          23HLOADING ECCENTRICITIES:, 13X, 2( 1PD12.5, 2X ), /       )
  390 FORMAT ( /, 5X, 42HTABLE 7:     FACTOR OF SAFETY OR OPERATING,
     1          36H PRESSURE AND/OR ALLOWABLE THETA & F, /, 18X,
     2          25HDEPENDING ON PROBLEM TYPE, /                            )
```

```
 400 FORMAT ( /, 10X, 27HONLY CRITICAL LOAD ANALYSIS , /                 )
 410 FORMAT ( /, 10X, 19HFACTOR OF SAFETY = , F6.3, 4H ON , A4, /       )
 420 FORMAT ( /, 10X, 21HOPERATING PRESSURE = , 1PD12.5, /              )
 430 FORMAT ( /, 10X, 32HOPERATING CYLINDER PRESSURE    = , 1PD12.5,//,
    1           10X, 32HALLOWABLE CROOKEDNESS ANGLE    = , 1PD12.5,
    2           10H  AT GLAND, //,10X,32HALLOWABLE TOTAL LATERAL FORCE =
    3           1PD12.5, 13H  ON BEARINGS, /                            )
 450 FORMAT ( ///, 10X, 30H*****  ERROR IN LENGTHS  *****, /            )
 460 FORMAT ( ///, 10X, 7H*****  ,
    1           32HERROR : PHD IS GREATER THAN CID , 6H *****, /        )
 470 FORMAT ( ///, 10X, 7H*****  ,
    1           37HERROR : RD IS GREATER THAN SBD  *****, /             )
 480 FORMAT ( //, 10X, 6H***** , 19HPROGRAM TERMINATED , 5H*****        )
 490 FORMAT ( 1H1                                                       )
C
C---- >>> READ AND ECHC RUN AND PROBLEM IDENTIFICATION
C
          IF ( NPROB .NE. IBLNK ) GO TO 500
      READ ( 5, 10 ) ( IDCARD( I ), I = 1, 40 )
 500  READ ( 5, 20 ) NPROB, ( IPROB( I ), I = 1, 19 )
C
C---- >>> TEST FOR END OF RUN
C
          IF ( NPROB .EQ. IBLNK ) GO TO 1700
      PRINT 90, ( IDCARD( I ), I = 1, 40 )
      PRINT 100, NPROB, ( IPROB( I ), I = 1, 19 )
C
C---- >>> READ TABLE 1:  PROBLEM TYPE AND TABLES TO BE RETAINED FROM
C                        PREVIOUS PROBLEM
C
      READ ( 5, 30 ) LPRTP, KEEP2, KEEP3, KEEP4, KEEP5, KEEP6, KEEP7
          IF ( KEEP2 .EQ. KEEP ) GO TO 510
C
C---- >>> READ TABLE 2:  UNITS CF MEASUREMENT
C
      READ ( 5, 40 ) LNTU, LODU, LPREU, LANGU
 510      IF ( KEEP3 .EQ. KEEP ) GO TO 540
      READ ( 5, 60 ) STROK, PHL, SBL, EPTK, CHDS, LFLUID
          IF ( LPRTP .EQ. 3 ) GO TO 520
C
C---- >>> READ TABLE 3:  LENGTHS AND DIAMETERS
C
      READ ( 5, 50 ) CL, RL, EXL, STPTB
 520  READ ( 5, 50 ) COD, CID, ROD, RID, CPD, RPD, PHD, SBD
      READ ( 5, 50 ) CSBC, PCL1, RCL1
      READ ( 5, 50 ) TRL, CLE, TRCA, R
C
C---- >>> CALCULATE GLAND CLEARANCE
C
              GC      = ZERO
          IF ( LPRTP .NE. 3 ) GC = CL - STROK - PHL
C
C---- >>> TEST FOR PROPER INPUT
C
          IF ( LPRTP .EQ. 3 ) GO TC 530
              A       = EXL - CHDS - EPTK - CL - SBL - RPD / TWO
          IF ( A .LT. STROK ) GO TO 1000
 530      IF ( ( PCL1 .GT. ZERC ) .OR. ( RCL1 .GT. ZERO ) ) GO TO 540
          IF ( PHD .GT. CIC ) GC TC 1100
          IF ( ROD .GT. SBD ) GO TO 1200
C
 540      IF ( KEEP4 .EQ. KEEP ) GC TC 585
C
C---- >>> READ TABLE 4:  PISTON RINGS AND ROD BEARINGS DETAILS
C
              I = 1
              J = 1
 550  READ ( 5, 60 ) PRW(I), PRT(I), PRE(I), PRK1(I), PROST(I), NEND
              PRK(I) = PRK1(I)
          IF ( NEND .EQ. IEND ) GO TO 560
              I = I + 1
          GO TO 550
 560          NPHBR  = I
 570  READ ( 5, 60 ) RBW(J), RBT(J), RBE(J), RBK1(J), RBDST(J), NEND
              RBK(J) = RBK1(J)
          IF ( NEND .EQ. IEND ) GO TO 580
              J = J + 1
          GU TO 57C
 580          NRDBR  = J
 585      IF ( KEEP5 .EQ. KEEP ) GC TC 590
C
C---- >>> READ TABLE 5:  WEIGHTS OF PARTS AND MATERIAL PROPERTIES
C
      READ ( 5, 50 ) WC1, WR1, WPH1, WSB1, ECYL, ERCD, FYCYL, FYROD
      READ ( 5, 50 ) PRC, ETR, FYTR, TRIF
 590      IF ( KEEP6 .EQ. KEEP ) GC TC 600
C
C---- >>> READ TABLE 6:  INCLINATION, END FIXITY, FRICTION COEFFICIENTS
C                        AND ECCENTRICITY OF LOADING
C
      READ ( 5, 70 ) CINCL, LCENC, LREND, FCC, FCR, ECLC, ECLR
 600      IF ( KEEP7 .EQ. KEEP ) GO TC 610
C
C---- >>> READ TABLE 7:  FACTOR OF SAFETY AND ITS TYPE, OPERATING
C                        PRESSURE AND ALLOWABLE THETA AND LATERAL FORCE
C                        DEPENDING ON THE PROBLEM TYPE
C
      READ ( 5, 80 ) FS, LFSTP, CPPRE, ALTH, ALF
 610      CONTINUE
C
C---- >>> PRINT ALL THE TABLES REAC
C
      PRINT 110
          IF ( LPRTP .EQ. 1 ) PRINT 120
          IF ( LPRTP .EQ. 2 ) PRINT 130
          IF ( LPRTP .EQ. 3 ) PRINT 140
      PRINT 160, KEEP2, KEEP3, KEEP4, KEEP5, KEEP6, KEEP7
          IF ( KEEP2 .NE. IBLNK ) GO TO 620
          IF ( KEEP3 .NE. IBLNK ) GO TO 620
          IF ( KEEP4 .NE. IBLNK ) GO TC 620
          IF ( KEEP5 .NE. IBLNK ) GO TO 620
          IF ( KEEP6 .NE. IBLNK ) GO TO 620
          IF ( KEEP7 .EQ. IBLNK ) PRINT 190
 620      CONTINUE
      PRINT 210, LNTU, LODU, LPREU, LANGU
      PRINT 220, STROK, PHL, SBL, EPTK, CHDS
```

```
      PRINT 230
          IF ( LPRTP .EQ. 3 ) GO TO 640
      PRINT 240, CL, RL, EXL, STPTB
      GO TO 650
  640 PRINT 250
  650 PRINT 260
          IF ( RID .GT. ZERO ) GO TO 670
      PRINT 270, COD, CID, ROD, RID
      GO TO 680
  670 PRINT 280, COD, CID, ROD, RID
          IF ( LFLUID .NE. LYES ) GO TO 675
      PRINT 282
      GO TO 680
  675 PRINT 284
  680 PRINT 290, CPD, RPD, PHD, SBD
      PRINT 310, CSBC, PCL1, RCL1
      PRINT 315, TRL, CLE, TRCA, R
      PRINT 320
      PRINT 330, ( PRW(I), PRT(I), PRE(I), PRK1(I),PRDST(I),I=1, NPHBR )
      PRINT 340
      PRINT 330, ( RBW(I), RBT(I), RBE(I), RBK1(I),RBDST(I),I=1, NRDBR )
      PRINT 350
      PRINT 360, WC1, WR1, WPH1, WSB1
      PRINT 370, ECYL, EROD, ETR, FYCYL, FYROD, FYTR, PRC, TRIF
      PRINT 380, CINCL, LCEND, LREND, FCC, FCR, ECLC, ECLR
      PRINT 390
          IF ( LPRTP .EQ. 1 .AND. FS .LE. ONE ) GO TO 690
          IF ( LPRTP .EQ. 1 ) PRINT 410, FS, LFSTP
          GO TO 700
  690 PRINT 400
  700     IF ( LPRTP .EQ. 2 ) PRINT 420, OPPRE
          IF ( LPRTP .EQ. 3 ) PRINT 430, OPPRE, ALTH, ALF
      RETURN
C
C---- >>> DIAGONOSTICS FOR ILLEGAL INPUTS
C
 1000 PRINT 450
      GO TO 1600
 1100 PRINT 460
      GO TO 1600
 1200 PRINT 470
 1600 PRINT 480
 1700 PRINT 490
C
C---- >>> END OF RUN IF ERROR IN INPUT IS ENCOUNTERED
C
      STOP
      END
```

```
      SUBROUTINE CONSTI
     I          ( ECYL, EROD, CHDS, LANGU,
     O            RDI, CYK, RDK, CSSTF, RSSTF                                )
C
C---- >>> SUBROUTINE TO CALCULATE CONSTANT TERMS FOR CONVENIENCE
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / BRGSTF / PRKX, SPRK, RBKY, SRBK
      COMMON / CAREAS / BAREAC, BAREAR, CAREAC, CAREAR, RAREAC
      COMMON / CLEAR  / PCL, RCL
      COMMON / CLERNC / CSBC, PCL1, RCL1
      COMMON / CRPROP / RDZ, CYZ, RDZI, CYZI, HSCCI, HSCCO, HSCRI, HSCRO
      COMMON / DIAMTS / COD, CID, ROD, RID, CPD, RPD, PHD, SBD
      COMMON / ENDS   / LCEND, LREND
      COMMON / FRCONS / FCCY, FCRD, CONM
      COMMON / INCLFR / CINCL, FCC, FCR
      COMMON / PISTON / PRW(5), PRT(5), PRE(5), PRK(5), PRDST(5), NPHBR
      COMMON / RODBRS / RBW(5), RBT(5), RBE(5), RBK(5), RBDST(5), NRDBR
      COMMON / WGTCON / WPH, WSB
      COMMON / WGTINI / WC1, WR1, WPH1, WSB1
      COMMON / WGTVER / WC, WR
C
      DATA ZERO, TWO, FOUR, SXTFOR / 0.0D00, 2.0D00, 4.0D00, 64.0D00 /
      DATA H180, AINFIN / 180.0D00, 1.0D20 /
      DATA PI / 3.14159265358979D00 /
      DATA LDEG, LFIX / 4HDEG , 3HFIX /
C
C---- >>> CALCULATE STIFFNESSES OF BEARINGS AND SEALS IF NOT INPUT
C
                SPRK    = ZERO
                PRKX    = ZERO
      DO 110 I = 1, NPHBR
          IF ( PRK(I) .GT. ZERO ) GO TO 100
                PRK(I) = CID * PRW(I) * PRE(I) / PRT(I)
  100           PRKX    = PRK(I) * PRDST(I) + PRKX
  110           SPRK    = PRK(I) + SPRK
                SRBK    = ZERO
                RBKY    = ZERO
      DO 130 I = 1, NRDBR
          IF ( RBK(I) .GT. ZERO ) GO TO 120
                RBK(I) = ROD * RBW(I) * RBE(I) / RBT(I)
  120           RBKY    = RBK(I) * RBDST(I) + RBKY
  130           SRBK    = RBK(I) + SRBK
C
C---- >>> CALCULATE CROSS SECTIONAL PROPERTIES
C
                ROD2    = ROD * ROD
                RID2    = RID * RID
                COD2    = COD * COD
                CID2    = CID * CID
                RDI     = PI * ( ROD2 * ROD2 - RID2 * RID2 ) / SXTFOR
                CYI     = PI * ( COD2 * COD2 - CID2 * CID2 ) / SXTFOR
                RDZ     = RDI * TWO / ROD
                CYZ     = CYI * TWO / COD
                RDZI    = 1.0D+20
          IF ( RID .GT. ZERO ) RDZI = RDI * TWO / RID
                CYZI    = CYI * TWO / CID
C
```

```
C---- >>> BORE AREAS AND CROSS SECTIONAL AREAS OF CYLINDER AND ROD
C
              BAREAC = PI * CIC2 / FCUR
              BAREAR = PI * RID2 / FCUR
              RAREAC = PI * ( CID2 - ROD2 ) / FOUR
              CAREAC = PI * ( CCD2 - CID2 ) / FOUR
              CAREAR = PI * ( ROD2 - RID2 ) / FOUR
C
C---- >>> CALCULATE HOOP STRESS CCEFFICIENT
C
              RDENC  = COD2 - CID2
              HSCCI  = ( CCD2 + CID2 ) / RDENC
              HSCCO  = TWO * CID2 / RDENC
              RDENR  = ROD2 - RIC2
              HSCRI  = ( ROD2 + RID2 ) / RDENR
              HSCRO  = TWO * RID2 / RDENR
              CYK    = DSQRT ( ECYL * CYI )
              RDK    = DSQRT ( EROD * RDI )
C
C---- >>> CALCULATE CLEARANCES AT PISTON HEAD AND STUFFING BOX
C
              PCL    = ( CID - PHD ) / TWO
          IF ( PCL1 .GT. ZERC ) PCL = PCL1
              RCL    = ( SBD - RCD ) / TWO + CSBC
          IF ( RCL1 .GT. ZERO ) RCL = RCL1 + CSBC
C
C---- >>> CALCULATE VERTICAL CCMPONENTS OF WEIGHTS
C
              TEMP   = PI / H180
              BETA   = CINCL
          IF ( LANGU .EQ. LDEG ) BETA = CINCL * TEMP
              CB     = DCOS( BETA )
              WC     = WC1 * CB
              WR     = WR1 * CB
              WPH    = WPH1 * CB
              WSB    = WSB1 * CB
C
C---- >>> CALCULATE FRICTION MCMENT COEFFICIENTS
C
              FCCY   = FCC * CPD / TWO
              FCRD   = FCR * RPC / TWO
C
C---- >>> ESTABLISH STIFFNESSES FOR ROTATIONAL SPRINGS AT SUPPORTS
C         ZERO IF PIN; VERY HIGH IF FIX.
C
              CSSTF  = ZERO
              RSSTF  = ZERC
          IF ( LCEND .EQ. LFIX ) CSSTF = AINFIN
          IF ( LREND .EQ. LFIX ) RSSTF = AINFIN
C
C---- >>> MOMENT DUE TO OVER HANG
C
              CONM   = WC * CHCS * CHDS / TWO
          IF ( CHDS .GT. ZERC ) CCNM = ZERO
          IF ( LCEND .EQ. LFIX ) CONM = ZERO
      RETURN
      END
```

```
      SUBROUTINE CONST2 ( FCCN )
C
C---- >>> SUBROUTINE TO CALCULATE THE CONSTANT TERMS INVOLVED IN
C         TIE ROD STRESS AND SEPARATICN PRESSURES CALCULATICNS
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / CAREAS / BAREAC, BAREAR, CAREAC, CAREAR, RAREAC
      COMMON / LENGTS / STROK, PHL, SBL, EPTK, CHDS, LFLUID
      COMMCN / FRCPTS / ECYL, ERCD, FYCYL, FYROD
      COMMON / SEPCON / SLAE, TEMPC, TEMPR, CCL, FBAC, FBAR
      COMMON / STPTBS / CL, RL, STPTB
      COMMCN / TIEROD / TRL, CLE, TRCA, R, PRC, ETR, FYTR, TRIF
C
      DATA ZERC, TWO / 0.0C00, 2.0D00 /
C
              SLAE   = TRL * CAREAC * ECYL / ( TRCA * ETR ) + CLE
              FBAC   = TRIF / BAREAC
              FBAR   = TRIF / RAREAC
              PLC    = CL - STPTB - PHL
              PLR    = CL - PHL
              TEMPC  = TWC * PRC * PLC
              TEMPR  = TWC * PRC * PLR
              FCON   = TEMPC / SLAE
              CCL    = CHDS + EPTK
          IF ( CCL .GT. ZERO ) RETURN
              FCON   = ( CCL + TEMPC ) / SLAE
      RETURN
      END
```

```
      SUBROUTINE TRIALP
     I          ( EROD, LPRTP, RDI, FYCYL, BAREAC, HSCCI, LCEND, FYROD,
     I            BAREAR, HSCRI,
     O            PINCR1, PINCR2                                          )
C
C---- >>> SUBROUTINE TO CALCULATE TRIAL LOAD AND LOAD INCREMENTS
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P1
      COMMON / LENGTS / STROK, PHL, SBL, EPTK, CHDS, LFLUID
C
      DATA TWO, FIFTY, FIVHUN / 2.0D00, 50.0D00, 500.0D00 /
      DATA PI / 3.141592653589793D00 /
      DATA LFIX, LYES / 3HFIX, 3HYES /
C
C---- >>> IF LPRTP = 3 CALCULATE APPROXIMATE EXTENDED LENGTH
C
          IF ( LPRTP - 3 ) 110, 100, 110
  100         EXL     = STROK + STROK + PHL + SBL + CHDS + EPTK
C
C---- >>> TRIAL LOAD (1) AS PER EULERS BUCKLING, CONSIDERING FULL
C         LENGTH STIFFNESS AS THAT OF ROD ONLY
C
  110         P1      = PI * PI * EROD * RDI / ( EXL * EXL )
          IF ( LCEND .EQ. LFIX ) P1 = TWO * P1
C
C---- >>> TRIAL LOAD (2) AS PER EXCESSIVE HOOP STRESS RESTRICTION IN CYL
C
              P2      = FYCYL * BAREAC / HSCCI
C
C---- >>> TRIAL LOAD (3) AS PER EXCESSIVE HOOP STRESS RESTRICTION IN ROD
C
              P3      = FYROD * BAREAR / HSCRI
          IF ( LFLUID .NE. LYES ) P3 = P2
C
C---- >>> TRIAL LOAD, SMALLER OF (1), (2) AND (3)
C
              P1      = DMIN1( P1, P2, P3 )
C
C---- >>> CALCULATE LOAD INCREMENTS
C
              PINCR1 = P1 / FIFTY
              PINCR2 = P1 / ( FIVHUN * TWO )
      RETURN
      END
```

```
      SUBROUTINE EQBRIM
     I          ( PRK, PRDST, RBK, RBDST, NPHBR, NRDBR, CYK, RDK, LPRTP,
     I            GC, RPD, BMG, CSSTF, RSSTF,
     O            CLT, RLT, CK, RK, BB1, BB2, TETA, DEFG, THC, TRM )
C
C---- >>> SUBROUTINE TO CALCULATE CONSISTENT VALUES OF DEFLECTIONS AND
C         CROOKEDNESS ANGLE BY ITERATING, FOR A PARTICULAR VALUE OF LOAD
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / BRGSTF / PRKX, SPRK, RBKY, SRBK
      COMMON / CANDDS / C1, C2, D1, D2
      COMMON / CLEAR  / PCL, RCL
      COMMON / CONSTS / EEL, FFL, AKTHC, AKTHR
      COMMON / ECCTRI / ECLC, ECLR
      COMMON / FRCONS / FCCY, FCRD, CONM
      COMMON / GLDFOR / FX(5), FY(5), F1, F2, F3, F4
      COMMON / LENGTS / STROK, PHL, SBL, EPTK, CHDS, LFLUID
      COMMON / REATNS / REC, RER
      COMMON / STPTBS / CL, RL, STPTB
      COMMON / TIEROD / TRL, CLE, TRCA, R, PRC, ETR, FYTR, TRIF
      COMMON / WGTCON / WPH, WSB
      COMMON / WGTVER / WC, WR
C
      DIMENSION PRK( NPHBR ), PRDST( NPHBR ), RBK( NRDBR ),RBDST(NRDBR)
C
      DATA ZERO, TWO, HUNDRD / 0.0D00, 2.0D00, 100.0D00 /
      DATA LFIX / 3HFIX /
C
              TRMOM  = TRM
              M      = 1
              N      = 1
          IF ( LPRTP .NE. 3 ) GO TO 50
C
C---- >>> CALCULATE CYLINDER, ROD AND EXTENDED LENGTHS IN CASE OF
C         STOP-TUBE LENGTH DETERMINATION ANALYSIS
C
              CL      = STROK + PHL + GC
              RL      = STROK + SBL + RPD / TWO + GC
              EXL     = CL + EPTK + CHDS + RL - GC
              TRL     = CL + EPTK + SBL
              CLE     = CL
          GO TO 50
C
C---- >>> CALCULATE TRANSFORMED CYLINDER AND ROD LENGTHS
C
   20         CLT     = CL + EPTK + CHDS - Y
              RLT     = RL - X
C
C---- >>> CALCULATE EQUIVALENT CONCENTRATED LATERAL LOAD AT STEP
C
              W       = WPH + WSB + WC * Y + WR * X
C
C---- >>> CALCULATE LATERAL REACTIONS AT SUPPORTS
C
              REC     = ( W  * RLT + CONM + WC * CLT * ( RLT + CLT / TWO
     *                  ) + WR * RLT * RLT / TWO ) / EXL
              RER     = W + WC * CLT + WR * RLT - REC
```

```
      CALL THCOS
     I          ( CYK, RDK, CLT, RLT, CSSTF, RSSTF, TETA, W, TRMOM,
     O           BB1, BB2, CK, RK, CK1L1, SK1L1, THC )
C
C---- >>> CALCULATE DEFLECTION AT SLIDING CONNECTION
C
                DEFG1   = ( AKTHC - AKTHR ) * CLT / EXL - wC * CLT * CLT /
     *                      ( TWC * P )
                DEFG    = C1 * CK1L1 + D1 * SK1L1 - EEL * CLT + FFL * CLT
     *                  - DEFG1 + BB1 - REC * CLT / P
C
C---- >>> CALCULATE CYLINDER SLOPE AT SLIDING CONNECTION
C
                THCG    = - C1 * CK * SK1L1 + D1 * CK * CK1L1 - EEL + FFL
     1                  - ( AKTHC - AKTHR ) / EXL - ( REC - wC * CLT ) / P
C
C---- >>> CALCULATE TIE RCD MOMENT
C
                TRM     = R * R * ( THC - THCG ) * TRCA * ETR / TRL
C
C---- >>> CALCULATE BENDING MCMENT AT INTERFACE
C
                BMG     = P * CLT * ( EEL - FFL ) + DEFG1 * P + P * ECLC
     *                  + REC * CLT - CCNM - P * ( FCCY + AKTHC - DEFG )
C
C---- >>> CALCULATE CROOKEDNESS ANGLE - THETA, AT SLIDING CONNECTION
C
   50 CALL THETA
     I          ( PRK, PRDST, RBK, RBDST, NPHBR, NRDBR, GC, BMG, PHL,SBL,
     O           X, Y, TETAF  )
                N       = N + 1
            IF ( N - 2 ) 20, 20, 60
   60           DTETA   = DABS( TETA / HUNDRD )
                DIFF    = DABS( TETAF - TETA )
                TETA    = TETAF
C
C---- >>> ARE INITIAL AND FINAL THETAS CLOSE?
C
            IF ( DIFF .LT. DTETA ) GO TC 80
            IF ( N .GT. 25 ) GO TO 80
            GO TO 20
   80           TRMOM   = TRMOM + TRM / HUNDRD
C
C---- >>> IS TIE RCD MCMENT CONVERGINC TU A CONSTANT VALUE?
C
            IF ( DABS( TRMOM ) .GT. DABS( TRM ) ) RETURN
                M       = M + 1
            IF ( M .GT. 100 ) RETURN
            GC TC 20
      END
```

```
      SUBROUTINE THETA
     I          ( PRK, PRDST, RBK, RBDST, NPHBR, NRDBR, GC, BMG, PHL,SBL,
     O           X, Y, TETA   )
C
C---- >>> SUBROUTINE TU CALCULATE CROOKEDNESS ANGLE AND FORCES AT
C           INTERFACE
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / BRGSTF / PRKX, SPRK, RBKY, SRBK
      COMMON / CLEAR / PCL, RCL
      COMMCN / GLDFCR / FX(5), FY(5), F1, F2, F3, F4
C
      DIMENSIUN PRK( NPHBR ), PRDST( NPHBR ), RBK( NRDBR ),RBDST(NRDBR)
C
      DATA ZERO, ONE, TWO / 0.0D00, 1.0D00, 2.0D00 /
C
C---- >>> MCNITOR FOR PROPER SIGN
C
                SIGN    = ONE
            IF ( BMG ) 80 , 100, 80
   80           SIGN    = BMG / DABS( BMG )
  100           SRPBK   = SRBK + SPRK
                F1      = ZERC
                F2      = ZERO
                F3      = ZERO
                F4      = ZERO
C
C---- >>> CASE 1:  NO METAL TO METAL CONTACT AT SLIDING CONNECTICN
C
                X       = ( RBKY + GC * SRBK - PRKX ) / SRPBK
                Y       = GC - X
            IF ( PCL .EQ. ZERO .AND. RCL .EQ. ZERO ) GO TO 690
                CF      = ZERC
            DO 130 I = 1, NPHBR
  130           CF      = CF + PRK(I) * ( X + PRDST(I) ) * ( X + PRDST(I))
            DO 140 I = 1, NRDBR
  140           CF      = CF + RBK(I) * ( Y + RBDST(I) ) * ( Y + RBDST(I))
                TETA    = BMG / CF
                D1      = ( X + PHL ) * DABS( TETA )
                D2      = ( Y + SBL ) * DABS( TETA )
            IF ( D1 .GE. PCL .AND. D2 .GE. RCL ) GO TO 170
            IF ( D1 - PCL ) 150, 200, 200
  150       IF ( D2 - RCL ) 750, 3CC, 3CO
  170           D22     = PCL * ( Y + SBL ) / ( X + PHL )
            IF ( D22 - RCL ) 200, 300, 300
C
C---- >>> CASE 2:  CONTACT AT FRCNT FACE OF PISTON HEAD
C
  2C0           XNUM    = ZERC
                XDEN    = ZERO
                A       = PHL + GC
                B       = DABS( BMG ) / PCL
            DO 210 I = 1, NPHBR
                TEMP    = PRK(I) * ( PHL - PRDST(I) )
                XDEN    = XDEN + TEMP
  210           XNUM    = XNUM + TEMP * PRDST(I)
                XNUM    = - XNUM
            DC 220 I = 1, NRDBR
```

```
                TEMP    = RBK(I) * ( A + RBDST(I) )
                XDEN    = XDEN + TEMP
  220           XNUM    = XNUM + TEMP * ( GC + RBDST(I) )
                XNUM    = XNUM - B * PHL
                XDEN    = B + XDEN
                X       = XNUM / XDEN
                Y       = GC - X
                TETA    = PCL / ( X + PHL ) * SIGN
                D3      = DABS( TETA * X )
                D2      = ( Y + SBL ) * DABS( TETA )
            IF ( D3 .GE. PCL .AND. D2 .GE. RCL ) GO TO 270
            IF ( D3 - PCL ) 240, 400, 400
  240       IF ( D2 - RCL ) 250, 600, 600
  250           F1      = TETA * ( RBKY + GC * SRBK - PRKX - X * SRPBK )
            GO TO 750
  270           TETA    = PCL * TWO / PHL
                D2      = ( PHL / TWO + GC + SBL ) * TETA
            IF ( D2 - RCL ) 400, 600, 600
C
C---- >>> CASE 3:  CONTACT AT FRONT FACE OF STUFFING BOX
C
  300           XNUM    = ZERO
                XDEN    = ZERO
                A       = SBL + GC
                B       = DABS( BMG ) / RCL
            DO 310 I = 1, NPHBR
                TEMP    = PRK(I) * ( A + PRDST(I) )
                XDEN    = XDEN + TEMP
  310           XNUM    = XNUM + TEMP * PRDST(I)
                XNUM    = - XNUM
            DO 320 I = 1, NRDBR
                TEMP    = RBK(I) * ( SBL - RBDST(I) )
                XDEN    = XDEN + TEMP
  320           XNUM    = XNUM + TEMP * ( GC + RBDST(I) )
                XNUM    = XNUM + B * A
                XDEN    = B + XDEN
                X       = XNUM / XDEN
                Y       = GC - X
                TETA    = RCL / ( Y + SBL ) * SIGN
                D1      = ( X + PHL ) * DABS( TETA )
                D4      = DABS( TETA * Y )
            IF ( D1 .GE. PCL .AND. D4 .GE. RCL ) GO TO 370
            IF ( D1 - PCL ) 340, 600, 600
  340       IF ( D4 - RCL ) 350, 500, 500
  350           F2      = TETA * ( X * SRPBK - RBKY - GC * SRBK + PRKX )
            GO TO 750
  370           TETA    = RCL * TWO / SBL
                D1      = ( PHL + GC + SBL / TWO ) * DABS( TETA )
            IF ( D1 - PCL ) 500, 600, 600
C
C---- >>> CASE 4:  CONTACT AT FRONT AND BACK FACES OF PISTON HEAD
C
  400           X       = - PHL / TWO
                TETA    = TWO * PCL / PHL * SIGN
                Y       = GC - X
C
        CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                 FX )
        CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                 FY )
```

```
            DO 470 I = 1, NPHBR
                F3      = F3 + FX(I)
  470           F1      = F1 + FX(I) * PRDST(I)
            DO 480 I = 1, NRDBR
                F3      = F3 - FY(I)
  480           F1      = F1 + FY(I) * ( GC + RBDST(I) )
                F1      = ( BMG - F1 ) / PHL
                F3      = F1 + F3
        RETURN
C
C---- >>> CASE 5:  CONTACT AT FRONT AND BACK FACES OF STUFFING BOX
C
  500           X       = GC + SBL / TWO
                TETA    = TWO * RCL / SBL * SIGN
                Y       = GC - X
        CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                 FX )
        CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                 FY )
            DO 570 I = 1, NPHBR
                F2      = - FX(I) * ( GC + PRDST(I) ) + F2
  570           F4      = - FX(I) + F4
            DO 580 I = 1, NRDBR
                F2      = F2 - FY(I) * RBDST(I)
  580           F4      = F4 + FY(I)
                F2      = ( BMG + F2 ) / SBL
                F4      = F2 + F4
        RETURN
C
C---- >>> CASE 6:  CONTACT AT FRONT FACE OF PISTON HEAD AND FRONT FACE
C                  OF STUFFING BOX
C
  600           TETA    = ( PCL + RCL ) / ( PHL + GC + SBL ) * SIGN
                X       = PCL / DABS( TETA ) - PHL
                Y       = GC - X
        CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                 FX )
        CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                 FY )
            DO 670 I = 1, NPHBR
                F1      = - FX(I) * ( SBL + GC + PRDST(I) ) + F1
  670           F2      = FX(I) + F2
            DO 680 I = 1, NRDBR
                F1      = F1 + FY(I) * ( SBL - RBDST(I) )
  680           F2      = - FY(I) + F2
                F1      = ( BMG + F1 ) / ( PHL + GC + SBL )
                F2      = F1 + F2
        RETURN
  690           TETA    = ZERO
  750   CALL GFORCE ( PRK, PRDST, TETA, X, NPHBR,                 FX )
        CALL GFORCE ( RBK, RBDST, TETA, Y, NRDBR,                 FY )
        RETURN
        END
```

```
      SUBROUTINE GFORCE
     I                   ( AK, DST, TETA, X, N,
     O                     F )
C
C---- >>> SUBROUTINE TO CALCULATE FORCES ON EACH BEARING
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      DIMENSION AK(N), DST(N), F(N)
C
         DO 10 I = 1, N
             F(I)    = AK(I) * ( X + DST(I) ) * TETA
   10    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE THCDS
     I          ( CYK, RDK, CLT, RLT, CSSTF, RSSTF, TETA, W, TRM,
     O            BB1, BB2, CK, RK, CK1L1, SK1L1, THC )
C
C---- >>> SUBROUTINE TO CALCULATE SLOPES AT SUPPORTS AND CONSTANTS IN
C          DEFLECTION EQUATIONS
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMON / CANDDS / C1, C2, D1, D2
      COMMON / CONSTS / EEL, FFL, AKTFC, AKTHR
      COMMON / ECCTRI / ECLC, ECLR
      COMMON / FRCONS / FCCY, FCRD, CONM
      COMMON / REATNS / REC, RER
      COMMON / WGTVER / WC, WR
C
      DATA ZERO, ONE / 0.D00, 1.D00 /
C
              SQP     = DSQRT ( P )
              CK      = SQP / CYK
              RK      = SQP / RDK
              CK2     = CK * CK
              RK2     = RK * RK
              AK1L1   = CK  * CLT
              AK2L2   = RK  * RLT
              AK2L1   = RK  * CLT
              AK2EL   = RK  * EXL
              TK1L1   = DTAN( AK1L1 )
              SK1L1   = DSIN( AK1L1 )
              CK1L1   = DCOS( AK1L1 )
              TK2L2   = DTAN( AK2L2 )
              SK2L2   = DSIN( AK2L2 )
              CK2L2   = DCOS( AK2L2 )
              CK2L1   = DCOS( AK2L1 )
              TK2L1   = DTAN( AK2L1 )
              CK2EL   = DCOS( AK2EL )
              SK2EL   = DSIN( AK2EL )
              TK2EL   = DTAN( AK2EL )
              AKCON   = CK / TK1L1 + RK / TK2L2
              BKCON   = CK * TK2L2 + RK * TK1L1
              CKCON   = RK - CK * TK1L1 * TK2L2
              DKCON   = RK * TK1L1 * TK2L1 + CK
              TT      = TK1L1 * TK2L2
              SS      = SK1L1 * SK2L2
              CC      = CK1L1 * CK2L2
              ST      = SK1L1 * TK2L2
              CCEL    = CK2L2 * CK2EL
              TS      = TK1L1 * SK2L2
              WRPK2   = WR / ( P * RK2 )
              WCPK2   = WC / ( P * CK2 )
              WCWR    = WRPK2 - WCPK2 + TRM / P
              AKCBP   = CSSTF / P
              AKRBP   = RSSTF / P
              EEL     = ( ECLR - ECLC ) / EXL
              FFL     = ( FCRD - FCCY ) / EXL
              BB1     = CONM / P + FCCY - ECLC - WCPK2 + TRM / P
              BB2     = FCRD - ECLR - WRPK2
              BB3     = TETA + W / P
```

```
C
C---- >>> CALCULATE SLOPES AT CYLINDER AND ROD SUPPORTS
C
                 A11     = ONE - AKCBP * CK * CKCON / BKCON + AKCBP / EXL
                 A12     = AKRBP * CK * RK / BKCON / CC - AKRBP / EXL
                 B1      = ( BB1 * CKCON / TT - WCWR * RK / ST - BB2 * RK
     *                   / SS + BB3 / SK1L1 ) * CK / AKCON - EEL + FFL
     *                   - REC / P
                 A21     = - AKCBP * CK * RK / BKCON /CC + AKCBP / EXL
                 A22     = ONE + AKRBP * CK2L1 * DKCON * RK / CCEL / BKCON
     *                   - AKRBP * RK * TK2EL - AKRBP / EXL
                 B2      = ( BB1 * CK / CC - BB2 * DKCON * CK2L1 / CCEL
     *                   - WCWR * CK / CK2L2 - BB3 * TK1L1 / CK2L2 ) * RK
     *                   / BKCON + BB2 * RK * TK2EL - EEL + FFL + RER / P
                 THDEN   = A11 * A22 - A12 * A21
                 THC     = ( B1 * A22 - A12 * B2 ) / THDEN
                 THR     = ( A11 * B2 - A21 * B1 ) / THDEN
                 AKTHC   = AKCBP * THC
                 AKTHR   = AKRBP * THR
                 BB1     = BB1 + AKTHC
                 BB2     = BB2 + AKTHR
C
C---- >>> CALCULATE CONSTANTS IN DEFLECTION EQUATIONS
C
                 C1      = -BB1
                 D1      = ( BB1 * CKCON / TT - WCWR * RK / ST - BB2 * RK
     *                   / SS + BB3 / SK1L1 ) / AKCON
                 D2      = ( BB1 * CK * CK2EL / SS - BB2 * DKCON * CK2L1
     *                   / TS - WCWR * CK * CK2EL / TS - BB3 * CK2EL
     *                   / SK2L2 ) / AKCON
                 C2      = ( - D2 * SK2EL - BB2 ) / CK2EL
      RETURN
      END
```

```
      SUBROUTINE STOPTB
     I          ( TETA, NPHBR, NRDBR, ALTH, ALF, STROK, ITERAT,      GC )
C
C---- >>> SUBROUTINE TO CALCULATE THE REQUIRED LENGTH OF STOP-TUBE
C
      IMPLICIT REAL * 8 ( A - H, C - Z )
      COMMON / GLDFOR / FX(5), FY(5), F1, F2, F3, F4
C
      DATA TWO, HUNDRD / 2.0D00, 100.0D00 /
C
C
C---- >>> INCREMENT FOR STOP-TUBE LENGTH
C
                 GCI     = STROK / HUNDRD
C
C---- >>> CALCULATE TOTAL LATERAL FORCE
C
                 TF      = DABS( F1 ) + DABS( F2 ) + DABS( F3 ) + DABS( F4)
      DO 10 I = 1, NPHBR
   10            TF      = TF + DABS( FX(I) )
      DO 20 I = 1, NRDBR
   20            TF      = TF + DABS( FY(I) )
                 F       = TF / TWO
C
C---- >>> CHECK TOTAL FORCE AND CROOKEDNESS ANGLE LIMITS
C
            IF ( F .LT. ALF .AND. DABS( TETA ) .LT. ALTH ) RETURN
                 GC      = GC + GCI
            IF ( GC - STROK / TWO / TWO ) 120, 120, 900
  120            ITERAT = 2
      RETURN
  900 PRINT 910
  910 FORMAT ( 1H1, ///, 5( 25H* * * * * ERROR * * * * *, / ),
     1           ///, 45HFORCE AND CROOKEDNESS ANGLE LIMITS AT          ,/
     2                45HSLIDING CONNECTION ARE TOO SMALL;              ,/
     3                45HRESULTS IN UNECONOMICAL DESIGN;                ,/
     4                45HSTOP TUBE LENGTH BECOMES > STROKE / 4;         ,/
     5                45HSUGGESTION - INCREASE LIMITING VALUES.         ,/ )
      STOP
      END
```

```
      SUBRCUTINE XATYMX
     I          ( CLT, CK, RK, DEFG,
     O            XCY, XRD, CSLPC, CSLPR                                   )
C
C---- >>> SUBROUTINE TO CALCULATE THE DISTANCES AT WHICH MAXIMUM
C         DEFLECTIONS OCCUR
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMCN EXL, P
      COMMCN / CANDDS / C1, C2, C1, D2
      COMMON / CONSTS / EEL, FFL, AKTHC, AKTHR
      COMMON / REATNS / REC, RER
      COMMCN / WGTVER / WC, WR
C
      DATA ZERO, HUNDRD / 0.D00, 100.D00 /
C
C---- >>> INCREMENT FOR X
C
                AINCR  = CLT / HUNDRD
                CSLP   = - EEL + FFL - ( AKTHC - AKTHR ) / EXL
                CSLPC  = CSLP - REC / P
                CSLPR  = CSLP + RER / P
                XCY    = CLT
                XRD    = CLT
C
C---- >>> POINT AT WHICH MAXIMUM DEFLECTION OCCURS IN CYLINDER
C
  100           ANG    = CK * XCY
                CSLOP  = - C1 * CK * DSIN( ANG ) + D1 * CK * DCOS( ANG )
     *                   + CSLPC + WC * XCY / P
         IF ( DEFG ) 140, 140, 120
  120    IF ( CSLOP ) 160, 160, 200
  140    IF ( CSLOP ) 200, 160, 160
  160           XCY    = XCY - AINCR
         GO TO 100
C
C---- >>> PCINT AT WHICH MAXIMUM CEFLECTION OCCURS IN ROD
C
  200           ANG    = RK * XRD
                RSLOP  = - C2 * RK * DSIN( ANG ) + D2 * RK * DCOS( ANG )
     *                   + CSLPR - WR * ( EXL - XRD ) / P
         IF ( DEFG ) 240, 240, 220
  220    IF ( RSLOP ) 300, 260, 260
  240    IF ( RSLOP ) 260, 260, 300
  260           XRD    = XRD + AINCR
         GO TO 200
  300 RETURN
      END
```

```
      SUBRCUTINE YMAXS
     I          ( XCY, XRD, CK, RK, CSLPC, CSLPR, BB1, BB2,
     O            YCMAX, YRMAX                                             )
C
C---- >>> SUBROUTINE TO CALCULATE MAX. DEFLECTIONS IN CYLINDER AND ROD
C
      IMPLICIT REAL * 8 ( A - H, C - Z )
      COMMON EXL, P
      COMMON / CANDDS / C1, C2, D1, D2
      COMMON / WGTVER / WC, WR
C
      DATA TWO / 2.0D00 /
C
                CANG   = XCY * CK
                RANG   = XRD * RK
                TWOP   = TWO * P
                XRDP   = EXL - XRD
C
C---- >>> MAXIMUM DEFLECTICN IN CYLINCER
C
                YCMAX  = C1 * DCOS( CANG ) + D1 * DSIN( CANG )
     *                   + CSLPC * XCY + BB1 + WC * XCY * XCY / TWOP
C
C---- >>> MAXIMUM DEFLECTION IN ROD
C
                YRMAX  = C2 * DCCS( RANG ) + D2 * DSIN( RANG )
     *                   - CSLPR * XRDP + BB2 + WR * XRDP * XRDP / TWOP
      RETURN
      END
```

```
      SUBROUTINE STRCHS
     I          ( KEYF, KEYT, KEYP, XCY, XRD, YCMAX, YRMAX, RIC, CHDS,
     I           OPPRE, FYRODT, FYCYLT, PINCR1, PINCR2, KEYST, LFLUID,
     I           TRM, FCON, TSTRT, TSTRB, KEYTR,
     O           HSC, HSR, CSTR, CSTRP, RSTR, RSTRP, CSS, NCSS, RSS,NRSS)
C
C---- >>> SUBRCUTINE TO CHECK THE MAXIMUM STRESSES WITH THE LIMITING
C         STRESSES
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON EXL, P
      COMMCN / CAREAS / BAREAC, BAREAR, CAREAC, CAREAR, RAREAC
      COMMON / CONSTS / EEL, FFL, AKTHC, AKTHR
      COMMON / CRPROP / RDZ, CYZ, RDZI, CYZI, HSCCI, HSCCO, HSCRI, HSCRO
      COMMON / ECCTRI / ECLC, ECLR
      COMMON / FRCONS / FCCY, FCRD, CCNM
      COMMON / REATNS / REC, RER
      COMMCN / TIERCD / TRL, CLE, TRCA, R, PRC, ETR, FYTR, TRIF
      COMMON / WGTVER / WC, WR
C
      DATA ZERC, TWC / 0.0000, 2.0000 /
      DATA LYES / 3HYES /
C
C---- >>> CALCULATE BENDING MCMENTS AT MAXIMUM DEFLECTION POINTS
C
               BMC1   = ( EEL - FFL +  ( AKTHC - AKTHR ) / EXL ) * P*XCY
               BMC    = DABS( BMC1 + REC * XCY - CONM - P * FCCY - AKTHC
     *                * P - TRM - WC * XCY * XCY / TWO + P*(ECLC+YCMAX))
               XRDP   = EXL - XRD
               BMR    = CABS( - BMC1 * XRDP / XCY + RER * XRDP - P
     *                * FCRD - AKTHR * P - WR * XRDP * XRDP / TWO
     *                + P * ( ECLR + YRMAX ) )
C
C---- >>> CALCULATE BENDING MOMENTS AT SUPPORTS
C
               BMCP   = DABS( - CONM - P * ( FCCY + AKTHC - ECLC )- TRM)
               BMRP   = DABS( - P * ( FCRD + AKTHR - ECLR ) )
C
C---- >>> CALCULATE FINAL TENSICNS IN TIE RODS
C
               FT     = TRIF - P * FCCN
               TRMF   = TRM / ( TWO * R )
               FTT    = FT / TWC - TRMF
               FTB    = FT / TWO + TRMF
          IF ( FTT .GT. ZERC .OR. FTB .GT. ZERO ) GO TO 10
               KEYTR  = 2
               KEYF   = 2
   10     CCNTINUE
C
C---- >>> CALCULATE ALL STRESSES
C
C---- >>>      HOOP STRESSES
C
               PRE    = P / BAREAC
               HSC    = HSCCI * PRE
               HSCO   = HSCCO * PRE
               HSR    = ZERC
          IF ( LFLUID .EQ. LYES ) HSR = HSCRI * PRE
               HSRO   = ZERC
          IF ( LFLUID .EQ. LYES ) HSRC = HSCRO * PRE
C
C---- >>>      LONGITUDINAL STRESSES
C
               FTSTR  = FT / CAREAC
               CSTR   = BMC / CYZ + FTSTR
               CSTRI  = BMC / CYZI + FTSTR
               CSTRP  = BMCP / CYZ + FTSTR
               CSTRPI = BMCP / CYZI + FTSTR
               PR     = P
          IF ( LFLUIU .EQ. LYES ) PR = P - PRE * BAREAR
               AXRST  = PR / CAREAR
               RSTR   = BMR / RDZ + AXRST
               RSTRI  = BMR / RDZI + AXRST
               RSTRP  = BMRP / RDZ + AXRST
               RSTRPI = BMRP / RDZI + AXRST
C
C---- >>>      TIE ROD LONGITUDINAL STRESSES
C
               TSTRT  = FTT * TWC / TRCA
               TSTRB  = FTB * TWC / TRCA
C
C---- >>>      SHEAR STRESSES
C
               CSSO   = HSCO + CSTR
               CSSI   = HSC + CSTRI
               CSSPO  = HSCC + CSTRP
               CSSPI  = HSC + CSTRPI
          IF (CSSPO.GT.CSSPI.ANC.CSSPC.GT.CSSO.AND.CSSPO.GT.CSSI)GO TO40
          IF ( CSSPI .GT. CSSC .AND. CSSPI .GT. CSSI ) GO TO 30
          IF ( CSSO .GT. CSSI ) GO TO 20
               CSS    = CSSI
               NCSS   = 2
          GO TO 50
   20          CSS    = CSSC
               NCSS   = 1
          GO TO 50
   30          CSS    = CSSPI
               NCSS   = 2
          GO TO 50
   40          CSS    = CSSPC
               NCSS   = 1
   50          RSS    = ZERO
               NRSS   = 0
          IF ( LFLUID .NE. LYES ) GC TO 90
               RSSPO  = HSRO + RSTRP
               RSSPI  = HSR + RSTRPI
               RSSO   = HSRC + RSTR
               RSSI   = HSR + RSTRI
          IF (RSSPC.GT.RSSPI.ANC.RSSPC.GT.RSSO.AND.RSSPO.GT.RSSI)GO TO60
          IF ( RSSPI .GT. RSSO .AND. RSSPI .GT. RSSI ) GO TO 70
          IF ( RSSO .GT. RSSI ) GO TO 60
               RSS    = RSSI
               NRSS   = 2
          GO TO 90
   60          RSS    = RSSC
               NRSS   = 1
```

```
          GO TO 90
   70          RSS     = RSSPI
               NRSS    = 2
          GO TO 90
   80          RSS     = RSSPO
               NRSS    = 1
   90     CONTINUE
          IF ( KEYF .NE. 1 ) GO TO 500
          IF ( KEYST .NE. 1 ) GO TO 500
C
C---- >>> CHECK WITH LIMITING STRESSES
C
               STRMX1 = DMAX1( CSTR, CSTRP, HSC, CSS )
               STRMX2 = DMAX1( RSTR, RSTRP, HSR, RSS )
          IF ( STRMX1 .GT. FYCYLT .OR. STRMX2 .GT. FYRODT ) GO TO 100
          IF ( ( TSTRT .GT. FYTR ) .OR. ( TSTRB .GT. FYTR ) ) GO TO 100
          IF ( KEYT .EQ. 2 ) GO TO 400
C
C---- >>> CHANGE THE TRIAL LOAD CORRESPONDINGLY
C
               P       = P + PINCR1
      RETURN
  100     IF ( KEYP .EQ. 2 ) GO TO 200
               P       = P - PINCR1 + PINCR2
               TRM     = ZERO
               KEYT    = 2
      RETURN
C
C---- >>> ITERATIVE REFINEMENT SECTION
C
  200          P       = P - PINCR2
               TRM     = ZERO
               KEYF    = 2
      RETURN
  400          P       = P + PINCR2
               KEYP    = 2
      RETURN
  500          KEYF    = 3
      RETURN
      END
```

```
      SUBROUTINE SEPPRE ( CLE )
C
C---- >>> SUBROUTINE TO CALCULATE THE SEPARATION PRESSURES FOR ALL
C         PISTON HEAD POSITIONS IN A CYCLE OF OPERATION
C
      IMPLICIT REAL * 8 ( A - H, O - Z )
      COMMON / CAREAS / BAREAC, BAREAR, CAREAC, CAREAR, RAREAC
      COMMON / SEPCON / SLAE, TEMPC, TEMPR, CCL, FBAC, FBAR
      COMMON / SEPRES / SP1, SP2, SP3, SP4, SP5, SP6
C
      DATA ONE / 1.0D00 /
C
               SP3     = FBAC / ( ONE - ( CLE - TEMPC ) / SLAE )
               SP6     = FBAR / ( ONE - ( CLE - TEMPR * BAREAC / RAREAC )
     1                   / SLAE )
          IF ( CCL ) 20, 10, 10
C
C---- >>> FOR SUPPORT AT CYLINDER CAP
C
   10          SP2     = FBAC * SLAE / TEMPC
               SP4     = FBAR / ( ONE - CLE / SLAE )
               SP5     = SP6
      RETURN
C
C---- >>> FOR INTERMEDIATE SUPPORT ALONG CYLINDER LENGTH
C
   20          SP1     = FBAC / ( ONE + CCL / SLAE )
               SP2     = FBAC / ( ONE - (-CCL - TEMPC ) / SLAE )
               SP4     = FBAR / ( ONE - ( CLE + CCL ) / SLAE )
               SP5     = FBAR / ( ONE - ( CLE + CCL - TEMPR * BAREAC /
     1                                             RAREAC ) / SLAE )
      RETURN
      END
```

```
      SUBROUTINE OUTPUT
     I          ( KWIT, BAREAC, XCY, XRD, YCMAX, YRMAX, CHDS, GC, TETA,
     I            FYCYLT, FYRODT, CSTR, CSTRP, RSTR, RSTRP,HSC,HSR, EPTK,
     I            FYTR, KEYTR, NPHBR, NRDBR, THC, CSS, NCSS, RSS, NRSS,
     I            TSTRT, TSTRB                                          )
C
C---- >>> SUBROUTINE TO PRINT ALL THE RESULTS
C
      IMPLICIT REAL * 8 ( A - H, C - Z )
      COMMON EXL, P
      COMMON / ENDS   / LCEND, LREND
      COMMON / FSOPTF / OPPRE, ALTH, ALF, FS, LFSTP
      COMMON / GLDFOR / FX(5), FY(5), F1, F2, F3, F4
      COMMON / ID     / IDCARD(40), NPROB, IPROB(19), LPRTP
      COMMON / SEPRES / SP1, SP2, SP3, SP4, SP5, SP6
      COMMON / UNITS  / LNTU, LODU, LPREU, LANGU
C
      DATA ZERO, ONE, TWO, H180 / 0.0D00, 1.0D00, 2.0D00, 180.0D00 /
      DATA PI / 3.14159265358979300 /
      DATA LDEG, LFIX / 4HDEG , 3HFIX /
C
C---- >>> FORMATS
C
  100 FORMAT ( 1H1, 5X, 36HPROGRAM SACTIE - STRESS ANALYSIS OF ,
    1           23HCYLINDERS WITH TIE RODS, //, 2( 5X, 20A4, / ), /     )
  110 FORMAT ( 5X, 8HPROBLEM , A4, //, 1X, 19A4                         )
  120 FORMAT ( //, 5X,35HRESULTS:      CRITICAL LOAD ANALYSIS, /        )
  130 FORMAT ( //, 5X,44HRESULTS:      ANALYSIS FOR A GIVEN OPERATING ,
    1                   8HPRESSURE, /                                   )
  140 FORMAT ( //, 5X,45HRESULTS:      ANALYSIS TO DETERMINE STOP-TUBE ,
    1                   6HLENGTH, /                                     )
  150 FORMAT (  /,14X,25HCRITICAL LOAD              = ,1PD10.3, 4X, A4,
    1          //,14X,25HMAXIMUM FLUID PRESSURE     = ,1PD10.3, 4X, A4,
    2          //,14X,25HCROOKEDNESS ANGLE          = ,1PD12.5, 2X, A4, /  )
  160 FORMAT (  /,14X,25HOPERATING PRESSURE         = ,1PD10.3, 4X, A4,
    1          //,14X,25HLOAD                       = ,1PD10.3, 4X, A4,
    2          //,14X,25HCROOKEDNESS ANGLE          = ,1PD12.5, 2X, A4, /  )
  180 FORMAT (  /, 5X,34HREQUIRED LENGTH OF STOP-TUBE     = 1PD10.3,4X,A4
    1          //, 5X,34HCORRESPONDING EXTENDED LENGTH    = 1PD10.3,4X,A4
    2          //, 5X,32HRESULTS WITH THIS STOP-TUBE ARE:, /              )
  250 FORMAT ( 1H1, /, 5X,40HANALYSIS AFTER APPLYING GIVEN FACTOR OF ,
    1                 10HSAFETY OF , F6.3, 2X, 2HON, 2X, A4, 2H: , /    )
  260 FORMAT (  /,14X,25HLOAD                       = ,1PD10.3, 4X, A4,
    1          //,14X,25HFLUID PRESSURE             = ,1PD10.3, 4X, A4,
    2          //,14X,25HCROOKEDNESS ANGLE          = ,1PD12.5, 2X, A4, /  )
  300 FORMAT (  /, 5X, 9HCYLINDER:,
    1          //,10X,29HMAXIMUM DEFLECTION            = ,1PD10.3, 4X, A4,
    2          //,10X,29HMAXIMUM LONGITUDINAL STRESS= ,1PD10.3, 4X, A4,
    3          //,10X,29HAT A DISTANCE FROM CYL SUP = ,1PD10.3, 4X, A4,
    4          //,10X,29HFACTOR OF SAFETY ON CYL    = ,1PD10.3, /          )
  310 FORMAT (  /,10X,29HMAX LONG STRESS AT CYL END = ,1PD10.3, 4X, A4,
    1          //,10X,29HFACTOR OF SAFETY ON CYL    = ,1PD10.3, /          )
  312 FORMAT (  /,10X,29HMAX SHEAR STRESS IN CYL    = ,1PD10.3, 4X, A4,
    1           /,10X,24HAT MAX LONG STRESS POINT                          )
  314 FORMAT ( 10X, 21HAND AT OUTER SURFACE                                )
  316 FORMAT ( 10X, 21HAND AT INNER SURFACE                                )
  318 FORMAT (  /,10X,29HFACTOR OF SAFETY ON CYL    = ,1PD10.3, /          )
  320 FORMAT (  /,10X,29HMAXIMUM HOOP STRESS IN CYL = ,1PD10.3, 4X, A4,
    1          //,10X,29HFACTOR OF SAFETY ON CYL    = ,1PD10.3, /          )
  325 FORMAT (  /,10X,29HEND DEFLECTION IN OVERHANG = ,1PD10.3, 4X, A4 )
  330 FORMAT (  /, 5X, 9HROD      :,
    1          //,10X,29HMAXIMUM DEFLECTION         = ,1PD10.3, 4X, A4,
    2          //,10X,29HMAXIMUM LONGITUDINAL STRESS= ,1PD10.3, 4X, A4,
    3          //,10X,29HAT A DISTANCE FROM CYL SUP = ,1PD10.3, 4X, A4,
    4          //,10X,29HFACTOR OF SAFETY ON ROD    = ,1PD10.3, /          )
  340 FORMAT (  /,10X,29HMAX LONG STRESS AT ROD END = ,1PD10.3, 4X, A4,
    1          //,10X,29HFACTOR OF SAFETY ON ROD    = ,1PD10.3, /          )
  342 FORMAT (  /,10X,29HMAX SHEAR STRESS IN ROD    = ,1PD10.3, 4X, A4,
    1           /,10X,24HAT MAX LONG STRESS POINT                          )
  348 FORMAT (  /,10X,29HFACTOR OF SAFETY ON ROD    = ,1PD10.3, /          )
  350 FORMAT (  /,10X,29HMAXIMUM HOOP STRESS IN ROD = ,1PD10.3, 4X, A4,
    1          //,10X,29HFACTOR OF SAFETY ON ROD    = ,1PD10.3, /          )
  360 FORMAT ( 1H1, //, 5X, 29HFORCES AT SLIDING CONNECTION:, //, 15X,
    1          23HPISTON BEARINGS (SEALS), 6X, 5HFORCE, /,25X, 2HNO, / )
  370 FORMAT ( /, 5( 25X, I2, 12X, 1PD10.3, 2X, A4, // )                  )
  380 FORMAT ( /,18X, 20HROD BEARINGS (SEALS), 6X, 5HFORCE,/,25X, 2HNO/)
  390 FORMAT ( //8X38HF1- FORCE AT PISTON HEAD FRONT FACE  =1PD11.3,2XA4
    1          //8X38HF2- FORCE AT STUFFING BOX FRONT FACE =1PD11.3,2XA4
    2          //8X38HF3- FORCE AT PISTON HEAD BACK FACE   =1PD11.3,2XA4
    3          //8X38HF4- FORCE AT STUFFING BOX INNER FACE =1PD11.3,2XA4
    4           /,11X,33H(ZERO FORCES INDICATE NO CONTACT) , /           )
  400 FORMAT ( ///, 10X, 39HTHETA EQUAL TO ZERO IMPLIES CONTINUOUS  ,
    1          17HCONTACT AT GLAND.   , /, 10X,
    2          34HABOVE FORCES CANNOT BE CALCULATED.
    3          33HHENCE, ARE PRINTED OUT AS ZERO'S.  ,  //               )
  420 FORMAT ( //, 5X, 9HTIE RODS:, /                                    )
  430 FORMAT ( //,10X,29HSTRESS IN TOP RODS            = ,1PD10.3, 4X, A4,
    1          //,10X,29HFACTOR OF SAFETY ON THESE  = ,1PD10.3, /         )
  440 FORMAT ( //,10X,29HSTRESS IN BOTTOM RODS         = ,1PD10.3, 4X, A4,
    1          //,10X,29HFACTOR OF SAFETY ON THESE  = ,1PD10.3, /         )
  450 FORMAT ( 1H1, ///, 5X,
    1          44HSEPARATION PRESSURES WITH CYLINDER STRAIGHT:,///, 13X,
    2          15HSTROKE POSITION,5X,13HPRESSURE ON  ,
    3          19HSEPARATION PRESSURE, /                                 )
  460 FORMAT (  /10X,33HRETRACTED (NO CONTACT)   CAP SIDE,
    1             5X,13HNO SEPARATION, /                                 )
  470 FORMAT (  /10X,33HRETRACTED (NO CONTACT)   CAP SIDE,4X,1PD10.3,
    1          2X, A4, /                                                 )
  480 FORMAT (   10X,33HEXTENDED  (NO CONTACT)   CAP SIDE,1PD14.3,2X,A4,
    1          //10X,33HEXTENDED  (CONTACT    )   CAP SIDE,1PD14.3,2X,A4,
    2          //10X,33HEXTENDED  (NO CONTACT)   ROD SIDE,1PD14.3,2X,A4,
    3          //10X,33HRETRACTED (NO CONTACT)   ROD SIDE,1PD14.3,2X,A4,
    4          //10X,33HRETRACTED (CONTACT    )   ROD SIDE,1PD14.3,2X,A4)
  490 FORMAT ( //, 5X, 27HFAILURE DUE TO SEPARATION; ,
    1          21HTOP OR BOTTOM TIE ROD, /, 5X,
    2          28HFORCE BECAME LESS THAN ZERO. , /                       )
C
               TEMP   = H180 / PI
          IF ( LANGU .EQ. LDEG ) TETA = TETA * TEMP
               PRE    = P / BAREAC
          IF ( KWIT .NE. 1 ) GO TO 540
C
C---- >>> PRINT ALL RESULTS
C
      PRINT 100, ( IDCARD( I), I = 1, 40 )
      PRINT 110, NPROB, ( IPROB(I), I = 1, 19 )
```

```
          GO TO ( 510, 520, 530 ), LPRTP
  510 PRINT 120
      PRINT 150, P, LODU, PRE, LPREU, TETA, LANGU
          GO TO 550
  520 PRINT 130
      PRINT 160, OPPRE, LPREU, P, LODU, TETA, LANGU
          GO TO 550
  530 PRINT 140
      PRINT 180, GC, LNTU, EXL, LNTU
      PRINT 150, P, LODU, OPPRE, LPREU, TETA, LANGU
          GO TO 550
  540 PRINT 250, FS, LFSTP
      PRINT 260, P, LODU, PRE, LPREU, TETA, LANGU
C
C---- >>> CALCULATE THE FACTOR OF SAFETY'S ON MAXIMUM STRESSES WITH
C         LIMITING STRESSES AND PRINT
C
  550              FCSF   = FYCYLT / CSTR
      PRINT 300, YCMAX, LNTU, CSTR, LPREU, XCY, LNTU, FCSF
          IF ( CSTRP .GT. ZERO ) FCSF = FYCYLT / CSTRP
          IF ( LCEND .EQ. LFIX ) PRINT 310, CSTRP, LPREU, FCSF
               FCSF   = FYCYLT / CSS
               CSS    = CSS / TWO
      PRINT 312, CSS, LPREU
          IF ( NCSS .EQ. 1 ) PRINT 314
          IF ( NCSS .EQ. 2 ) PRINT 316
      PRINT 318, FCSF
               FCSF   = FYCYLT / HSC
      PRINT 320, HSC, LPREU, FCSF
          IF ( ( CHDS + EPTK ) .GT. ZERO ) GO TO 560
               ENDDF  = THC * CHDS
      PRINT 325, ENDDF, LNTU
  560          FCSF   = FYRODT / RSTR
      PRINT 330, YRMAX, LNTU, RSTR, LPREU, XRD, LNTU, FCSF
          IF ( RSTRP .GT. ZERO ) FCSF = FYRODT / RSTRP
          IF ( LREND .EQ. LFIX ) PRINT 340, RSTRP, LPREU, FCSF
          IF ( HSR .EQ. ZERO ) GO TO 570
               FCSF   = FYRODT / RSS
               RSS    = RSS / TWO
      PRINT 342, RSS, LPREU
          IF ( NRSS .EQ. 1 ) PRINT 314
          IF ( NRSS .EQ. 2 ) PRINT 316
      PRINT 348, FCSF
               FCSF   = FYRODT / HSR
      PRINT 350, HSR, LPREU, FCSF
  570          FCSF   = FYTR / TSTRT
      PRINT 420
      PRINT 430, TSTRT, LPREU, FCSF
               FCSF   = FYTR / TSTRB
      PRINT 440, TSTRB, LPREU, FCSF
          IF ( KWIT .EQ. 1 .AND. KEYTR .EQ. 2 ) PRINT 490
      PRINT 360
      PRINT 370, ( I, FX(I), LODU, I = 1, NPHBR )
      PRINT 380
      PRINT 370, ( I, FY(I), LODU, I = 1, NRDBR )
      PRINT 390, F1, LODU, F2, LODU, F3, LODU, F4, LODU
          IF ( TETA .EQ. ZERO ) PRINT 400
          IF ( KWIT .EQ. 1 .AND. FS .GT. ONE ) RETURN
      PRINT 450
          IF ( CHDS + EPTK ) 600, 590, 590
  590 PRINT 460
          GO TO 610
  600 PRINT 470, SP1, LPREU
  610 PRINT 480, SP2, LPREU, SP3, LPREU, SP4, LPREU, SP5,LPREU,SP6,LPREU
      RETURN
      END
```

```
     00000000011111111112222222222333333333344444444445555555555666666666677777777778
     12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
  1  EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
  2  CODED  JUNE 9, 1976   BY   K. L. SESHASAI
  3  TIE1      LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER.
  4      1
  5            INCH      KIPS      KSI       DEG
  6  50.0      6.13      4.44      0.76      3.0                 NO
  7  56.13     56.82     116.71    0.0
  8  7.0       6.0       3.0       0.0       4.75      4.75      5.989     3.009
  9  0.0
 10  61.33     56.63     4.0       3.1
 11  0.316     0.451     500.0               2.375
 12  0.365     0.25      1000.0              3.9
 13  0.316     0.451     500.0               5.45                END
 14  0.35      0.2       750.0               3.15                END
 15  0.0032    0.002     0.05      0.07      29000.0   29000.0   125.0     125.0
 16  0.25      29000.0   125.0     240.0
 17  0.0                           PIN  PIN  +0.025    +0.025    +0.1      +0.12
 18  2.0       LOAD
 19  TIE2      LPRTP=1; P-F; HOLLOW ROD WITH NO FLUID; VERTICAL CYLINDER.
 20      1     KEEP                          KEEP
 21  50.0      6.13      4.44      0.76      3.0
 22  56.13     56.82     116.71    0.0
 23  7.0       6.0       3.0       1.5       4.75                5.989
 24  0.0                 0.009
 25  61.33     56.63     4.0       3.1
 26                                2100.0    2.375
 27                                8800.0    3.9
 28                                2100.0    5.45                END
 29                                3900.0    3.15                END
 30  90.0                          PIN  FIX  -0.02               +0.1      -0.05
 31  4.0       STRS
 32  TIE3      LPRTP=1; F-F; SOLID ROD; 30 DEG INCLINED CYL.
 33      1
 34            INCH      LBS       PSI       DEG
 35  50.0      6.13      4.44      0.76      3.0
 36  56.13     56.82     116.71
 37  7.0       6.0       3.0       0.0
 38  0.005     0.011     0.009
 39  61.33     56.63     4.0       3.1
 40                                2100000.0 2.375
 41                                8800000.0 3.9
 42                                2100000.0 5.45                END
 43  0.35      0.2       750000.0            1.75
 44  0.35      0.4       250000.0            3.5                 END
 45  3.2       2.0       50.0      70.0      29000000. 29000000. 75000.0   125000.0
 46  0.25      29000000.0125000.0  240000.0
 47  30.0                          FIX  FIX                      -0.05     -0.025
 48
 49  TIE4      LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER WITH A OVERHANG.
 50      1
 51            INCH      KIPS      KSI       RAD
 52  60.0      6.13      4.44      0.76      -15.0
 53  66.13     66.82     118.71    0.0
 54  6.5       5.5       2.75      0.0       2.0       3.0       5.49      2.76
```

```
     00000000011111111112222222222333333333344444444445555555555666666666677777777778
     12345678901234567890123456789012345678901234567890123456789012345678901234567890
CARD
 55  0.005     0.01      0.008
 56  71.33     66.63     4.0       2.8
 57  0.316     0.451     500.0               2.375
 58                                8800.0    3.9
 59                                2100.0    5.45                END
 60  0.35      0.2       750.0               3.15                END
 61  0.003     0.00175   0.04      0.06      29000.0   29000.0   100.0     125.0
 62  0.25      29000.0   125.0     240.0
 63  0.0                           PIN  PIN  +0.05                         +0.01
 64  1.0       LOAD
 65  TIE5      LPRTP=2; F-P; HOLLOW ROD WITH FLUID; INCLINED CYLINDER; METRIC UNITS.
 66      2
 67            CM        KGS       KGSC      RAD
 68  127.0     15.57     11.28     1.93      7.62                YES
 69  142.57    144.38    296.5     0.0
 70  17.78     15.24     7.62      3.8                 12.0      15.22     7.64
 71  0.01
 72  155.78    144.07    25.0      7.75
 73  0.8       1.15      35000.0             6.0
 74  1.0       0.8       70000.0             10.0
 75                                371000.0  13.5                END
 76  1.0       0.5       50000.0             8.0                 END
 77  1.5       1.0       23.0      32.0      2100000.0 2100000.0 7050.0    8800.0
 78  0.25      2100000.0 10000.0   125000.0
 79  0.75                          FIX  PIN            -0.05               +0.1
 80                      175.0
 81  TIE6      LPRTP=3; P-P; SOLID ROD; HORIZONTAL CYLINDER.
 82      3
 83            INCH      KIPS      KSI       DEG
 84  60.0      6.13      4.44      0.76      3.0                 NO
 85  7.0       6.0       3.0       0.0       4.75      4.75      5.989     3.009
 86  0.005
 87                      4.0       3.1
 88                                2100.0    2.375
 89                                8800.0    3.9
 90                                2100.0    5.45                END
 91                                3900.0    3.15                END
 92  0.0032    0.002     0.05      0.07      29000.0   29000.0   100.0     125.0
 93  0.25      29000.0   125.0     240.0
 94  0.0                           PIN  PIN  0.0       -0.05               +0.1
 95                      2.0       0.0075    10.0
 96            THIS IS A BLANK CARD
```

```
PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976    BY   K. L. SESHASAI

PROBLEM TIEL

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER.

INPUT DATA:

TABLE 1:     CONTROL DATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD

              TABLES RETAINED FROM PREVIOUS PROBLEM

                2     3     4     5     6     7

                   NO KEEP OPTIONS EXERCISED

TABLE 2:     UNITS OF MEASUREMENT

             LENGTH      LOAD      PRESSURE   ANGULAR

              INCH       KIPS        KSI        DEG

TABLE 3:     CYLINDER DIMENSIONS

    LENGTHS:

              STROKE       PISTON HEAD  STUFFING BOX    END PLATE    HINGE DIST.

           5.00000D 01   6.13000D 00   4.44000D 00   7.60000D-01   3.00000D 00

             CYLINDER         ROD        EXTENDED      STOP TUBE

           5.61300D 01   5.68200D 01   1.16710D 02   0.0

    DIAMETERS:

           CYL. OUTER    CYL. INNER     ROD OUTER     ROD INNER

           7.00000D 00   6.00000D 00   3.00000D 00   0.0             SOLID ROD

            CYL. PIN *    ROD PIN *   PISTON HEAD @  STUF. BOX @

           4.75000D 00   4.75000D 00   5.98900D 00   3.00900D 00
          (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

    CLEARANCES BETWEEN:

            CYLINDER      CYLINDER         ROD
              AND           AND            AND
         STUFFING BOX  PISTON HEAD @  STUF. BOX @

           0.0           0.0           0.0
                      (@ ZERO, OTHER OPTION IS INPUT)

    TIE RODS DETAILS:

         CLEAR TIE ROD LENGTH                   =  6.13300D 01
         EXACT CYLINDER LENGTH                  =  5.66300D 01
         TOTAL TIERODS CROSS SECTIONAL AREA     =  4.00000D 00
         DIST OF TIE RODS FROM CYL AXIS         =  3.10000D 00
             ( IN PLANE OF BENDING )
```

```
TABLE 4:     BEARINGS AND SEALS

    PISTON BEARINGS:

                 A              A              A              B         DISTANCE FROM
               WIDTH        THICKNESS    YOUNGS MODULUS   STIFFNESS       BACK FACE

            3.16000D-01   4.51000D-01   5.00000D 02   0.0              2.37500D 00
            3.65000D-01   2.50000D-01   1.00000D 03   0.0              3.90000D 00
            3.16000D-01   4.51000D-01   5.00000D 02   0.0              5.45000D 00

    ROD BEARINGS:

                 A              A              A              B         DISTANCE FROM
               WIDTH        THICKNESS    YOUNGS MODULUS   STIFFNESS       BACK FACE

            3.50000D-01   2.00000D-01   7.50000D 02   0.0              3.15000D 00

          (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                     ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)

TABLE 5:     WEIGHTS AND MATERIAL PROPERTIES

    WEIGHTS OF PARTS:

              CYLINDER         ROD         PISTON HEAD  STUFFING BOX
                (PER UNIT LENGTH)

            3.20000D-03   2.00000D-03   5.00000D-02   7.00000D-02

    MATERIAL PROPERTIES:

                              CYLINDER        ROD          TIERODS

         YOUNGS MODULUS     2.90000D 04   2.90000D 04   2.90000D 04

         YIELD STRESS       1.25000D 02   1.25000D 02   1.25000D 02

         POISSONS RATIO     2.50000D-01

    TOTAL INITIAL FORCE IN TIE RODS =  2.40000D 02

TABLE 6:     INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

    CYL INCLINATION WITH HORIZONTAL =  0.0

                                             CYLINDER END     ROD END

    SUPPORT CONDITIONS:                          PIN            PIN

    FRICTION COEFFICIENTS AT SUPPORTS:      2.50000D-02   2.50000D-02
          (ZERO IF FIXED END)
    LOADING ECCENTRICITIES:                 1.00000D-01   1.20000D-01

TABLE 7:     FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
             DEPENDING ON PROBLEM TYPE

    FACTOR OF SAFETY =  2.000 ON LOAD
```

```
 PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TIE1

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER.

RESULTS:     CRITICAL LOAD ANALYSIS

        CRITICAL LOAD           =  1.296D 02    KIPS

        MAXIMUM FLUID PRESSURE =  4.583D 00    KSI

        CROOKEDNESS ANGLE       =  4.80323D-02  DEG

CYLINDER:

     MAXIMUM DEFLECTION          =  1.901D 00    INCH

     MAXIMUM LONGITUDINAL STRESS=  3.530D 01    KSI

     AT A DISTANCE FROM CYL SUP =  5.896D 01    INCH

     FACTOR OF SAFETY ON CYL     =  3.541D 00

     MAX SHEAR STRESS IN CYL     =  3.166D 01    KSI
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTOR OF SAFETY ON CYL     =  1.973D 00

     MAXIMUM HOOP STRESS IN CYL =  2.997D 01    KSI

     FACTOR OF SAFETY ON CYL     =  4.171D 00

ROD     :

     MAXIMUM DEFLECTION          =  2.080D 00    INCH

     MAXIMUM LONGITUDINAL STRESS=  1.252D 02    KSI

     AT A DISTANCE FROM CYL SUP =  7.135D 01    INCH

     FACTOR OF SAFETY ON ROD     =  9.987D-01


TIE RODS:


     STRESS IN TOP RODS          =  5.176D 01    KSI

     FACTOR OF SAFETY ON THESE  =  2.415D 00


     STRESS IN BOTTOM RODS       =  6.064D 01    KSI

     FACTOR OF SAFETY ON THESE  =  2.061D 00
```

```
FORCES AT SLIDING CONNECTION:

         PISTON BEARINGS (SEALS)      FORCE
                 NO

                  1                2.550D 00  KIPS

                  2                2.183D 01  KIPS

                  3                7.969D 00  KIPS


           ROD BEARINGS (SEALS)      FORCE
                 NO

                  1                1.346D 01  KIPS



  F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0          KIPS

  F2- FORCE AT STUFFING BOX FRONT FACE =  1.888D 01   KIPS

  F3- FORCE AT PISTON HEAD BACK FACE   =  0.0          KIPS

  F4- FORCE AT STUFFING BOX INNER FACE =  0.0          KIPS
     (ZERO FORCES INDICATE NO CONTACT)
```

```
ANALYSIS AFTER APPLYING GIVEN FACTOR OF SAFETY OF  2.000  ON  LOAD:

          LOAD                   =  6.479D 01     KIPS

          FLUID PRESSURE         =  2.292D 00     KSI

          CROOKEDNESS ANGLE      =  7.464120-03  DEG

CYLINDER:

     MAXIMUM DEFLECTION          =  1.4830-01     INCH

     MAXIMUM LONGITUDINAL STRESS=  2.378D 01     KSI

     AT A DISTANCE FROM CYL SUP =  5.763D 01     INCH

     FACTOR OF SAFETY ON CYL     =  5.256D 00


     MAX SHEAR STRESS IN CYL     =  1.931D 01     KSI
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTOR OF SAFETY ON CYL     =  3.237D 00


     MAXIMUM HOOP STRESS IN CYL =  1.498D 01     KSI

     FACTOR OF SAFETY ON CYL     =  8.343D 00

ROD      :

     MAXIMUM DEFLECTION          =  1.6210-01     INCH

     MAXIMUM LONGITUDINAL STRESS=  1.701D 01     KSI

     AT A DISTANCE FROM CYL SUP =  7.031D 01     INCH

     FACTOR OF SAFETY ON ROD     =  7.350D 00


TIE RODS:


     STRESS IN TOP RODS          =  5.769D 01     KSI

     FACTOR OF SAFETY ON THESE   =  2.167D 00


     STRESS IN BOTTOM RODS       =  5.851D 01     KSI

     FACTOR OF SAFETY ON THESE   =  2.136D 00
```

```
FORCES AT SLIDING CONNECTION:

            PISTON BEARINGS (SEALS)      FORCE
                      NO


                      1              3.1300-02  KIPS

                      2              1.871D 00  KIPS

                      3              8.7330-01  KIPS


              ROD BEARINGS (SEALS)      FORCE
                     NO


                     1              2.775D 00  KIPS



   F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         KIPS

   F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         KIPS

   F3- FORCE AT PISTON HEAD BACK FACE   =  0.0         KIPS

   F4- FORCE AT STUFFING BOX INNER FACE =  0.0         KIPS
      (ZERO FORCES INDICATE NO CONTACT)




SEPARATION PRESSURES WITH CYLINDER STRAIGHT:

       STROKE POSITION     PRESSURE ON  SEPARATION PRESSURE

     RETRACTED (NO CONTACT)   CAP SIDE      NO SEPARATION
     EXTENDED  (NO CONTACT)   CAP SIDE      7.238D 01  KSI
     EXTENDED  (CONTACT    )   CAP SIDE      9.967D 00  KSI
     EXTENDED  (NO CONTACT)   ROD SIDE      1.541D 01  KSI
     RETRACTED (NO CONTACT)   ROD SIDE      1.271D 01  KSI
     RETRACTED (CONTACT    )   ROD SIDE      1.271D 01  KSI
```

```
PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TC DEMCNSTRATE ALL THE CPTIONS ANC VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PRCBLEM TIE2

  LPRTP=1; P-F; HOLLOW ROD WITH NO FLUID; VERTICAL CYLINDER.

INPUT CATA:

TABLE 1:     CCNTRGL UATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD


             TABLES RETAINED FROM PREVIOUS PROBLEM

               2     3     4     5     6     7
             KEEP              KEEP

TABLE 2:     UNITS CF MEASUREMENT

            LENGTH       LOAD      PRESSURE   ANGULAR

             INCH        KIPS        KSI        DEG


TABLE 3:     CYLINDER DIMENSICNS

    LENGTHS:

             STROKE       PISTCN HEAD  STUFFING BCX    END PLATE    HINGE DIST.

          5.000000 01   6.13000D 00   4.44000D 00   7.60000D-01   3.00000D 00


            CYLINDER          ROD         EXTENDED      STOP TUBE

          5.61300D 01   5.68200C 01   1.16710D 02   0.0

    CIAMETERS:

          CYL. OUTER    CYL. INNER     ROD OUTER     ROD INNER

          7.00000D 00   6.00000D 00   3.00000D 00   1.50000D 00  HOLLOW ROD
                                                                 WITH NO FLUID

           CYL. PIN *    ROC PIN *   PISTCN HEAD @  STUF. BOX @

          4.75000D 00   0.0           5.98900D 00   0.0
        (* ZERC, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

    CLEARANCES BETWEEN:

           CYLINDER      CYLINDER        ROC
             AND           AND           AND
         STUFFING BOX  PISTCN HEAD @  STUF. BOX @

          0.C            0.0           9.C0000D-03
                       (@ ZERO, OTHER OPTION IS INPUT)

    TIE RODS CETAILS:

        CLEAR TIE ROD LENGTH                   =  6.13300D 01
        EXACT CYLINDER LENGTH                  =  5.66300D 01
        TOTAL TIERODS CROSS SECTIONAL AREA     =  4.00000D 00
        DIST OF TIE RODS FRCM CYL AXIS         =  3.10000D 00
             ( IN PLANE OF BENDING )
```

```
TABLE 4:     BEARINGS AND SEALS

    PISTON BEARINGS:

                   A                A               A              B        DISTANCE FROM
                 WIDTH          THICKNESS   YOUNGS MODULUS    STIFFNESS      BACK FACE

               0.C              0.0            0.0            2.10000D 03   2.37500D 00
               0.0              0.0            0.0            8.80000D 03   3.90000D 00
               0.0              0.0            0.0            2.10000D 03   5.45000D 00

    ROD BEARINGS:

                   A                A               A              B        DISTANCE FROM
                 WIDTH          THICKNESS   YOUNGS MODULUS    STIFFNESS      BACK FACE

               0.C              0.0            0.0            3.90000D 03   3.15000D 00

          (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                     ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:     WEIGHTS AND MATERIAL PROPERTIES

    WEIGHTS OF PARTS:

              CYLINDER          RCD         PISTON HEAD  STUFFING BOX
               *(PER UNIT LENGTH)

             3.20000D-03   2.00000D-03   5.00000D-02   7.00000D-02


    MATERIAL FROPERTIES:

                                CYLINDER        RCD          TIERODS

          YOUNGS MODULUS     2.90000D 04   2.90000D 04   2.90000D 04

          YIELC STRESS       1.25000D 02   1.25000D 02   1.25000D 02

          POISSCNS RATIO     2.50000D-01


    TCTAL INITIAL FORCE IN TIE RODS =  2.40000D 02

TABLE 6:     INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

    CYL INCLINATICN WITH HORIZONTAL =  9.00000D 01

                                               CYLINDER END     ROD END

    SUPPORT CONDITIONS:                             PIN            FIX

    FRICTION COEFFICIENTS AT SUPPCRTS:   -2.00000D-02   0.0
         (ZERC IF FIXED END)
    LCADING ECCENTRICITIES:               1.00000D-01  -5.00000D-02

TABLE 7:     FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
             DEPENDING ON PROBLEM TYPE


    FACTOR OF SAFETY =  4.000 ON STRS
```

```
 PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMCNSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PRCBLEM TIE2

  LPRTP=1; P-F; HOLLCW ROD WITH NO FLUID; VERTICAL CYLINDER.

RESULTS:     CRITICAL LOAD ANALYSIS

          CRITICAL LOAD          =  2.9670 02    KIPS

          MAXIMLM FLUID PRESSURE =  1.0490 01    KSI

          CROOKEDNESS ANGLE      =  6.207400-02  DEG

CYLINDER:

     MAXIMUM DEFLECTION         =  7.9130-01    INCH

     MAXIMUM LCNGITUDINAL STRESS=  2.8350 01    KSI

     AT A DISTANCE FROM CYL SUP =  5.7610 01    INCH

     FACTCR OF SAFETY CN CYL    =  4.4080 00


     MAX SHEAR STRESS IN CYL    =  4.7890 01    KSI
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTCR OF SAFETY CN CYL    =  1.3050 00


     MAXIMUM HCOP STRESS IN CYL =  6.8610 01    KSI

     FACTOR OF SAFETY ON CYL    =  1.8220 00

ROC      :

     MAXIMUM DEFLECTION         =  8.2910-01    INCH

     MAXIMUM LCNGITUDINAL STRESS=  1.2480 02    KSI

     AT A DISTANCE FRCM CYL SUP =  6.4530 01    INCH

     FACTOR OF SAFETY ON ROD    =  1.0020 00


     MAX LONG STRESS AT ROD END =  1.2480 02    KSI

     FACTOR OF SAFETY CN RCD    =  1.0020 00


TIE RODS:


     STRESS IN TOP RODS         =  4.7710 01    KSI

     FACTCR OF SAFETY ON THESE  =  2.6200 00


     STRESS IN BCTTCM RODS      =  5.4890 01    KSI

     FACTOR OF SAFETY ON THESE  =  2.2770 CC
```

```
FORCES AT SLIDING CONNECTION:

          PISTCN BEARINGS (SEALS)      FCRCE
                  NO


                   1                2.2480-01  KIPS

                   2                1.5480 01  KIPS

                   3                7.2210 CO  KIPS


            RCD BEARINGS (SEALS)       FORCE
                  NO


                   1                2.2930 01  KIPS



   F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         KIPS

   F2- FORCE AT STUFFING BOX FRONT FACE =  C.0         KIPS

   F3- FORCE AT PISTCN HEAD BACK FACE   =  0.0         KIPS

   F4- FORCE AT STUFFING BOX INNER FACE =  C.0         KIPS
     (ZERO FORCES INDICATE NC CONTACT)
```

```
ANALYSIS AFTER APPLYING GIVEN FACTOR OF SAFETY OF  4.000  ON  STRS:

          LOAD                     =  3.431D 01    KIPS

          FLUID PRESSURE           =  1.213D 00    KSI

          CROOKEDNESS ANGLE        =  7.13899D-04  DEG

CYLINDER:

      MAXIMUM DEFLECTION           =  7.486D-03    INCH

      MAXIMUM LONGITUDINAL STRESS=  2.315D 01    KSI

      AT A DISTANCE FROM CYL SUP =  5.761D 01    INCH

      FACTOR OF SAFETY ON CYL      =  5.400D 00


      MAX SHEAR STRESS IN CYL      =  1.562D 01    KSI
      AT MAX LONG STRESS POINT
      AND AT INNER SURFACE

      FACTOR OF SAFETY ON CYL      =  4.000D 00


      MAXIMUM HOOP STRESS IN CYL =  7.934D 00    KSI

      FACTOR OF SAFETY ON CYL      =  1.576D 01

ROD    :

      MAXIMUM DEFLECTION           =  7.707D-03    INCH

      MAXIMUM LONGITUDINAL STRESS=  7.152D 00    KSI

      AT A DISTANCE FROM CYL SUP =  6.280D 01    INCH

      FACTOR OF SAFETY ON ROD      =  1.748D 01


      MAX LONG STRESS AT ROD END =  7.152D 00    KSI

      FACTOR OF SAFETY ON ROD      =  1.748D 01


TIE RODS:


      STRESS IN TOP RODS           =  5.888D 01    KSI

      FACTOR OF SAFETY ON THESE    =  2.123D 00


      STRESS IN BOTTOM RODS        =  5.911D 01    KSI

      FACTOR OF SAFETY ON THESE    =  2.115D 00
```

```
FORCES AT SLIDING CONNECTION:

              PISTON BEARINGS (SEALS)       FORCE
                     NO


                      1                 2.586D-03  KIPS

                      2                 1.780D-01  KIPS

                      3                 8.305D-02  KIPS


                RCD BEARINGS (SEALS)        FORCE
                     NO


                      1                 2.637D-01  KIPS



   F1- FORCE AT PISTON HEAD FRONT FACE   =  0.0          KIPS

   F2- FORCE AT STUFFING BOX FRONT FACE =  0.0          KIPS

   F3- FORCE AT PISTON HEAD BACK FACE    =  0.0          KIPS

   F4- FORCE AT STUFFING BOX INNER FACE =  0.0          KIPS
      (ZERO FORCES INDICATE NO CONTACT)
```

```
SEPARATION PRESSURES WITH CYLINDER STRAIGHT:

         STROKE POSITION      PRESSURE ON  SEPARATION PRESSURE

      RETRACTED (NO CONTACT)   CAP SIDE     NO SEPARATION
      EXTENDED  (NO CONTACT)   CAP SIDE     7.238D 01  KSI
      EXTENDED  (CONTACT    )  CAP SIDE     9.967D 00  KSI
      EXTENDED  (NO CONTACT)   ROD SIDE     1.541D 01  KSI
      RETRACTED (NO CONTACT)   ROD SIDE     1.271D 01  KSI
      RETRACTED (CONTACT    )  ROD SIDE     1.271D 01  KSI
```

```
PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PROBLEM TIE3

  LPRTP=1; F-F; SOLID ROD; 30 DEG INCLINED CYL.

INPUT DATA:

TABLE 1:     CONTROL DATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD


              TABLES RETAINED FROM PREVIOUS PROBLEM

                 2     3     4     5     6     7

                    NO KEEP OPTIONS EXERCISED


TABLE 2:     UNITS OF MEASUREMENT

             LENGTH      LOAD     PRESSURE   ANGULAR

              INCH       LBS        PSI        DEG


TABLE 3:     CYLINDER DIMENSIONS

     LENGTHS:

                STROKE       PISTON HEAD  STUFFING BOX    END PLATE     HINGE DIST.

             5.000000D 01   6.130000D 00   4.440000D 00   7.600000D-01   3.000000D 00


              CYLINDER          ROD          EXTENDED       STOP TUBE

             5.613000D 01   5.682000D 01   1.167100D 02   0.0

    DIAMETERS:

             CYL. OUTER     CYL. INNER      ROD OUTER      ROD INNER

             7.000000D 00   6.000000D 00   3.000000D 00   0.0            SOLID ROD


              CYL. PIN *     ROD PIN *    PISTON HEAD @  STUF. BOX @

             0.0            0.0            0.0            0.0
            (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

    CLEARANCES BETWEEN:

              CYLINDER       CYLINDER         ROD
                AND            AND            AND
            STUFFING BOX  PISTON HEAD @  STUF. BOX @

             5.000000D-03   1.100000D-02   9.000000D-03
                          (@ ZERO, OTHER OPTION IS INPUT)

    TIE RODS DETAILS:

          CLEAR TIE ROD LENGTH                  =  6.133000D 01
          EXACT CYLINDER LENGTH                 =  5.663000D 01
          TOTAL TIERODS CROSS SECTIONAL AREA    =  4.000000D 00
          DIST OF TIE RODS FROM CYL AXIS        =  3.100000D 00
               ( IN PLANE OF BENDING )
```

```
TABLE 4:     BEARINGS AND SEALS

     PISTON BEARINGS:

                  A             A              A              B         DISTANCE FROM
                WIDTH       THICKNESS   YOUNGS MODULUS    STIFFNESS       BACK FACE

             0.0            0.0            0.0            2.100000D 06   2.375000D 00
             0.0            0.0            0.0            8.800000D 06   3.900000D 00
             0.0            0.0            0.0            2.100000D 06   5.450000D 00

     ROD BEARINGS:

                  A             A              A              B         DISTANCE FROM
                WIDTH       THICKNESS   YOUNGS MODULUS    STIFFNESS       BACK FACE

             3.500000D-01   2.000000D-01   7.500000D 05   0.0            1.750000D 00
             3.500000D-01   4.000000D-01   2.500000D 05   0.0            3.500000D 00

          (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                         ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:     WEIGHTS AND MATERIAL PROPERTIES

     WEIGHTS OF PARTS:

              CYLINDER          ROD         PISTON HEAD  STUFFING BOX
                 (PER UNIT LENGTH)

             3.200000D 00   2.000000D 00   5.000000D 01   7.000000D 01


     MATERIAL PROPERTIES:

                                  CYLINDER          ROD          TIERODS

          YOUNGS MODULUS       2.900000D 07   2.900000D 07   2.900000D 07

          YIELD STRESS         7.500000D 04   1.250000D 05   1.250000D 05

          POISSONS RATIO       2.500000D-01


     TOTAL INITIAL FORCE IN TIE RODS =  2.400000D 05


TABLE 6:     INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =  3.000000D 01

                                                 CYLINDER END     ROD END

     SUPPORT CONDITIONS:                             FIX            FIX

     FRICTION COEFFICIENTS AT SUPPORTS:         0.0             0.0
          (ZERO IF FIXED END)
     LOADING ECCENTRICITIES:                   -5.000000D-02  -2.500000D-02


TABLE 7:     FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
             DEPENDING ON PROBLEM TYPE


     ONLY CRITICAL LOAD ANALYSIS
```

```
 PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TIE3

  LPRTP=1; F-F; SOLID ROD; 30 DEG INCLINED CYL.

RESULTS:     CRITICAL LOAD ANALYSIS

         CRITICAL LOAD          =  2.316D 05     LBS

         MAXIMUM FLUID PRESSURE =  8.191D 03     PSI

         CROOKEDNESS ANGLE      =  4.28971D-04   DEG

CYLINDER:

     MAXIMUM DEFLECTION          =  5.526D-03    INCH

     MAXIMUM LONGITUDINAL STRESS=  2.104D 04     PSI

     AT A DISTANCE FROM CYL SUP =  5.753D 01     INCH

     FACTOR OF SAFETY ON CYL     =  3.565D 00

     MAX LONG STRESS AT CYL END =  2.151D 04     PSI

     FACTOR OF SAFETY ON CYL     =  3.487D 00

     MAX SHEAR STRESS IN CYL     =  3.749D 04     PSI
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTOR OF SAFETY ON CYL     =  1.000D 00

     MAXIMUM HOOP STRESS IN CYL =  5.356D 04     PSI

     FACTOR OF SAFETY ON CYL     =  1.400D 00

ROD      :

     MAXIMUM DEFLECTION          =  6.078D-03    INCH

     MAXIMUM LONGITUDINAL STRESS=  3.323D 04     PSI

     AT A DISTANCE FROM CYL SUP =  6.846D 01     INCH

     FACTOR OF SAFETY ON ROD     =  3.761D 00

     MAX LONG STRESS AT ROD END =  3.352D 04     PSI

     FACTOR OF SAFETY ON ROD     =  3.730D 00

TIE RODS:

     STRESS IN TOP RODS          =  5.337D 04     PSI

     FACTOR OF SAFETY ON THESE  =  2.342D 00

     STRESS IN BOTTOM RODS       =  5.305D 04     PSI

     FACTOR OF SAFETY ON THESE  =  2.356D 00
```

```
FORCES AT SLIDING CONNECTION:

           PISTON BEARINGS (SEALS)      FORCE
                     NO

                     1              1.967D-01  LBS

                     2              1.013D 02  LBS

                     3              4.654D 01  LBS

             ROD BEARINGS (SEALS)       FORCE
                     NO

                     1              1.212D 02  LBS

                     2              2.880D 01  LBS

  F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         LBS
  F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         LBS
  F3- FORCE AT PISTON HEAD BACK FACE   =  0.0         LBS
  F4- FORCE AT STUFFING BOX INNER FACE =  0.0         LBS
     (ZERO FORCES INDICATE NO CONTACT)

SEPARATION PRESSURES WITH CYLINDER STRAIGHT:

          STROKE POSITION      PRESSURE ON  SEPARATION PRESSURE

      RETRACTED (NO CONTACT)    CAP SIDE      NO SEPARATION
      EXTENDED  (NO CONTACT)    CAP SIDE      7.238D 04  PSI
      EXTENDED  (CONTACT   )    CAP SIDE      9.967D 03  PSI
      EXTENDED  (NO CONTACT)    ROD SIDE      1.541D 04  PSI
      RETRACTED (NO CONTACT)    ROD SIDE      1.271D 04  PSI
      RETRACTED (CONTACT   )    ROD SIDE      1.271D 04  PSI
```

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PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PROBLEM TIE4

  LPRTP=1: P-P; SOLID ROD; HORIZONTAL CYLINDER WITH A OVERHANG.

INPUT DATA:

TABLE 1:      CONTROL DATA

     PROBLEM TYPE = 1 - CRITICAL LOAD ANALYSIS & ANALYSIS FOR A FACTORED LOAD


              TABLES RETAINED FROM PREVIOUS PROBLEM

                 2     3     4     5     6     7

                    NO KEEP OPTIONS EXERCISED


TABLE 2:      UNITS OF MEASUREMENT

             LENGTH      LOAD      PRESSURE   ANGULAR

              INCH       KIPS        KSI        RAD


TABLE 3:      CYLINDER DIMENSIONS

     LENGTHS:

                STROKE        PISTON HEAD  STUFFING BOX    END PLATE    HINGE DIST.

             6.000000D 01   6.130000D 00   4.440000D 00   7.600000D-01  -1.500000D 01


              CYLINDER          ROD         EXTENDED      STOP TUBE

             6.613000D 01   6.682000D 01   1.187100D 02   0.0

     DIAMETERS:

             CYL. OUTER     CYL. INNER     ROD OUTER      ROD INNER

             6.500000D 00   5.500000D 00   2.750000D 00   0.0            SOLID ROD


              CYL. PIN *     ROD PIN *    PISTON HEAD @  STUF. BOX @

             2.000000D 00   3.000000D 00   5.490000D 00   2.760000D 00
            (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

     CLEARANCES BETWEEN:

              CYLINDER       CYLINDER         ROD
                AND            AND            AND
            STUFFING BOX  PISTON HEAD @  STUF. BOX @

             5.000000D-03   1.000000D-02   8.000000D-03
                          (@ ZERO, OTHER OPTION IS INPUT)

     TIE RODS DETAILS:

          CLEAR TIE ROD LENGTH                 =  7.133000D 01
          EXACT CYLINDER LENGTH                =  6.663000D 01
          TOTAL TIERODS CROSS SECTIONAL AREA   =  4.000000D 00
          DIST OF TIE RODS FROM CYL AXIS       =  2.800000D 00
               ( IN PLANE OF BENDING )
```

```
TABLE 4:      BEARINGS AND SEALS

     PISTON BEARINGS:

                  A              A              A              B         DISTANCE FROM
                WIDTH        THICKNESS    YOUNGS MODULUS   STIFFNESS      BACK FACE

             3.160000D-01   4.510000D-01   5.000000D 02   0.0            2.375000D 00
             0.0            0.0            0.0            8.800000D 03   3.900000D 00
             0.0            0.0            0.0            2.100000D 03   5.450000D 00

     ROD BEARINGS:

                  A              A              A              B         DISTANCE FROM
                WIDTH        THICKNESS    YOUNGS MODULUS   STIFFNESS      BACK FACE

             3.500000D-01   2.000000D-01   7.500000D 02   0.0            3.150000D 00

          (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                          ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:      WEIGHTS AND MATERIAL PROPERTIES

     WEIGHTS OF PARTS:

             CYLINDER          ROD         PISTON HEAD  STUFFING BOX
                (PER UNIT LENGTH)

            3.000000D-03   1.750000D-03   4.000000D-02   6.000000D-02


     MATERIAL PROPERTIES:

                              CYLINDER         ROD          TIERODS

          YOUNGS MODULUS    2.900000D 04   2.900000D 04   2.900000D 04

          YIELD STRESS      1.000000D 02   1.250000D 02   1.250000D 02

          POISSONS RATIO    2.500000D-01


     TOTAL INITIAL FORCE IN TIE RODS =  2.400000D 02


TABLE 6:      INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =  0.0

                                             CYLINDER END    ROD END

     SUPPORT CONDITIONS:                         PIN           PIN

     FRICTION COEFFICIENTS AT SUPPORTS:    5.000000D-02   0.0
          (ZERO IF FIXED END)
     LOADING ECCENTRICITIES:               0.0            1.000000D-02


TABLE 7:      FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
              DEPENDING ON PROBLEM TYPE


     ONLY CRITICAL LOAD ANALYSIS
```

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 PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TIE4

  LPRTP=1; P-P; SOLID ROD; HORIZONTAL CYLINDER WITH A OVERHANG.

RESULTS:     CRITICAL LOAD ANALYSIS

          CRITICAL LOAD          =  7.504D 01    KIPS

          MAXIMUM FLUID PRESSURE =  3.158D 00    KSI

          CROOKEDNESS ANGLE      =  1.26334D-03  RAD

CYLINDER:

      MAXIMUM DEFLECTION         =  2.470D 00    INCH

      MAXIMUM LONGITUDINAL STRESS=  3.697D 01    KSI

      AT A DISTANCE FROM CYL SUP =  4.952D 01    INCH

      FACTOR OF SAFETY ON CYL    =  2.705D 00


      MAX SHEAR STRESS IN CYL    =  2.710D 01    KSI
      AT MAX LONG STRESS POINT
      AND AT INNER SURFACE

      FACTOR OF SAFETY ON CYL    =  1.845D 00


      MAXIMUM HOOP STRESS IN CYL =  1.908D 01    KSI

      FACTOR OF SAFETY ON CYL    =  5.241D 00


      END DEFLECTION IN OVERHANG = -7.572D-01    INCH
ROD     :

      MAXIMUM DEFLECTION         =  2.900D 00    INCH

      MAXIMUM LONGITUDINAL STRESS=  1.215D 02    KSI

      AT A DISTANCE FROM CYL SUP =  6.784D 01    INCH

      FACTOR OF SAFETY ON ROD    =  1.029D 00



TIE RODS:


      STRESS IN TOP RODS         =  5.589D 01    KSI

      FACTOR OF SAFETY ON THESE  =  2.236D 00



      STRESS IN BOTTOM RODS      =  6.159D 01    KSI

      FACTOR OF SAFETY ON THESE  =  2.030D 00
```

```
FORCES AT SLIDING CONNECTION:

            PISTON BEARINGS (SEALS)      FORCE
                       NO


                       1                9.523D-03  KIPS

                       2                1.700D 01  KIPS

                       3                8.168D 00  KIPS



              ROD BEARINGS (SEALS)       FORCE
                       NO


                       1                2.518D 01  KIPS



   F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         KIPS

   F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         KIPS

   F3- FORCE AT PISTON HEAD BACK FACE   =  0.0         KIPS

   F4- FORCE AT STUFFING BOX INNER FACE =  0.0         KIPS
      (ZERO FORCES INDICATE NO CONTACT)
```

```
SEPARATION PRESSURES WITH CYLINDER STRAIGHT:

         STROKE POSITION     PRESSURE ON  SEPARATION PRESSURE

     RETRACTED (NO CONTACT)   CAP SIDE      1.075D 01  KSI
     EXTENDED  (NO CONTACT)   CAP SIDE      9.466D 00  KSI
     EXTENDED  (CONTACT   )   CAP SIDE      1.197D 01  KSI
     EXTENDED  (NO CONTACT)   ROD SIDE      1.734D 01  KSI
     RETRACTED (NO CONTACT)   ROD SIDE      1.422D 01  KSI
     RETRACTED (CONTACT   )   ROD SIDE      1.519D 01  KSI
```

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PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMCNSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PROBLEM TIE5

  LPRTP=2; F-P; HOLLCW ROD WITH FLUID; INCLINED CYLINDER; METRIC UNITS.

INPUT CATA:

TABLE 1:     CCNTROL DATA

     PROBLEM TYPE = 2 - ANALYSIS FOR A PARTICULAR PRESSURE


            TABLES RETAINED FROM PREVIOUS PROBLEM

               2     3     4     5     6     7

                  NO KEEP OPTIONS EXERCISED


TABLE 2:     UNITS OF MEASUREMENT

           LENGTH      LCAD      PRESSURE   ANGULAR

            CM          KGS        KGSC        RAD


TABLE 3:     CYLINDER DIMENSIONS

     LENGTHS:

             STROKE      PISTON HEAD  STUFFING BOX   END PLATE    HINGE DIST.

           1.27000D 02   1.55700D 01   1.12800D 01   1.93000D 00   7.62000D 00

           CYLINDER         RCD         EXTENDEC      STOP TUBE

           1.42570D 02   1.44380D 02   2.96500D 02   0.0

     DIAMETERS:

           CYL. OUTER    CYL. INNER     ROD OUTER     ROD INNER

           1.77800D 01   1.52400D 01   7.62000D 00   3.80000D 00   HOLLOW ROD
                                                                   WITH FLUID

            CYL. PIN *    ROD PIN *   PISTON HEAD @  STUF. BOX @

           0.0           1.20000D 01   1.52200D 01   7.64000D 00
          (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

     CLEARANCES BETWEEN:

            CYLINDER       CYLINDER        ROD
              AND            AND           AND
          STUFFING BOX   PISTCN HEAD @  STUF. BOX @

           1.00000D-02   0.0            0.0
                       (@ ZERO, CTHER CPTICN IS INPUT)

     TIE RCDS CETAILS:

          CLEAR TIE ROD LENGTH                = 1.55780D 02
          EXACT CYLINDER LENGTH               = 1.44070D 02
          TOTAL TIERCDS CRCSS SECTIONAL AREA  = 2.50000D 01
          DIST OF TIE RODS FROM CYL AXIS      = 7.75000D 00
             ( IN PLANE OF BENDING )
```

```
TABLE 4:     BEARINGS AND SEALS

     PISTON BEARINGS:

                 A             A              A             B        DISTANCE FROM
               WIDTH       THICKNESS   YCUNGS MODULUS   STIFFNESS     BACK FACE

            8.00000D-01   1.15000D 00   3.50000D 04   0.0            6.00000D 00
            1.00000D 00   8.00000D-01   7.00000D 04   0.0            1.00000D 01
            0.C           0.0           0.0           3.71000D 05    1.35000D 01

     RCD BEARINGS:

                 A             A              A             B        DISTANCE FROM
               WIDTH       THICKNESS   YOUNGS MODULUS   STIFFNESS     BACK FACE

            1.00000D 00   5.00000D-01   5.00000D 04   0.0            8.00000D 00

          (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                   ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:     WEIGHTS AND MATERIAL PROPERTIES

     WEIGHTS OF PARTS:

             CYLINDER         ROD        PISTCN HEAD  STUFFING BCX
                (PER UNIT LENGTH)

            1.50000D 00   1.00000D 00   2.30000D 01   3.20000D 01


     MATERIAL PROPERTIES:

                                CYLINDER        ROD          TIERODS

          YOUNGS MODULUS      2.10000D 06   2.10000D 06   2.10000D 06

          YIELD STRESS        7.05000D 03   8.80000D 03   1.00000D 04

          POISSONS RATIO      2.50000D-01

     TOTAL INITIAL FORCE IN TIE RODS =  1.25000D 05


TABLE 6:     INCLINATION, FIXITY, FRICTICN COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =  7.50000D-01

                                           CYLINDER END    ROD END

     SUPPORT CCNDITIONS:                       FIX           PIN

     FRICTION COEFFICIENTS AT SUPPORTS:    0.0          -5.00000D-02
          (ZERC IF FIXED END)
     LOADING ECCENTRICITIES:               0.0           1.00000D-01


TABLE 7:     FACTOR OF SAFETY CR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
             DEPENDING ON PROBLEM TYPE


     OPERATING PRESSURE =  1.75000D 02
```

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 PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI

PROBLEM TIE5

  LPRTP=2; F-P; HOLLOW ROD WITH FLUID; INCLINED CYLINDER; METRIC UNITS.

RESULTS:     ANALYSIS FOR A GIVEN OPERATING PRESSURE


          OPERATING PRESSURE       =  1.750D 02    KGSC

          LOAD                     =  3.192D 04    KGS

          CROOKEDNESS ANGLE        = -2.38437D-05  RAD

CYLINDER:

     MAXIMUM DEFLECTION          =  5.415D-02    CM

     MAXIMUM LONGITUDINAL STRESS=  1.864D 03    KGSC

     AT A DISTANCE FROM CYL SUP =  1.470D 02    CM

     FACTOR OF SAFETY ON CYL     =  3.782D 00


     MAX LONG STRESS AT CYL END =  2.004D 03    KGSC

     FACTOR OF SAFETY ON CYL     =  3.519D 00


     MAX SHEAR STRESS IN CYL     =  1.562D 03    KGSC
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTOR OF SAFETY ON CYL     =  2.256D 00


     MAXIMUM HOOP STRESS IN CYL =  1.144D 03    KGSC

     FACTOR OF SAFETY ON CYL     =  6.161D 00

ROD      :

     MAXIMUM DEFLECTION          =  9.156D-02    CM

     MAXIMUM LONGITUDINAL STRESS=  1.076D 03    KGSC

     AT A DISTANCE FROM CYL SUP =  2.220D 02    CM

     FACTOR OF SAFETY ON ROD     =  8.175D 00


     MAX SHEAR STRESS IN ROD     =  6.604D 02    KGSC
     AT MAX LONG STRESS POINT
     AND AT INNER SURFACE

     FACTOR OF SAFETY ON ROD     =  6.662D 00


     MAXIMUM HOOP STRESS IN ROD =  2.909D 02    KGSC

     FACTOR OF SAFETY ON ROD     =  3.026D 01
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TIE RODS:


      STRESS IN TOP RODS          =  4.906D 03    KGSC

      FACTOR OF SAFETY ON THESE  =  2.039D 00


      STRESS IN BOTTOM RODS       =  4.802D 03    KGSC

      FACTOR OF SAFETY ON THESE  =  2.082D 00



FORCES AT SLIDING CONNECTION:

            PISTON BEARINGS (SEALS)       FORCE
                     NO


                     1               -7.956D 00  KGS

                     2               -1.558D 02  KGS

                     3               -7.430D 01  KGS


              ROD BEARINGS (SEALS)       FORCE
                     NO


                     1               -2.380D 02  KGS



   F1- FORCE AT PISTON HEAD FRONT FACE  =  0.0         KGS

   F2- FORCE AT STUFFING BOX FRONT FACE =  0.0         KGS

   F3- FORCE AT PISTON HEAD BACK FACE   =  0.0         KGS

   F4- FORCE AT STUFFING BOX INNER FACE =  0.0         KGS
      (ZERO FORCES INDICATE NO CONTACT)



SEPARATION PRESSURES WITH CYLINDER STRAIGHT:

        STROKE POSITION      PRESSURE ON  SEPARATION PRESSURE

     RETRACTED (NO CONTACT)   CAP SIDE     NO SEPARATION

     EXTENDED  (NO CONTACT)   CAP SIDE     5.984D 03  KGSC

     EXTENDED  (CONTACT   )   CAP SIDE     6.017D 02  KGSC

     EXTENDED  (NO CONTACT)   ROD SIDE     1.234D 03  KGSC

     RETRACTED (NO CONTACT)   ROD SIDE     1.023D 03  KGSC

     RETRACTED (CONTACT   )   ROD SIDE     1.023D 03  KGSC
```

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PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMONSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PROBLEM TIE6

  LPRTP=3; P-P; SOLID ROD; HORIZONTAL CYLINDER.

INPUT DATA:

TABLE 1:     CONTROL DATA

     PROBLEM TYPE = 3 - ANALYSIS TO DETERMINE SUITABLE STOP-TUBE LENGTH


             TABLES RETAINED FROM PREVIOUS PROBLEM

                2     3     4     5     6     7

                  NO KEEP OPTIONS EXERCISED


TABLE 2:     UNITS OF MEASUREMENT

            LENGTH     LOAD     PRESSURE   ANGULAR

             INCH      KIPS       KSI        DEG


TABLE 3:     CYLINDER DIMENSIONS

     LENGTHS:

              STROKE       PISTON HEAD  STUFFING BOX    END PLATE    HINGE DIST.

           6.000000 01   6.130000 00   4.440000 00   7.600000-01   3.000000 00

             CYLINDER          ROD          EXTENDED        STOP TUBE

         THESE NOT INPUT BECAUSE STOP TUBE LENGTH ANALYSIS IS ASKED


     DIAMETERS:

           CYL. OUTER    CYL. INNER     ROD OUTER     ROD INNER

           7.000000 00   6.000000 00   3.000000 00   0.0              SOLID ROD


            CYL. PIN *    ROD PIN *   PISTON HEAD @  STUF. BOX @

           4.750000 00   4.750000 00   5.989000 00   3.009000 00
          (* ZERO, THE END IS FIXED) (@ ZERO, OTHER OPTION IS INPUT)

     CLEARANCES BETWEEN:

            CYLINDER       CYLINDER          ROD
              AND            AND             AND
          STUFFING BOX   PISTON HEAD @   STUF. BOX @

           5.000000-03    0.0             0.0
                         (@ ZERO, OTHER OPTION IS INPUT)

     TIE RODS DETAILS:

         CLEAR TIE ROD LENGTH                  =  0.0
         EXACT CYLINDER LENGTH                 =  0.0
         TOTAL TIERODS CROSS SECTIONAL AREA    =  4.000000 00
         DIST OF TIE RODS FROM CYL AXIS        =  3.100000 00
              ( IN PLANE OF BENDING )
```

```
TABLE 4:     BEARINGS AND SEALS

     PISTON BEARINGS:

                  A              A                A              B          DISTANCE FROM
                WIDTH        THICKNESS    YOUNGS MODULUS     STIFFNESS       BACK FACE

               0.0            0.0            0.0             2.100000 03    2.375000 00
               0.0            0.0            0.0             8.800000 03    3.900000 00
               0.0            0.0            0.0             2.100000 03    5.450000 00

     ROD BEARINGS:

                  A              A                A              B          DISTANCE FROM
                WIDTH        THICKNESS    YOUNGS MODULUS     STIFFNESS       BACK FACE

               0.0            0.0            0.0             3.900000 03    3.150000 00

            (A IS USED TO CALCULATE B - HENCE, EITHER A OR  B IS INPUT
                         ZERO'S ABOVE INDICATE THAT THEY ARE NOT INPUT)


TABLE 5:     WEIGHTS AND MATERIAL PROPERTIES

     WEIGHTS OF PARTS:

              CYLINDER          ROD         PISTON HEAD  STUFFING BOX
                (PER UNIT LENGTH)

             3.200000-03   2.000000-03   5.000000-02   7.000000-02


     MATERIAL PROPERTIES:

                                CYLINDER        ROD          TIERODS

           YOUNGS MODULUS     2.900000 04   2.900000 04   2.900000 04

           YIELD STRESS       1.000000 02   1.250000 02   1.250000 02

           POISSONS RATIO     2.500000-01


     TOTAL INITIAL FORCE IN TIE RODS =  2.400000 02


TABLE 6:     INCLINATION, FIXITY, FRICTION COEFFICIENTS, LOADING ECCENTRICITY

     CYL INCLINATION WITH HORIZONTAL =  0.0

                                          CYLINDER END     ROD END

     SUPPORT CONDITIONS:                      PIN           PIN

     FRICTION COEFFICIENTS AT SUPPORTS:   0.0            -5.000000-02
          (ZERO IF FIXED END)
     LOADING ECCENTRICITIES:              0.0             1.000000-01


TABLE 7:     FACTOR OF SAFETY OR OPERATING PRESSURE AND/OR ALLOWABLE THETA & F
             DEPENDING ON PROBLEM TYPE


     OPERATING CYLINDER PRESSURE    =  2.000000 00

     ALLOWABLE CROOKEDNESS ANGLE    =  7.500000-03  AT GLAND

     ALLOWABLE TOTAL LATERAL FORCE =  1.000000 01  ON BEARINGS
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 PROGRAM SACTIE - STRESS ANALYSIS OF CYLINDERS WITH TIE RODS

EXAMPLE PROBLEMS TO DEMCNSTRATE ALL THE OPTIONS AND VARIATIONS IN INPUT DATA
CODED  JUNE 9, 1976   BY   K. L. SESHASAI


PRCBLEM TIE6

  LPRTP=3; P-P; SOLID RCD; HORIZONTAL CYLINDER.


RESULTS:     ANALYSIS TO DETERMINE STOP-TUBE LENGTH


REQUIRED LENGTH OF STOP-TUBE    =  3.600D 00    INCH

CCRRESPCNDING EXTENDED LENGTH   =  1.403D 02    INCH

RESULTS WITH THIS STOP-TUBE ARE:


           CRITICAL LOAD           =  5.655D 01    KIPS

           MAXIMUM FLUIC PRESSURE =  2.000D 00    KSI

           CROOKEDNESS ANGLE       =  7.43594D-03  DEG


CYLINDER:

      MAXIMUM DEFLECTION          =  5.026D-01    INCH

      MAXIMUM LCNGITUDINAL STRESS=  2.515D 01    KSI

      AT A DISTANCE FROM CYL SUP =  6.844D 01    INCH

      FACTOR OF SAFETY ON CYL    =  3.976D 00


      MAX SHEAR STRESS IN CYL    =  1.895D 01    KSI
      AT MAX LONG STRESS POINT
      AND AT INNER SURFACE

      FACTOR OF SAFETY ON CYL    =  2.639D 00


      MAXIMUM HCOP STRESS IN CYL =  1.308D 01    KSI

      FACTOR OF SAFETY ON CYL    =  7.647D 00


ROD      :

      MAXIMUM DEFLECTION          =  5.580D-01    INCH

      MAXIMUM LCNGITUDINAL STRESS=  2.628D 01    KSI

      AT A DISTANCE FROM CYL SUP =  8.487D 01    INCH

      FACTOR OF SAFETY ON ROD    =  4.756D 00


TIE RCDS:



      STRESS IN TOP RODS         =  5.751D 01    KSI

      FACTOR OF SAFETY CN THESE  =  2.174D 00



      STRESS IN BOTTOM RODS      =  5.905D 01    KSI

      FACTCR OF SAFETY ON THESE  =  2.117D 00
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FORCES AT SLIDING CCNNECTICN:

             PISTCN BEARINGS (SEALS)      FORCE
                    NO


                     1               2.534D-01  KIPS

                     2               2.803D 00  KIPS

                     3               1.091D 00  KIPS


                RCD BEARINGS (SEALS)      FORCE
                    NC


                     1               4.148D 00  KIPS



   F1- FORCE AT PISTCN HEAD FRCNT FACE   =  0.0        KIPS

   F2- FORCE AT STUFFING BOX FRONT FACE =  0.0        KIPS

   F3- FORCE AT PISTON HEAD BACK FACE   =  0.0        KIPS

   F4- FORCE AT STUFFING BOX INNER FACE =  0.0        KIPS
      (ZERO FORCES INDICATE NO CONTACT)




SEPARATION PRESSURES WITH CYLINDER STRAIGHT:


        STROKE POSITICN      PRESSURE CN  SEPARATION PRESSURE


     RETRACTED (NC CONTACT)   CAP SIDE     NO SEPARATION

     EXTENDED  (NO CONTACT)   CAP SIDE     6.967D 01  KSI

     EXTENDED  (CONTACT   )   CAP SIDE     9.932D 00  KSI

     EXTENDED  (NO CONTACT)   ROD SIDE     1.544D 01  KSI

     RETRACTED (NO CONTACT)   ROD SIDE     1.264D 01  KSI

     RETRACTED (CCNTACT   )   ROD SIDE     1.264D 01  KSI
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VITA

Kolar L. Seshasai

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Doctor of Philosophy

Thesis: STRESS AND DEFLECTION ANALYSIS OF REGULAR, TELESCOPING AND TIE ROD CYLINDERS

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