AN INVESTIGATION OF THE FATIGUE STRENGTH OF CONCRETE SLABS REINFORCED WITH WELDED WIRE FABRICS

By

PYARE MOHAN

Bachelor of Science
Agra University
Agra, India
1957

Bachelor of Technology (Honors)
Indian Institute of Technology
Kharagpur, India
1961

Submitted to the Faculty of the Graduate School of
the Oklahoma State University
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
August, 1963

AN INVESTIGATION OF THE FATIGUE STRENGTH OF CONCRETE SLABS REINFORCED WITH WELDED WIRE FABRICS

Thesis Approved:

Thesis Adviser

Roger L. Flanders

Dean of the Graduate School

PREFACE

The study of concrete slabs reinforced with welded wire fabrics under repeated loading is presented in this thesis. Fatigue strength of the specimens is determined. The modes of failures under static and repeated loadings are studied. The S-N diagram for the test specimens is established.

In completing his graduate work, the writer wishes to express his sincere appreciation to the following individuals and organizations:

To the Sheffield Division of ARMCO Steel Corporation in Kansas City, Missouri, for providing the welded wire fabrics for this study;

To the Division of Engineering Research and the School of Civil Engineering for awarding the Graduate Research Assistantship which made this year of graduate study financially possible;

To Professor Gordon G. Smith for his guidance, friendship, and valuable criticism throughout the preparation of this thesis;

To Professors Roger L. Flanders, Robert L. Peurifoy, and David M. MacAlpine for their helpful advice and encouragement throughout the writer's graduate program;

To Messrs. Cecil K. Sharp, Preston G. Wilson, and Arlin L. Harris for their friendship and assistance during the entire testing program;

To the writer's parents, Dr. L. M. Simlote and Shakuntla Simlote, for their love, encouragement, and financial support during the writer's

graduate work;

Finally, to Mrs. Virginia Neff for her careful and excellent typing of the manuscript.

June 26, 1963 P. M.
Stillwater, Oklahoma

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER I

INTRODUCTION

1.1 General

The increased use of concrete reinforced with welded wire fabric as a construction material demands additional knowledge of its behavior under loads other than static loads. Such knowledge is necessary not only for the present but for providing a rational basis for the conception of improved and extended applications in the future. At the present time few studies have been made of fatigue of concrete slabs reinforced with welded wire fabrics.

1.2 Uses of Welded Wire Fabrics

Concrete reinforced with welded wire fabric is used successfully and economically in practically every form of reinforced concrete construction. Some of its more important uses are in:

1. Short-span slab floor construction in multi-story buildings and buildings surrounded by earth,
2. Reinforced concrete wall construction,
3. Concrete slabs resting on the ground such as basement floors, driveways, paved industrial areas, filling stations, etc.,
4. Multiple-arch concrete roof construction,
5. Canal lining with cement gun work.

1.3 Advantages of Welded Wire Fabric

The use of welded wire fabric in short-span slab concrete construction has many advantages (1)*:

1. It can be placed easily and quickly with a considerable saving in labor cost.

2. It requires less steel because building codes for welded wire fabric made from cold-drawn wire allow higher working stress. Thus, a saving is made in purchasing, transporting, and handling steel.

3. Welded wire fabric provides uniform distribution of reinforcing steel throughout the concrete slab. It has smaller steel members that are closely and uniformly spaced, which allow the steel to be draped and accurately placed at points of maximum stress. This type of reinforcement distributes load stresses widely and equally throughout the concrete slab.

4. Welded wire fabric can fulfill the design requirements accurately as they are available in a wide range of styles.

5. Welded wire fabric available in long lengths in rolls assure continuity of slab action by providing continuous reinforcement.

6. Welded wire fabric allows a large variety of trades to work on and around it after it is placed and before the slab is placed as there are fewer possibilities of displacement of steel. Hence, it is more adaptable to construction work.

As a result of these various uses and advantages of welded wire fabric reinforcement, engineers have become more aware of the necessity to understand the action of concrete reinforced with welded wire

---

* This and subsequent numerals in parentheses refer to the list of references in the Bibliography.

fabric under fatigue and impact loadings. At this date to the writer's knowledge very few such studies have been made.

1.4 Object and Scope of the Investigations

The purpose of this study is to investigate the action of welded wire fabric under repeated loads when used as reinforcement in concrete slab sections.

The objects of the preliminary fatigue tests are three-fold:

First, to investigate the type of failures under static and repeated loads;

Second, to establish S-N curve;

Third, to find the fatigue strength as a percentage of ultimate static strength.

A total of seventeen 8 in. by 5 in. by 51 in. concrete slab specimens were tested for this study. Static tests on one specimen from each set of three specimens were made to determine an index of the ultimate static strength. The other specimens were subjected to repeated loads for finding the fatigue strength of the slabs as a percent of static strength.

CHAPTER II

REVIEW OF LITERATURE

2.1 General

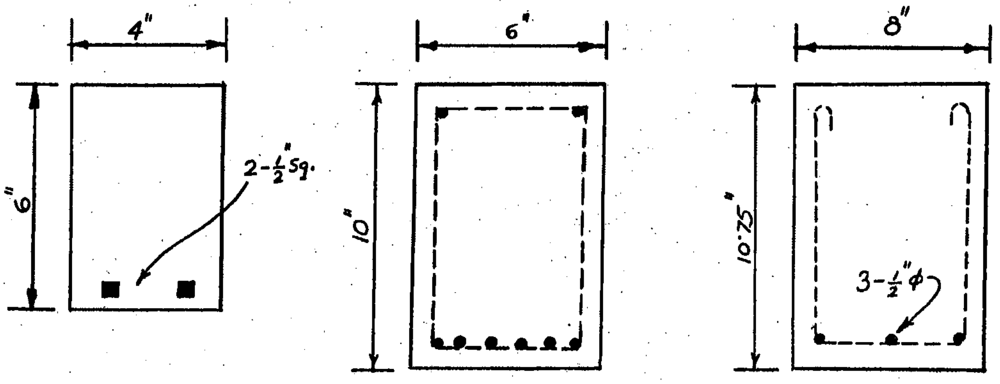
Since the beginning of the 20th Century many studies have been made in this country and abroad on fatigue of concrete. An extensive annotated bibliography(2) of the previous studies up to 1958 has been published by the America Concrete Institute. Also, Professor G. M. Nordby(3) published a comprehensive summary of the previous investigations on fatigue of concrete starting from 1898 to 1957. Most of the early works on this subject are exploratory only, but investigations conducted more recently have evolved theories which can be applied to design. These studies also provide better understanding of concrete and concrete structures.

The cross-sections of the selected reinforced concrete beams tested for fatigue by various investigators are shown in Fig. 2-1.

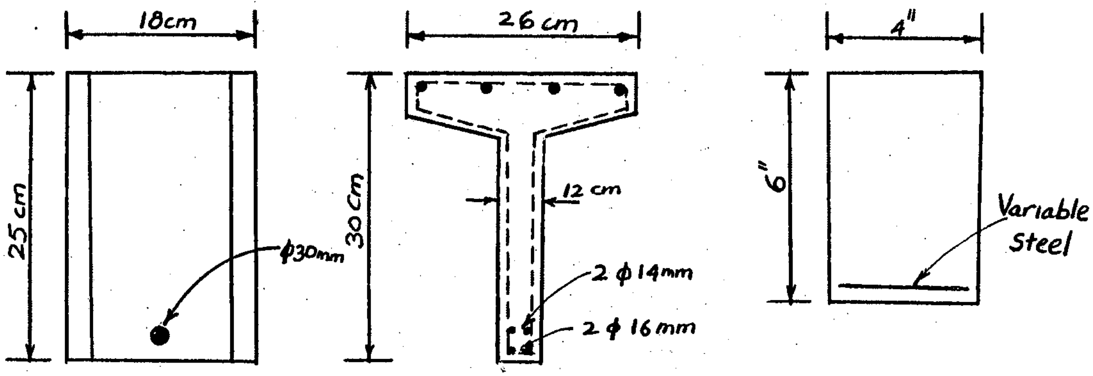
2.2 Summary of Important Studies

Some of the important investigations on this subject are summarized here. Probably, Feret was the first to test reinforced concrete structures. His work was followed by tests by Jarvis, Talbot, Hatt, and Berry.

The first extensive tests on reinforced concrete beams were made by Van Ornum(4) in 1907. He tested 4 in. by 6 in. by 72 in. beams reinforced with 2 1/2 percent steel. The beams were loaded at 2 to



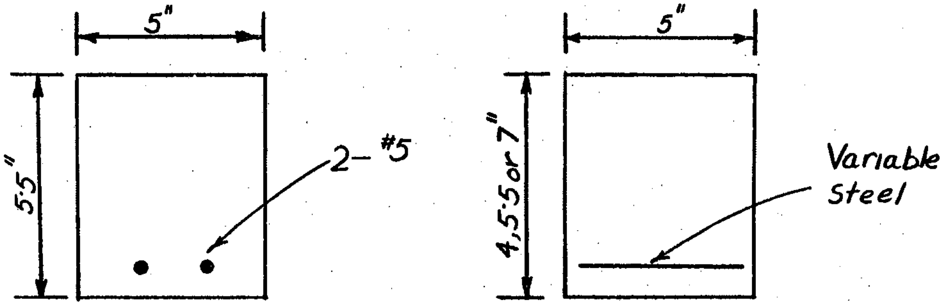
Van Ornum (4) Probst (5) Lea (7)



Le Camus (8)
(one of his sections)

Valette (9)

Kesler (11, 12)



Stelson-Cernica (17) Stelson-Verna (14)

Fig. 2-1. Cross Sections of the Selected Reinforced Concrete Beams Tested for Fatigue

4 cycles per minute. Fifty-nine beams were tested at the age of 1 month and 23 at the age of 12 months. He determined a fatigue limit of 50 percent of static ultimate strength. He found that the number of repetitions to failure reduce rapidly at stresses above 55 percent of the static ultimate load. Also, he noticed that the failure in beams was either through the development of a tension crack or through a diagonal tension crack which gradually increases in size during the test. When the penetration of the crack reached far enough, the beam failed by steel fatigue.

In 1931 Probst(5) reported on the investigations made at Karlsruhe Institute of Technology in Germany on the effects of repeated loadings on reinforced concrete. The main purpose of these tests was to study the formation of fissures in reinforced concrete beams under repeated loading and their influence on the loading capacity. Specimens were cast as rectangular beams of 6 in. by 10 in. cross-section and 6 ft. long. They were loaded symmetrically by two concentrated loads 2 ft. apart. Load applications were repeated 90 times per minute. These beams were so designed that failure would depend upon the yield of longitudinal bars. Reinforced beam specimens showed an endurance limit of 50 percent of static strength. Probst concluded that repeated loads below some critical value do not affect the ultimate carrying capacity of the beams and cracks open and close as long as the elastic limit of steel is not exceeded.

In Austria Saliger (6) conducted one of the most extensive tests on reinforced concrete beams. He made fatigue tests on 36 T-beams 9 ft. long with 0.56 and 1.40 percent reinforcements. The reinforcement consisted of 1/2 in. to 1 in. diameter bars of four different kinds of steel (ST-37, ST-55, ST-80, Isteg*). The average 400 to 500 days concrete strength was 4700 psi. The load frequency was 160 cycles per minute. From these tests Saliger concluded that:

a) adequate security against fatigue could be obtained by limiting the maximum permissible stresses in design to one third of the concrete strength obtained from cube tests and one half of the yield stress for steel,

b) for the same load the performance of high strength bars was better,

c) use of Isteg steel permits higher design stresses for the concrete because it did not elongate and allow crack penetration as rapidly as other steels.

The first series of tests made to find the fatigue strength of reinforced concrete beams was carried out by Lea(7) in England. The beams were reinforced with three 1/2 in. diameter structural grade steel smooth bars (0.9 percent steel) and were tested under ranges of loadings fluctuating between a small minimum value and a maximum. From the results it was concluded that the upper limit of fatigue strength based on 10 million repetitions of loading was 70 percent of the ultimate load. However, based on 1 million cycles, the upper limit would become 80 percent of the ultimate load. If the design working load is calculated for an allowable stress of 18000 psi in steel, the results gave load factor of 3.1 against failure under static load, and 2.5 for repeated loads. Under repeated loading, the beams failed as a result of yield of

---

*Isteg (Internationale Stegdecken) steel is cold deformed steel. It consists of 2 round bars of equal diameter and twisted together to form a twin steel bar.

the steel which led to crushing of concrete.

In another comprehensive series of tests Le Camus (8) determined the fatigue strength on the basis of 1 million cycles on reinforced concrete beams that had been designed in such a way to fail as a result of:

a) fatigue of longitudinal reinforcement,
b) crushing of the concrete,
c) fatigue of shear reinforcement both in the form of 45° stirrups and vertical stirrups,
d) shear of the concrete.

He tested 25 beams in fatigue in addition to static specimens. For beams designed to fail in tension only 0.23 percent steel was used. The interesting fact about these tests is the low fatigue strengths for the shear reinforcements in concrete specimens. His results are summarized in the following table.

Reinforced Concrete Beams Designed to Fail by	Fatigue Strengths, as Percent of Static Ultimate Strength
Fatigue of Tensile Steel	60
Fatigue of Concrete in Compression	65
Fatigue of Inclined Stirrups	47
Fatigue of Vertical Stirrups	41
Fatigue of Concrete in Shear	48

Vallete(9) has reported several isolated tests on railroad bridge beams reinforced with structural grade steel and loaded at a frequency of 500 cycles per min. Out of three typical beams tested two failed by fatigue of steel. In one case failure due to fatigue of the steel occurred after 2, 600, 000 cycles by a load producing 8, 000 to 40, 000 psi stress in steel and in the other case after 93, 000 cycles when the range of stress in steel was 8, 000 to 44, 000 psi. In each case the maximum stress in the steel was close to its yield strength. He did not find any wear of concrete or loosening of the concrete around the cracks. He concluded that structural grade steel reinforcement possesses the safety prescribed for all kinds of rolling or stationary loads.

Ros (10) made fatigue tests on 26 T-beams to study the effects of:

a) three different kinds of steels; mild steel (ST-N) (structural grade steel), high tensile steel (ST-52) (hard grade steel), and Tor-steel*,

b) two different amounts of reinforcement,

c) two different concrete compressive strengths.

The maximum load was increased in several increments until the beam was broken. His results showed that the beams reinforced with structural grade steel developed a higher proportion of their static strength than those reinforced with hard grade steel. He also noted that high-tensile and cold-worked steels fractured by fatigue in all cases at failure, whereas beams reinforced with structural grade steel failed as a result of yield of the steel for small percentages of steel in

---

*Tor-steel is cold deformed steel equivalent to U. S. structural grade steel but consists of a single twisted bar.

the section and of crushing of concrete or in a few cases fracture of the steel for beams with higher percentages of steel in the section.

Recently Kesler and Chang(11, 12) have contributed considerably to the knowledge of fatigue in reinforced concrete beams. In the first series fatigue tests were made on 39 concrete beams with 1.86 and 2.89 percent tensile reinforcements to determine the static and fatigue strengths of the beams in shear. The 4 in. by 6 in. by 64 in. specimens were tested on a 60 in. span. Based on 10 million cycles they found fatigue strength for cracking as 57 percent of the static cracking load and 63 percent of the static ultimate load for fatigue failure. In another study, a total of 25 specimens of the same size as in the first but with 1.02 percent tensile steel were tested for investigating the fatigue behavior. The results indicated that for this type of specimens the magnitude of the repeated load determines the mode of failure. From this study it was concluded that in general a low magnitude of repeated load (giving M/M_s* ratio approximately equal to or less than 0.7) causes flexure failure, fatigue failure. A high magnitude repeated load (giving M/M_s ratio approximately equal to or greater than 0.7) results in shear failure.

More recently, Stelson has reported on two studies made at Carnegie Institute of Technology. In the first series 11 beam specimens of 5 in. by 5 1/2 in. cross-section, 7 ft. long and reinforced with No. 5 high bond and high grade rods were tested by Stelson and Cernica (13)

---

[*] M = Critical moment developed in a simply supported beam, in in. - lbs.

M_s = Maximum shear moment, in in. - lbs.

under repeated loads. The loads were applied at a frequency of 320 cycles per min. The elastic design load was 2610 lbs. and the ultimate load was 8800 lbs. Fatigue strength at 500,000 cycles was found to be 5720 lbs. The ultimate load was 3.37 times the design load, and the fatigue load was 2.18 times the design load.

In the second extensive study Stelson and Verna (14) tested 60 reinforced concrete beam specimens under repeated loading. The specimens were 78 in. long, 5 in. wide and 4, 5 1/2, or 7 in. deep. The beams were simply supported over a 72 in. span and loaded at the third points. Repeated cyclic loading from 10 percent of the ultimate static load to a maximum load until failure or 1 million cycles were applied 420 times per min. If no failure occurred, the maximum load was increased on the same beam, and the program was repeated. The different modes of failure were explained in terms of nominal shear stress, nominal bond stress, concrete compression stress, and steel tension stress. From the test results it was concluded that the bond failure was the most vulnerable to fatigue damage and that shear or diagonal tension failures were likely to occur if the specimens were not weak in bond. Tests also indicated that the modes of failure depended on the load level as well as the static failure mode.

Ivanov-Diatlov (15) made tests on beams approximately 3 in. by 8 in. by 3 ft. 3 in. long to investigate the effects of pulsating loads on the propagation of cracks, change in flexure rigidity, and flexure strength. The load was applied 500 times per min. It was found that web reinforcement increases the fatigue strength. Tests also showed that the web reinforcement of welded wire fabric or stirrups welded to longitudinal steel resulted in brittle fracture at the welds. The static strength of beams previously loaded to 60 or 65 percent of the ultimate strength to 2 million cycles was not changed.

2.3 Conclusions from Literature Review

From the above summary of the previous investigations the following conclusions are drawn:

1) In reinforced concrete beams under repeated loads cracks develop at a maximum load smaller than the load causing visible cracks under static loads. Under fatigue loads cracks do not appear as long as the maximum repeated load does not exceed 50 percent of the static cracking load. When the range of the fatigue load is larger but within the limiting range, cracking and permanent deformation increases with increasing numbers of cycles until a condition of stability is reached. At this stage the dynamic deformation is almost elastic, and no further increase in the length or size of the crack takes place. This stage is achieved after fewer cycles of loading for beams with concrete of greater age, and permanent deformation and cracking is less significant than for beams with younger concrete (5). As long as steel is not stressed beyong the elastic limit, cracks open and close completely under repeated loads, and their maximum width does not exceed 0.01 in. With this size of crack the danger of corrosion of steel is negligible.

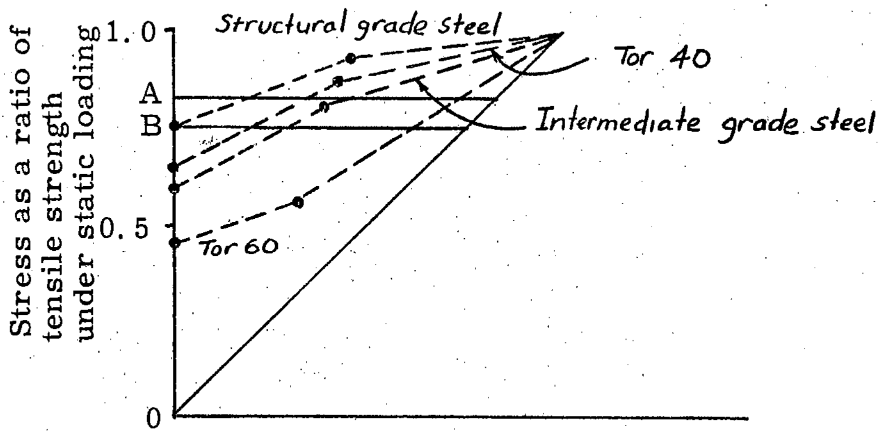
2) Within the range of allowable stresses in the materials, many repetitions of load have no effect on the subsequent deformation at higher loads or the ultimate strength under static conditions.

3) A concrete beam reinforced with a nominal percentage of structural grade steel under static loads fails by yielding of steel, which causes crushing of the concrete. Under repeated loads a similar beam is also likely to fail in this way, but the maximum load is considerably less than the ultimate load under static loads. It is unlikely

that the steel will fail because of fatigue, for fatigue loads cause appreciable permanent deformation even before the static yield stress is reached. This deformation together with the reduction in the bond between the steel and the concrete because of repeated loads hastens the failure (Le Camus , Ros, and Lea). In this type of failure the value of the minimum load has little effect on the maximum load (16).

4) If the percentage of structural grade steel in the beam section is very small, the fatigue fracture of steel may occur instead of crushing of the concrete by the yield of steel. For such beams the modified Goodman diagram may be expected to be similar to that for the steel. On the other hand, when the percentage of steel in the specimen section is high enough to cause fatigue failure of concrete, the modified diagram for the beam would be similar to that for the concrete.

5) A beam reinforced with a normal proportion of intermediate grade steel and subjected to static load fails by crushing of the concrete when the steel stress equals or exceeds yield stress. Under repeated loads, however, these high tensile strength steels may fail in fatigue when the maximum value of the stress in the steel is considerably below the yield stress. Fig. 2-2 shows a modified Goodman diagram for reinforcing steels. It may be observed that with these steels of higher tensile strengths, when the minimum stress is zero, the maximum stress is less than the static yield stress. Also for these steels the minimum value of the stress has an important influence on the maximum value. Therefore for concrete beams with these steels as reinforcement the fatigue strength increases as the minimum load is increased, until a stage is reached where the permanent deformation of the steel may be sufficient to cause failure of the concrete (16).



A yield stress for structural grade steel and intermediate grade steel.
B equivalent yield stress for cold-worked steels Tor 40 and Tor 60.

Fig. 2-2 Modified Goodman Diagram for Steels (16)

6) For concrete beams reinforced with normal percentage of structural grade steel the load factor against failure based on allowable load is greater than 2, and it may be greater for beams with larger or smaller proportions of structural grade steel. For beams reinforced with intermediate grade steel the load factor against failure, based on normal permissible load is greater than 1.30 (16).

7) The reinforced concrete elements, generally have four modes of failure:

a) concrete failure in compression,

b) diagonal tension failure in shear zone,

c) bond failure between concrete and steel,

d) brittle failure of tensile steel.

CHAPTER III

MATERIALS

The materials used in this study included cement, sand, coarse aggregates, water, and reinforcing steel.

3.1 Cement

Portland cement type I was used in making the concrete. The cement available in 1 cu. ft. paper bags weighing 94 lbs. was obtained from the Ideal Cement Company in Ada, Oklahoma. About 85 percent of this cement passed the No. 200 sieve and had a specific surface of 1500 sq. cm. per gm.

3.2 Sand

Sand used for concrete mix was obtained from the Arkansas River near Ponca City, Oklahoma. The specific gravity of the sand was 2.60. The sand had 1 percent absorption. The sieve analysis for the sand was performed in accordance with ASTM Specification C 136. The sand had a fineness modulus of 2.97.

3.3 Coarse Aggregates

The coarse aggregate used in the investigations was crushed stone available in the local area. The specific gravity of the coarse aggregate was 2.64. Absorption of aggregates was 2 percent. The sieve analysis of the coarse aggregates was performed according to ASTM Specification C 136. Coarse aggregates had a fineness modulus of 7.19.

According to ASTM Specification C 29 the unit weight of coarse aggregates was determined to be 100 lbs. per cu. ft.

3.4 Water

Ordinary tap water at room temperature was used in mixing concrete for the specimens.

3.5 Welded Wire Fabrics

Welded wire fabrics for this project were furnished by the Sheffield Division of ARMCO Steel Corporation in Kansas City, Missouri. In this investigation welded wire fabric style 212-05 was used. It conformed to the ASTM Specification A 185, and the cold drawn wire used in fabrication of wire fabrics conformed to ASTM Specification A 82.

Stress-strain tests were made on samples of the longitudinal wires. The ultimate strength of the wire was found to be 80,900 psi. The yield strength was calculated as 65,000 psi from the stress-strain curve using a 0.2 percent offset.

3.6 Concrete Mix

The concrete mix used for casting all the specimens had a cement:sand:coarse aggregate ratio by weight of 1:3:4·36 and water-cement ratio of 0.645. The maximum aggregate size was 1 in., and slump was 4 in. approximately. The 28-days cylinder strength for each slab specimen was determined from the control cylinders 6 in. in diameter and 12 in. long. One companion cylinder was cast with each slab from the same batch of concrete and was cured under conditions identical to those of the slabs. The compressive strengths of the concrete from these cylinder tests were used to compute the ultimate static capacity of the slab specimens. These values were compared with the ultimate loads obtained from the static tests.

3.7 Description of Specimens

All the specimens had dimensions and details as shown in Fig. 3-1. The slab specimens used for this study were of rectangular cross-section, 8 in. wide, 5 in. deep and 51 in. long. The reinforcement consisted of welded wire fabric style 212-05 with No. 0 longitudinal wires spaced 2 in. apart, and No. 5 transverse wires 12 in. apart. The tensile reinforcement was placed with its centroid 1 in. from the bottom of the slab. The slabs were under-reinforced and had 0.92 percent tensile steel.

3.8 Preparation of Specimens

In order to simulate the slightly rusted conditions of wires as found in the field, the wire fabrics were kept in curing room for 24 hours prior to placing in the specimens.

Specimens were cast in wooden forms. The wire fabrics were placed in such a way that the center of the longitudinal wires was 1 in. from the bottom of the specimen, with transverse wires placed above the longitudinal wires. Holes were drilled in the forms for the accurate positioning of the wires.

In specimens B-1 through B-12, to measure tensile strains in longitudinal wires in the maximum moment zone, one SR-4 strain gage was attached to one of the middle longitudinal wires. These electrical

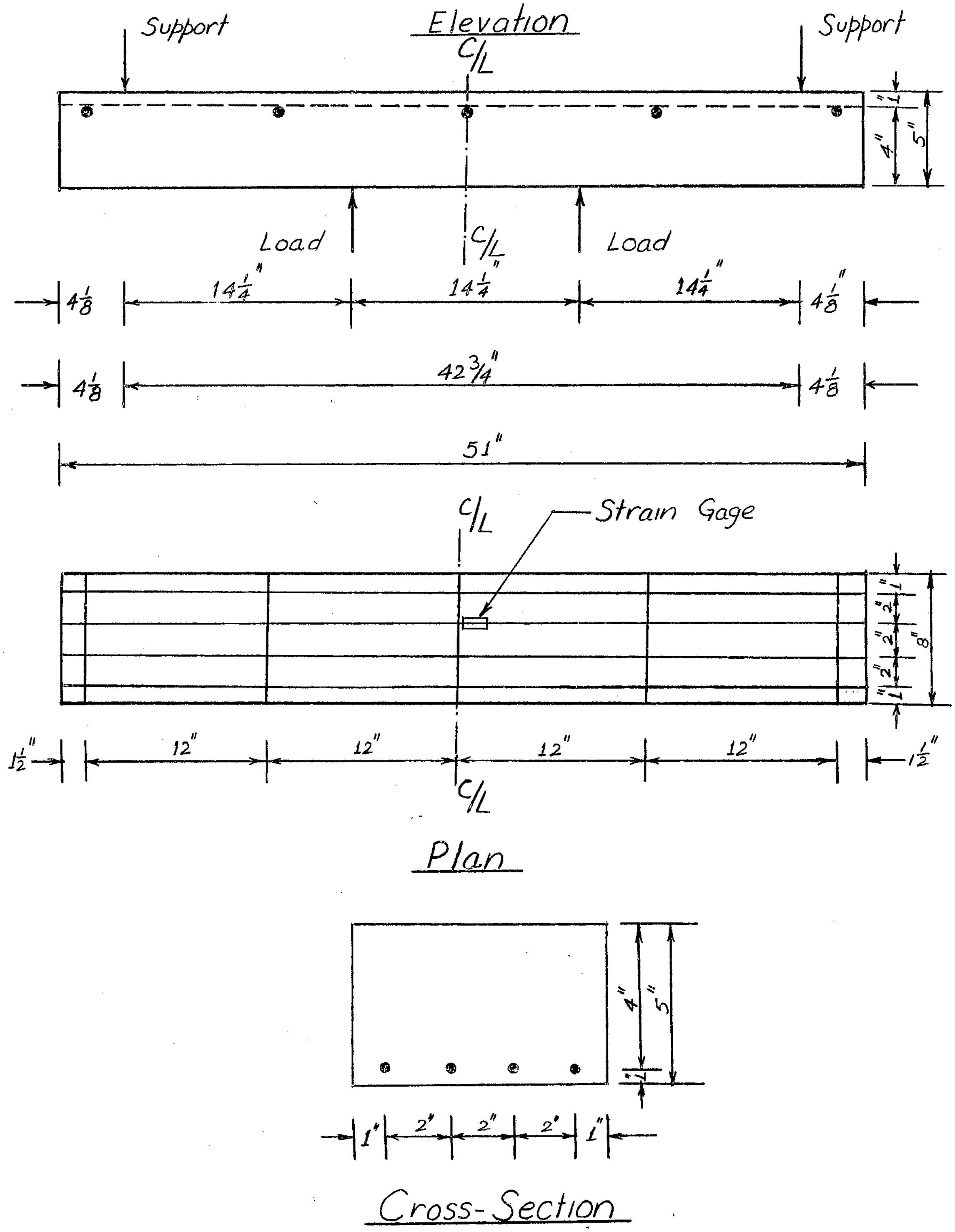


Fig. 3-1 Details of Typical Slab Specimen

resistance strain gages type A-7 were placed on the vertical side of the longitudinal wires and water-proofed before casting of the slab.

The concrete was mixed in a tilting drum mixer of 1 1/2 cu. ft. capacity for 3 to 4 min. Immediately after mixing the slump was determined. The capacity of the mixer being small, one batch of concrete was required for each slab specimen and one 6 in. by 12 in. control cylinder. Each layer was vibrated for about 45 seconds with an electric internal vibrator. Since one batch of concrete was mixed for each slab specimen, there was little control on the strength of the concrete from specimen to specimen.

The wooden forms were removed on the second day after casting. After the forms were removed, the specimens were cured for 28 days in the fog room at 70° F, and after 28 days they were stored in the laboratory until tested. Each slab was tested approximately 90 days after casting. The control cylinders were cured under similar conditions and were tested on the 28th day. Again, there was no control on the increase of concrete strength from 28 days to the time of the tests.

CHAPTER IV

EQUIPMENT AND PROCEDURE

4.1 Equipment

Two fatigue testing machines were used in this study, one for steel samples and the other for the concrete specimens. Both of these machines, made by Losenhousen Company of Germany, are designed to perform axial, shear, torsion, and static and dynamic flexural tests. These machines can be used to test all ASTM specimens, and others may be tested with special fixtures.

The Losenhausenwerk machine, used for testing steel, has a maximum static loading capacity of 20 metric tons tension or compression. This machine has a dynamic loading capacity of 10 metric tons, tension or compression. It can not alternate the load from tension to compression but can fluctuate from a maximum load to a minimum load.

The larger Losenhausenwerk machine was used for static and dynamic tests of slabs. Plate I shows a view of this machine. This machine has a maximum static loading capacity of 60 metric tons, tension or compression. The dynamic loading range is 40 metric tons. Any alternating load can be obtained with a range of 40 metric tons in any combination of tension and compression. The load capability diagram of this machine is shown in Fig. 4-1.

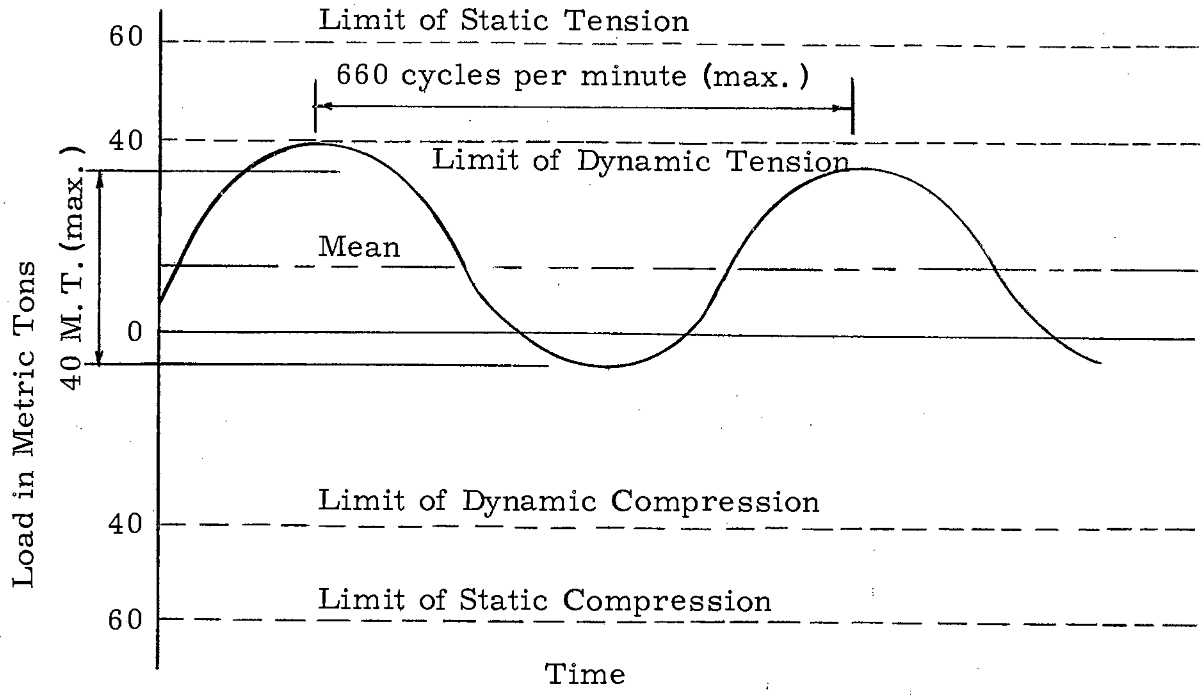


Fig. 4-1 Load Capability Diagram of Fatigue Machine

The speed of load applications can be varied from 0 to a maximum of 660 cycles per min. The machine has electric relay circuits which provide for automatic shut off at failure. The testing machine is of the type which applies a constant maximum load to the specimen even though "creep" may occur. A system of electrical circuits keeps the maximum load constant during the testing of a specimen.

4.2 Loading Apparatus

All specimens were simply supported on a 42.75 in. span. Two equal loads were applied at the third points. A maximum moment zone was in the middle third of the span. Fig. 4-2 is a schematic diagram showing the loading and operating arrangement. The specimens were installed so as no torsional load was applied because of misalignment in the loading frame. To ensure uniform distribution of loads, 1/2 in.

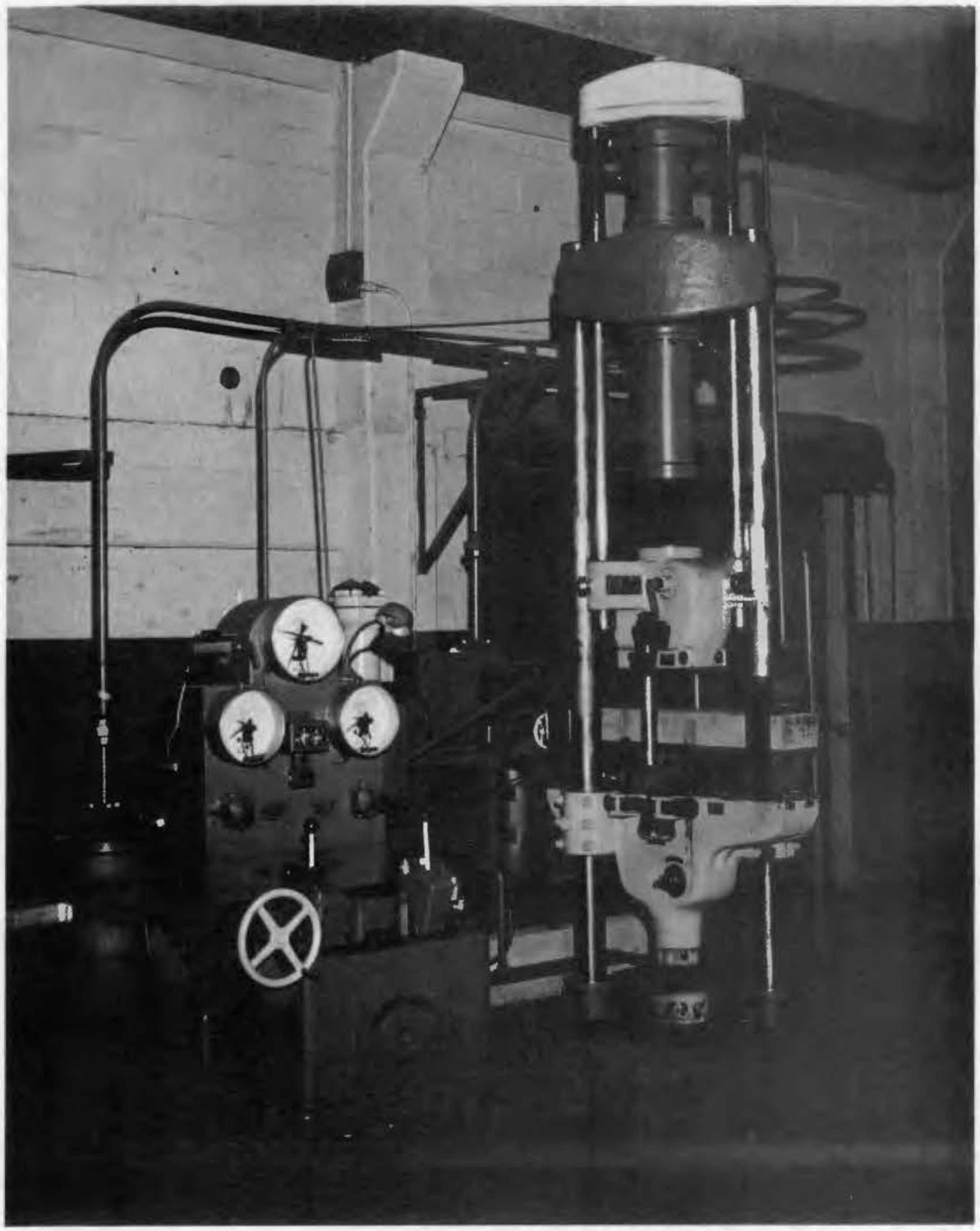


PLATE NO. I

60 METRIC TON FATIGUE TESTING MACHINE

thick layers of capping compound were used at points of loads and supports, between bearing plates and concrete. The load from the machine was transferred to the slab through a 8 in. by 18 in. by 1 in. thick steel plate.

In order to find the load in pounds acting on the slab directly from the machine dials, the pendulum dial of the fatigue machine was calibrated. For this purpose, two SR-4 strain gages at right angles to each other were attached to the lower side of the loading plate near its center, thus converting the loading plate into a dynamometer. The dynamometer was calibrated on another accurate testing machine. Next, while testing one slab for static loading, the above dynamometer was used to calibrate the pendulum dial of the fatigue testing machine. Here, however, the author would like to indicate that the only purpose of this calibration was to check the linearity of the dial readings of the fatigue testing machine. The load values in pounds are quite innificant, for the concrete specimens were extremely non-homogeneous, and there was a large variation in concrete strengths between sets of slabs. The maximum and minimum dynamic loads are expressed as percentages of the ultimate static load applied to the static test sample.

4.3 Testing Procedure

a) Dynamic tests on steel

In order to find the fatigue strengths of the longitudinal wires of the welded wire fabric approximately 20 to 24 in. long samples with at least one weld were tested under repeated loads on the smaller fatigue testing machine. Samples were tested at various loads which were percentages of the ultimate load. An arbitrary minimum load of 12.6 percent of the ultimate load was used throughout this series. The

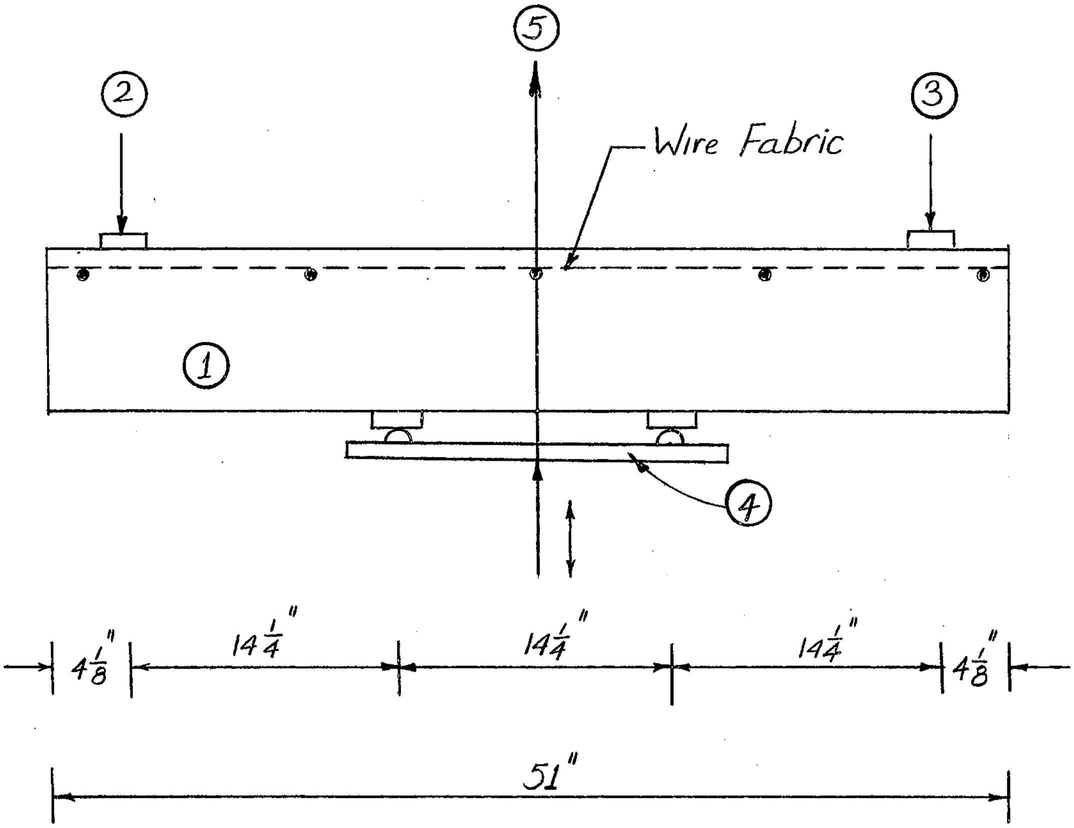


Fig. 4-2 Schematic Diagram of Loading Apparatus

(1) Concrete slab specimen; (2) Simple support;

(3) Simple support; (4) Steel loading plate;

(5) Loading head

magnitudes of the loads were continuously controlled by the system of electrical circuits. The load was applied at a frequency of 460 cycles per min.

b) Static tests on concrete specimens

The determination of the ultimate static load of the test specimen was essential for the selection of a fatigue load and for the interpretation of the test results. Once a specimen fails under repeated loading it is obviously impossible to find the ultimate static strength at the point of failure. One out of every 3 slabs cast on the same day under the same conditions was tested for static ultimate load on the 60 metric ton fatigue machine. This value was used as the ultimate strength for the other two companion specimens.

The SR-4 strain gages were used to measure the strains in steels. No conclusive results were obtained. The remaining two slabs in the set were tested with dynamic loads of percentages of the ultimate static load.

c) Dynamic tests on concrete specimens

The 60 metric ton testing machine was also used to apply the repeated loads to the specimens. Based on the ultimate static load determined from the static tests, each slab was loaded with a sinusoidally varying load which was a certain percentage of the ultimate static load. The loads were applied at the rate of 250 cycles per min. This speed was selected because at this frequency vibrations in other components of the testing machine were not in resonance. The specimens were carefully examined for cracks during the early cycles of loading, and their lengths were measured. Later during the test casual examinations for the cracks were made at about one hour intervals or when the machine was shut off by automatic switches.

In these tests the electrical circuits continuously and accurately controlled the maximum load applied. An automatic shut-off was used to stop the machine when the specimens failed. The number of cycles of load was recorded on an automatic Veeder-Root Counter.

In the beginning, the series of tests was started by testing the first specimen at a very small load. Much time elapsed before it was discovered that the load was below the fatigue limit, but after a few tests, the procedure was reversed to approach the fatigue limit from higher loads. A specimen was dynamically loaded at a high load, which caused failure after a few cycles. The next specimen was loaded at a lower maximum load than the previous specimen. The number of cycles required to cause failure was greater than the number of cycles required to cause failure of the previous specimen. Each time, when one slab failed, a new specimen was set on the machine. This procedure was followed until the last specimens were dynamically loaded at a maximum load for which failure did not occur even after 1, 500, 000 cycles. Such specimens were then subjected to static tests to find whether the ultimate strength of the specimen was affected by low dynamic loads.

The number of cycles at failure was plotted along the abscissa against the ratio of the maximum repeated load to the ultimate static load as the ordinates. At the point where the specimens did not fail the S-N curve was almost parallel to the abscissa.

CHAPTER V

EXPERIMENTAL TEST DATA

5.1 Sieve Analysis of the Aggregates

Tables I and II show the results of the sieve analysis tests for sand and coarse aggregates respectively. The aggregate gradation chart is shown in Fig. 5-1.

5.2 Ultimate and Yield Strengths of Steel

Tests were made on No. 0 longitudinal wires of the fabric for plotting stress-strain curve and determining its ultimate strength. Results of these experiments are listed in Table III. The stress-strain curve is shown in Fig. 5-2. From this plot the yield stress was calculated at 0.2 percent offset.

5.3 Specimen Characteristics

The sizes and spacings of the longitudinal and transverse wires, the strength of concrete at the age of 28 days, and the calculated values of the ultimate load capacity of each specimen (as illustrated in Appendix A) are tabulated in Table IV.

Specimens A-1, A-4, A-6, and B-3 listed in this table failed because of malfunction of the controls. In the beginning of the testing program the loads were applied vertically downwards on the specimens. When the machine would stop due to malfunction of the relay system, the difference of pressure within compression and tension cylinders of the testing machine would increase, resulting in a large downward force on the specimens. The specimens were broken before completion of the fatigue tests. To rectify this, the slabs were turned upside down as shown in Fig. 4-2., and now loads were applied vertically upwards. Any malfunction of the automatic relay system would result in the specimen being unloaded.

5.4 Calibration of Machine Dials

The SR-4 strain gages of the dynamometer were calibrated on the universal testing machine. The load applied in pounds and the corresponding strain indicator readings are given in Table V. A graph of loads vs the strain indicator readings is shown in Fig. 5-3.

The same strain gages of the dynamometer were used to calibrate the pendulum dial of the machine. The compression dial of the machine was held fixed at 5.0 metric tons and the readings of the pendulum dial were increased in steps of 0.2 metric ton. The corresponding readings of the strain indicator were recorded as listed in Table VI. Using this table and Fig. 5-3, a straight line plot between the dial readings and actual load in pounds was drawn as shown in Fig. 5-4.

5.5 Dynamic Tests on Steel

Table VII lists the results of the dynamic tests made on longitudinal wires. The table includes the maximum loads as percentage of the ultimate load, number of cycles to failure, and the modes of failure. From this table S-N curve for the steel was plotted between the maximum load as percentage of the ultimate load and the number of cycles as shown in Fig. 5-5.

TABLE I

SIEVE ANALYSIS OF SAND

Sieve Sizes	Cumulative gms retained	Cumulative % retained	Cumulative % passing
1 1/2"	0	0	0
1"	0	0	0
3/4"	0	0	0
1/2"	0	0	0
3/8"	0	0	0
No. 4	11.5	2.30	97.7
No. 8	55.8	11.15	88.85
No. 16	146.2	29.30	70.70
No. 30	297.5	59.40	40.60
No. 50	476.8	95.50	4.50
No. 100	495.7	99.10	0.90
Pan	500.0	100.00	0.00

Fineness modulus = 2.97

TABLE II

SIEVE ANALYSIS OF COARSE AGGREGATES

Sieve Sizes	Cumulative gms retained	Cumulative % retained	Cumulative % passing
1 1/2"	0	0	0
1"	63.00	1.54	98.46
3/4"	610.10	14.95	85.05
1/2"	2261.70	55.40	54.60
3/8"	3210.00	78.50	22.50
No. 4	3986.20	97.70	2.30
No. 8	4009.60	98.00	2.00
No. 16	4012.50	98.30	1.70
No. 30	4015.30	98.40	1.60
No. 50	4022.60	98.50	1.50
No. 100	4031.30	98.60	1.40
Pan	4090.00	100.00	0.00

Fineness modulus = 7.19

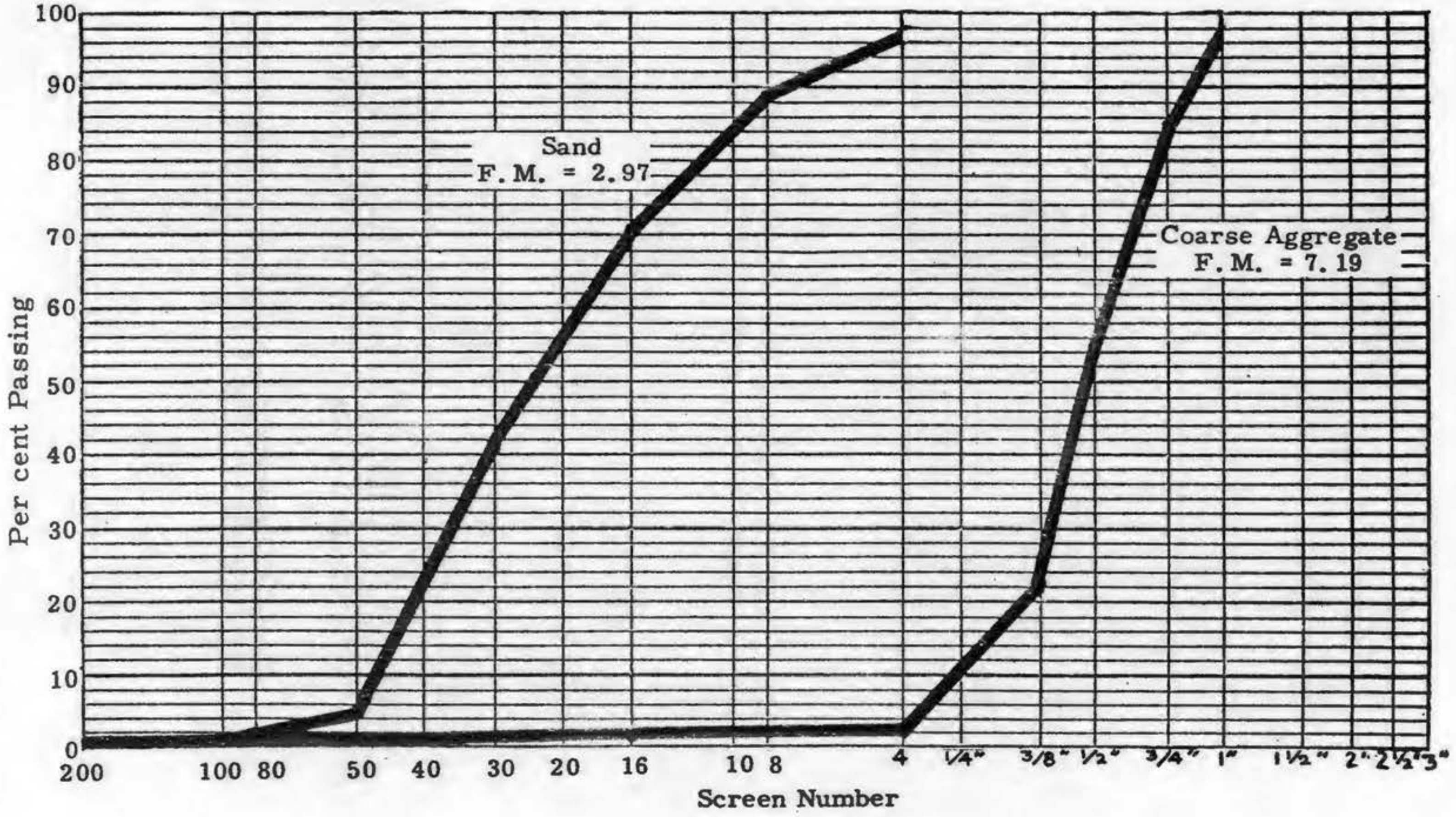


Fig. 5-1 Aggregate Gradation Chart

TABLE III

STRESS-STRAIN CURVE FOR TENSILE STEEL

Elongation in.	Strain	loads, in lbs.			Mean Value	Mean Stress psi
		Specimen 1	Specimen 2	Specimen 3		
0.0005	.00025		440	850*	440	6,600
.0010	.00050	830	850	1420*	840	12,700
.0015	.00075	1280	1300	1950*	1290	19,000
.0020	.00100	1640	1760	2410*	1700	25,800
.0025	.00125	2070	2210	2910*	2140	32,400
.0030	.00150	2470	2650	3350*	2560	38,800
.0035	.00175	2890	3040	3710*	2965	45,000
.0040	.00200	3250	3380	4000*	3315	51,100
.0045	.00225	3530	3670	4230*	3600	54,500
.0050	.00250	3810	3950	4430*	3880	58,800
.0055	.00275	4060	4210	4590	4286	64,900
.0060	.00300	4270	4440	4740	4483	67,900
.0065	.00325	4480	4650	4870	4667	70,700
.0070	.00350	4650	4820	4960	4810	73,000
.0075	.00375	4790	4960	5030	4926	74,600
.0080	.00400	4890	5070	5090	5017	76,100
.0085	.00425	4970	5140	5140	5083	77,000

* These values are not included for the mean value.

TABLE III (continued)

Elongation in.	Strain	loads, in lbs.			Mean Value	Mean Stress psi
		Specimen 1	Specimen 2	Specimen 3		
.0090	.00450	5030	5200	5170	5133	77,600
.0095	.00475	5080	5240	5190	5170	78,400
.0100	.00500	5120	5270	5220	5203	79,000
.0105	.00525	5130	5290	5235	5218	79,100
.0110	.00550	5160	5320	5250	5243	79,300
ultimate		5300	5350	5380	5343	80,900

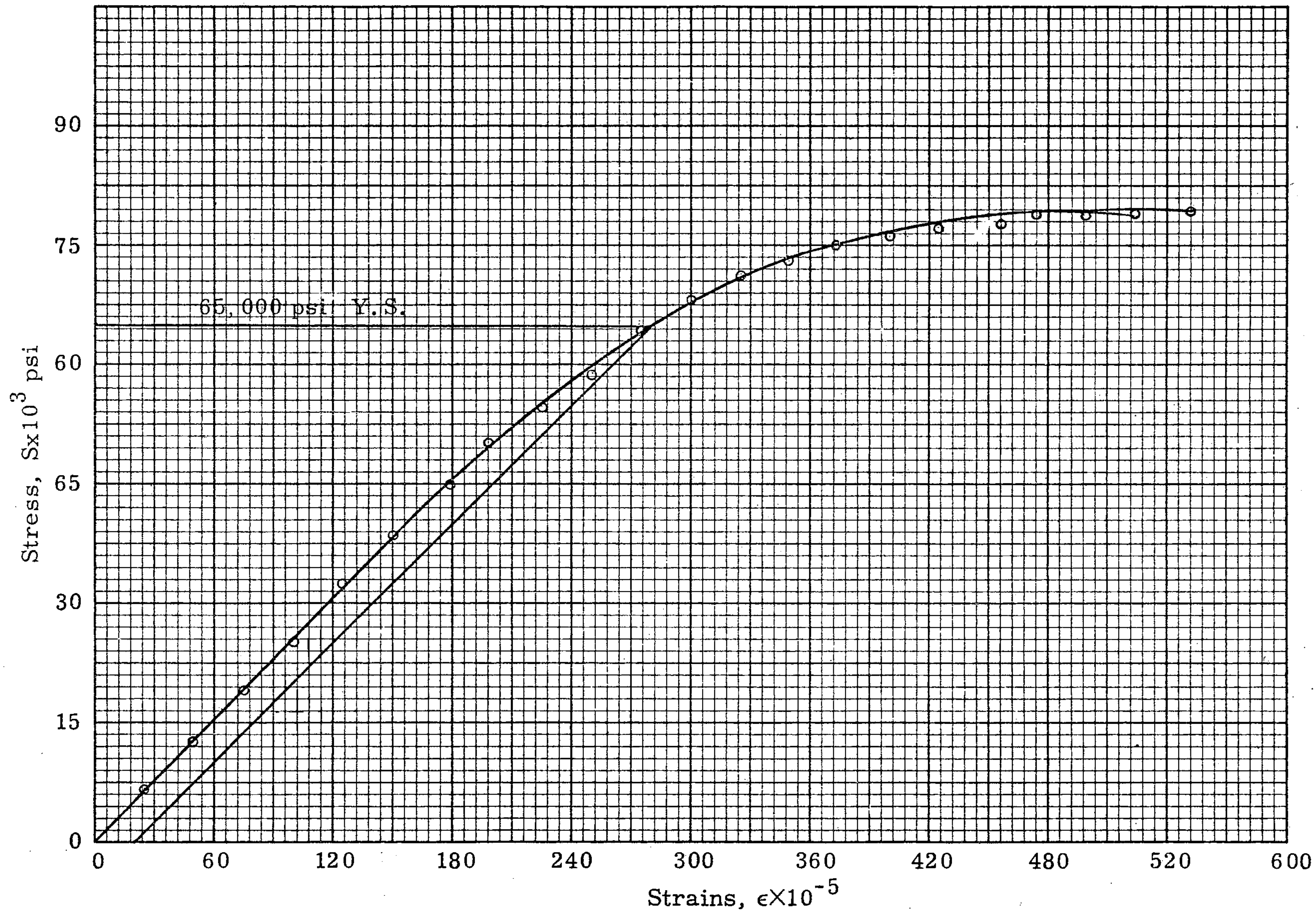


Fig. 5-2 Stress-Strain Curve for Tensile Steel

TABLE IV

SLAB SPECIMEN PROPERTIES

Specimens	Welded Wire Fabrics				28 Days Concrete psi	Computed Ultimate Load lbs.
	Wire Sizes		Spacings, In.			
	Long.	Trans.	Long.	Trans.		
A-1*	0	5	2	12		
A-2	0	5	2	12	4740	9950
A-3	0	5	2	12	4770	9950
A-4*	0	5	2	12		
A-5	0	5	2	12	4310	9860
A-6*	0	5	2	12		
B-1	0	5	2	12	4740	9950
B-2	0	5	2	12	4700	9950
B-3*	0	5	2	12		
B-4	0	5	2	12	4460	9920
B-5	0	5	2	12	4700	9950
B-6	0	5	2	12	4420	9910
B-7	0	5	2	12	4550	9940
B-8	0	5	2	12	4420	9910
B-9	0	5	2	12	4700	9950
B-10	0	5	2	12	4620	9930
B-11	0	5	2	12	4660	9945
B-12	0	5	2	12	4510	9930
B-13	0	5	2	12	4310	9860
B-14	0	5	2	12	4240	9840
B-15	0	5	2	12	4380	9870

* These specimens failed due to machine failure as explained on p. 27.

TABLE V

CALIBRATION OF DYNAMOMETER

Number	Load, in lbs.	Strain-Indicator Readings
1	0	0
2	1, 000	130
3	2, 000	225
4	3, 000	330
5	4, 000	380
6	5, 000	460
7	6, 000	560
8	7, 000	680
9	8, 000	780
10	9, 000	815
11	10, 000	920
12	11, 000	1, 000
13	12, 000	1, 110
14	13, 000	1, 160
15	14, 000	1, 250

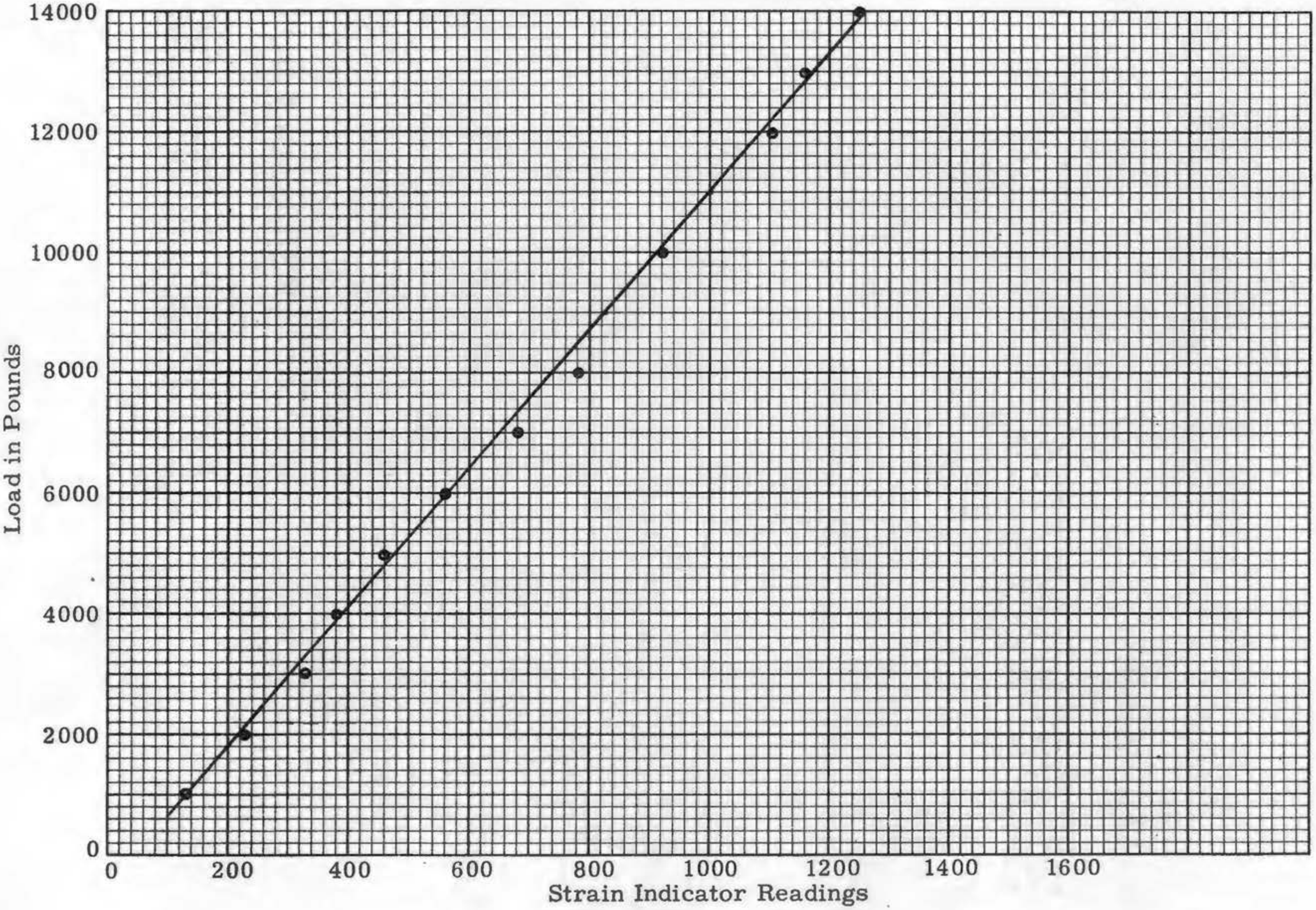


Fig. 5-3 Calibration of Dynamometer

TABLE VI

CALIBRATION OF PENDULUM DIAL

Compression dial readins	Pendulum dial readings	Strain-indicator readings
5.0	5.0	0.0
5.0	5.2	30
5.0	5.4	90
5.0	5.6	100
5.0	5.8	140
5.0	6.0	200
5.0	6.2	260
5.0	6.4	290
5.0	6.6	330
5.0	6.8	350
5.0	7.0	400
5.0	7.2	460
5.0	7.4	480
5.0	7.6	500
5.0	7.8	540
5.0	8.0	560
5.0	8.2	600
5.0	8.4	700
5.0	8.6	790
5.0	8.8	810
5.0	9.0	830
5.0	9.2	840
5.0	9.4	880
5.0	9.6	920
5.0	9.8	960
5.0	10.0	980
5.0	10.2	1,010
5.0	10.4	1,040
5.0	10.6	1,150

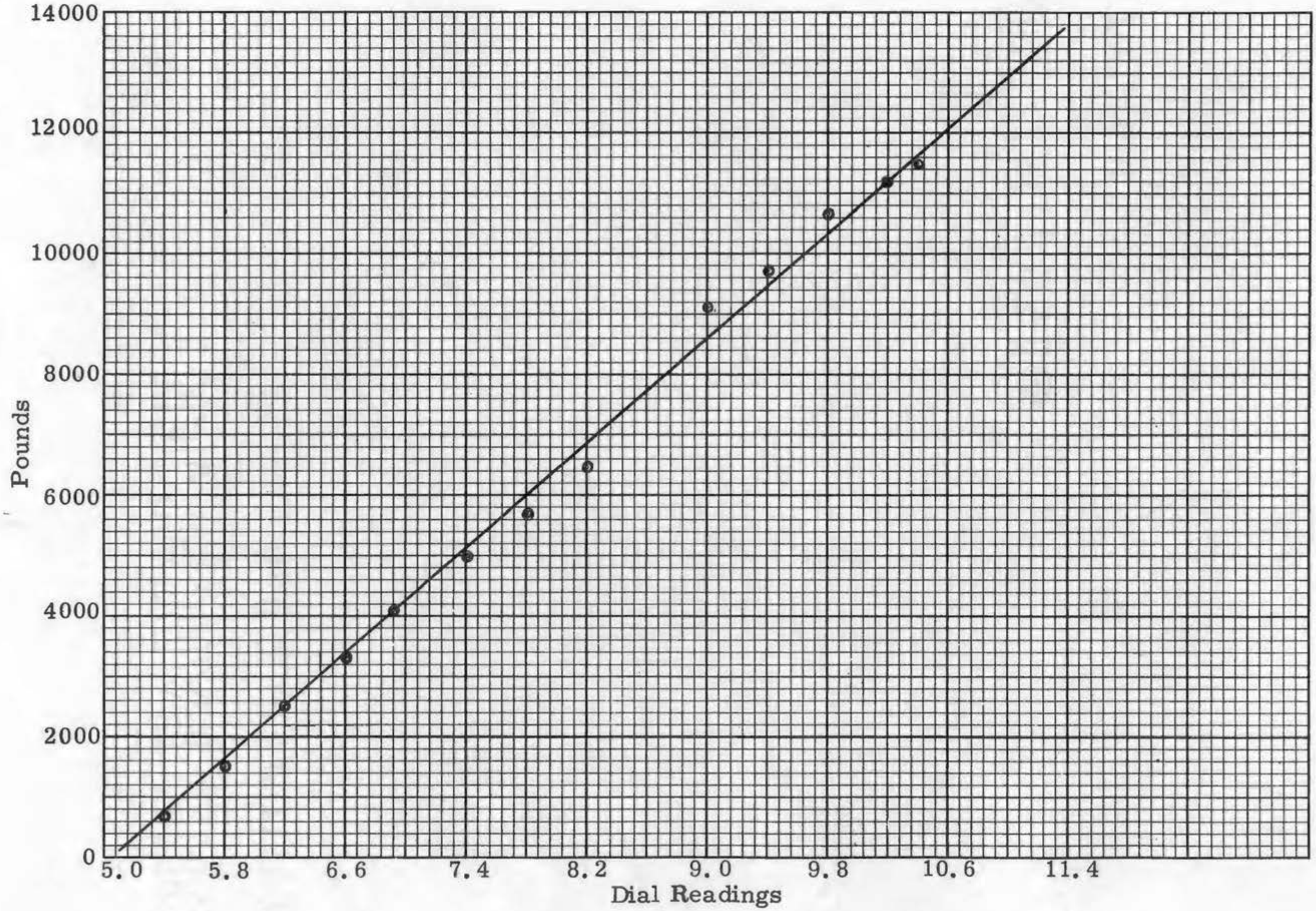


Fig. 5-4 Calibration of Pendulum Dial

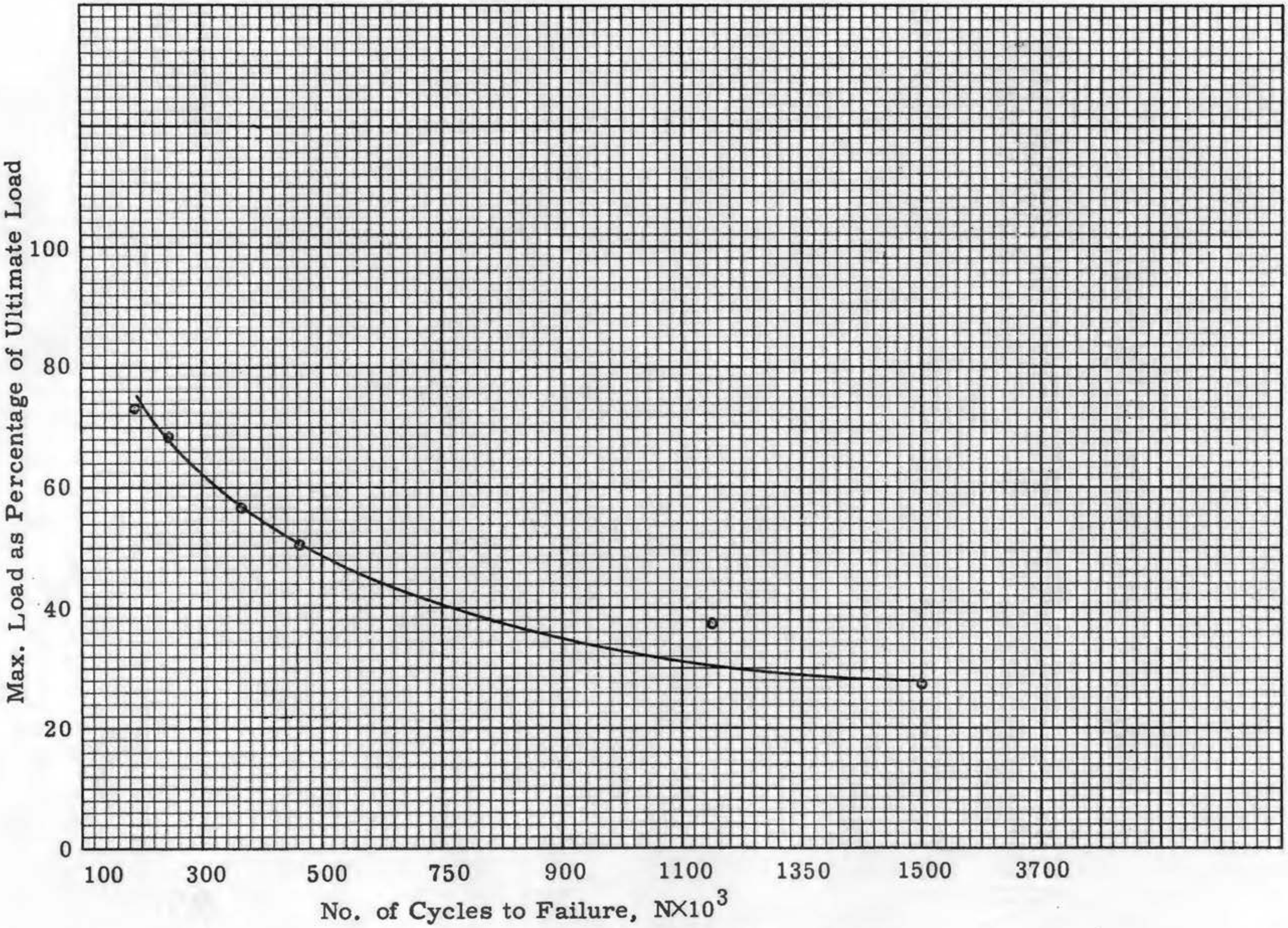


Fig. 5-5 S-N Curve for Tensile Steel

TABLE VII

DYNAMIC TESTS ON STEEL

No.	Maximum Load as Percent of Ultimate Load	No. of Cycles to Failure	Modes of Failure
1	73.5	189,670	Fracture Near Weld
2	68.1	240,538	"
3	56.6	362,166	"
4	50.4	460,116	"
5	37.8	1,125,732	"
6	27.8	No Failure	No Failure

5.6 Static and Dynamic Tests on Slabs

The ultimate static loads and the modes of failures of the slab specimens tested under static loads are listed in Table VIII.

Table IX shows the results of the dynamic tests on 12 specimens. It gives the ultimate load capacity obtained from tests on companion slab specimens, maximum and minimum loads, number of cycles to failure, and the modes of failure of each specimen tested for fatigue load. From these results the S-N curve for the concrete slab specimens was plotted as shown in Fig. 5-6.

TABLE VIII

STATIC TESTS ON CONCRETE SPECIMENS

Specimen No.	Ultimate Static Load		Mode of Failure
	Dial Readings M. T.	lbs.	
A-2*	6.3	13,460	Diag. Tens.
A-3	5.6	11,950	Diag. Tens.
B-1	5.6	11,950	Steel Failure
B-6*	5.3	11,280	Diag. Tens.
B-8	5.0	10,650	Diag. Tens.
B-10	5.4	11,500	Steel Failure
B-13*	5.2	11,090	Diag. Tens.
B-14	5.3	11,280	Diag. Tens.

* These specimens were tested for static load, when they did not fail under repeated loading.

TABLE IX

DYNAMIC TESTS ON CONCRETE SPECIMENS

Specimens	Ultimate Load Dial Readings, M. T.	Max. Load Percent of Ulti.	Min. Load Percent of Ulti.	Cycles of Loads	Modes of Failure
A-2*	5.6	20.10	3.44	1,500,000	No Failure
A-5	5.6	16.40	5.36	1,500,000	No Failure
B-2	5.6	56.70	9.20	13,600	Diagonal Tension
B-4	5.3	29.30	5.68	201,870	Fatigue of Steel Near Weld
B-5	5.3	36.80	5.68	325,870	Fatigue of Steel Near Weld
B-6*	5.3	29.30	5.68	1,500,000	No Failure
B-7	5.0	47.00	10.32	20,460	Diagonal Tension
B-9	5.0	55.40	10.32	12,850	Diagonal Tension
B-11	5.4	40.00	9.56	213,120	Diagonal Tension
B-12	5.4	36.10	9.56	315,290	Diagonal Tension
B-13*	5.3	32.00	5.66	1,500,000	No Failure
B-15	5.3	40.70	9.74	301,600	Failure Under Load

* These specimens were tested for static load, when they did not fail under dynamic loading after 1,500,000 cycles.

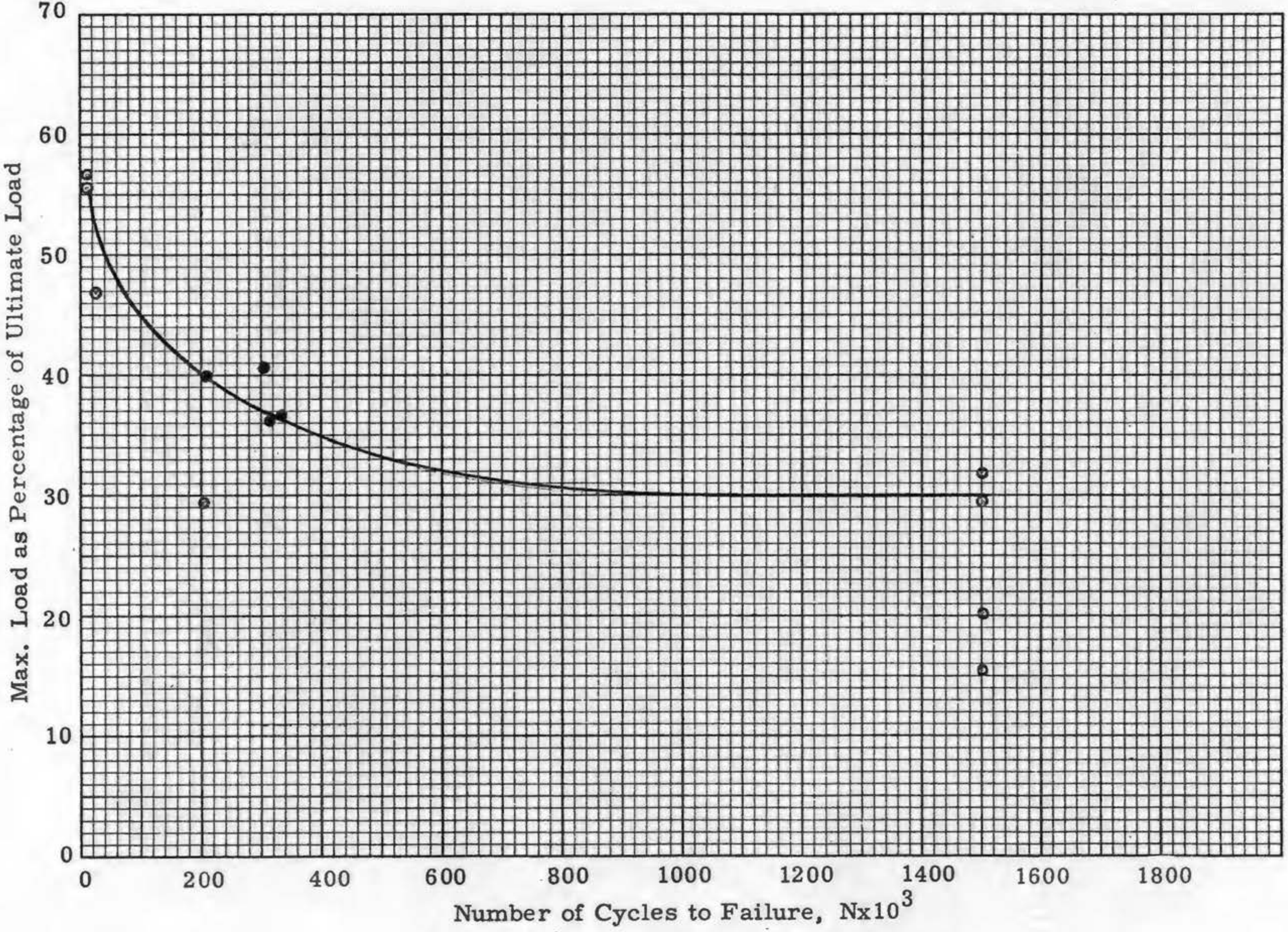


Fig. 5-6 S-N Curve for Concrete Slabs

CHAPTER VI

DISCUSSION OF RESULTS

6.1 Dynamic Tests on Steel

The results in Table VII show, that in all cases longitudinal wires with welded joints failed by the fracture of the wire near the welded joint when subjected to repeated loads. This may be due to the higher concentration of stresses near a weld. It was noticed also that as the maximum repeated load was increased beyond 55 to 60 percent of the ultimate, the life of the samples decreased faster than when the maximum load was less than between 30 to 55 percent of the ultimate. As shown in Fig. 5-5, and based on 1,500,000 cycles the fatigue strength of the steel was 27.8 percent of the ultimate load.

6.2 Static Tests on Concrete Specimens

The results in Table VIII show that when slabs reinforced with welded wire fabric are subjected to static loads, they failed either in diagonal tension or because of failure of the steel in the maximum moment zone. Six of the eight specimens tested under static loads failed by diagonal tension. In concrete, diagonal tension failures occurred at all load levels. In both cases of steel failures, loads were high.

The tests on specimens A-2, B-6, and B-13 show that repeated loads up to 30 percent of the ultimate static load have no appreciable effect on the ultimate static loading capacity of the slabs. Previous investigations (5) on concrete have shown similar results.

6.3 Dynamic Tests on Concrete Specimens

Table IX shows that five of the twelve specimens tested under repeated loads failed by diagonal tension in concrete, two by fatigue fracture of steel near a weld, and one by tensile failure of concrete under the load by excessive yielding of the longitudinal wires. Four specimens did not fail after 1,500,000 cycles of loading.

Specimens B-5 and B-12 were loaded with almost the same maximum load. One failed by the fatigue fracture of the tensile steel near the weld, the other failed in diagonal tension. Of slabs B-4 and B-6, subjected to the same range of loading, B-4 failed by the fatigue fracture of steel near the weld, and B-6 did not fail even after 1,500,000 cycles. Specimens B-11 and B-15 with approximately the same range of loading failed by two different failures. For loads above 40 percent of the ultimate load the number of cycles to failure decreased very rapidly. In no case did failure occur in bond.

The differences in the modes of failure under similar loads may be due to the non-homogeneity of the specimens, or they may be due to the variations in the properties of the concrete and steel from specimen to specimen. The specimens used in this study were more vulnerable to diagonal tension failure, and to a small extent to fatigue fracture failure near weld. This may be due to the fact that there was no steel to reinforce the shear region of the section.

The fatigue strength of specimens based on 1,500,000 cycles was approximately 30 percent of their ultimate strength. Previous investigations (4), (5), (8) on concrete beams reinforced with steel bars showed a fatigue strength of 50 to 55 percent of the ultimate static strength.

6.4 Cracks and Behavior of Specimens Under Loads

During the entire testing program cracks were examined soon after the loading was started. Small tensile cracks appeared early in the maximum moment region of all of the specimens. In some cases cracks appeared early in the maximum moment region of all of the specimens. In some cases cracks appeared in the shear zone. Cracks were found in specimens which did not fail under dynamic loading even after 1,500,000 cycles. As the number of cycles increased, the crack lengths increased towards the compression surface of the specimens. It was noticed visually that with the enlarging of the cracks, the deflections of the specimens increased. In cases of specimens with strain gages, strains in the steel increased with increased numbers of load cycles.

The diagonal tension failures which were more common were gradual and progressive. Steel fracture and the tensile failure of concrete under load, were sudden. Plate II illustrates the failures in 3 specimens tested in this study.

6.5 Modes of Failure for Fatigue

The three types of failure exhibited by tested slabs were:

a) diagonal tension,
b) fracture of tensile steel near weld,
c) tensile failure of concrete under load by excessive yielding of steel.

Fig. 6-1 shows a schematic diagram of these types of failures.

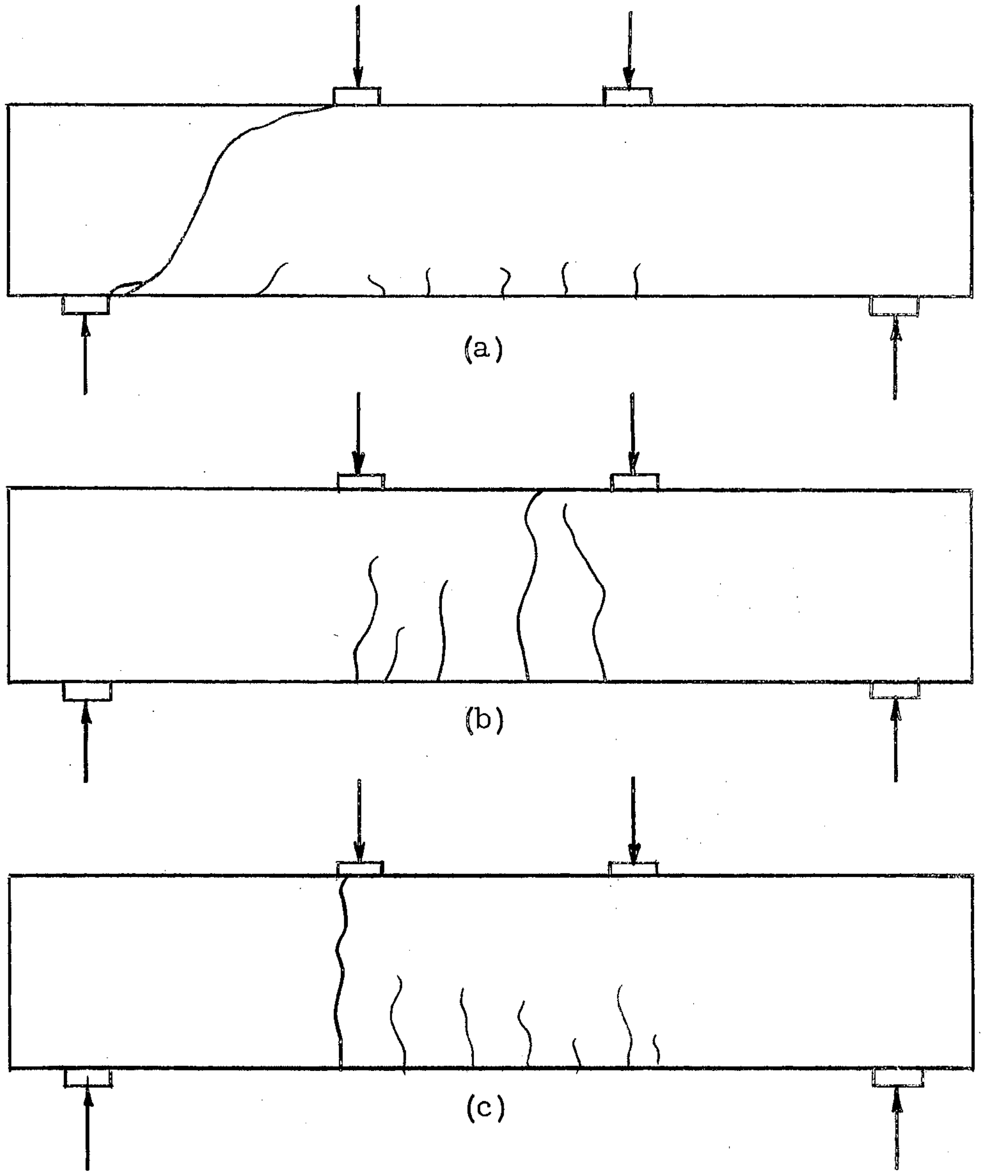


Fig. 6-1 Types of Failures

a) Diagonal Tension Failures
b) Steel Fractures
c) Failure Under Load

Diagonal Tension Failure

The specimens showed progressive failure in diagonal tension. With the initial applications of loads, small tension cracks were formed. As the number of cycles increased, the cracks progressed toward the zone of compression, crossed the longitudinal wires in one of the shear spans, became flatter, and then stopped progressing at some point "a" in Fig. 6-2.

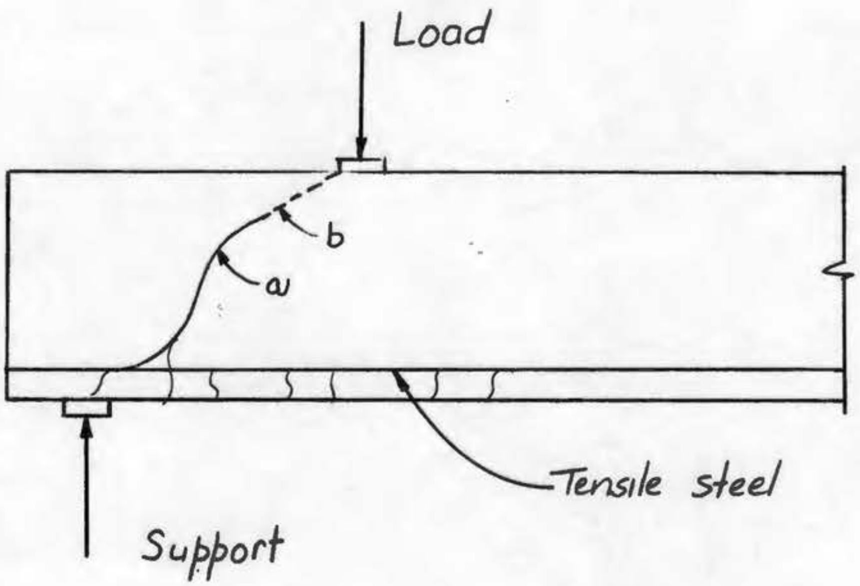


Fig. 6-2 Development of Diagonal Tension Failure

The further growth of the crack started after many more load cycles had been applied. After this period, however, the tension crack extended very slowly at a very flat slope until finally sudden failure occurred as indicated at point "b".

In some cases it was noticed that a well-developed crack progressed to a level above the neutral axis, but would not progress further. Later in the test a second crack would develop and move rapidly across the section and usually resulted in complete failure. The diagonal tension cracks progressed from the tensile face to the load point at an angle of about 30° with the longitudinal steet.

Steel Fatigue Failure

Two specimens showed this type of failure near welds. In both cases this type of failure was sudden. These specimens failed after only 200, 000 cycles of loads. These failures occurred in the maximum moment zone when the maximum loads were 29. 3 and 36. 8 percent of the ultimate load.

Failure Under Load

Only one specimen exhibited this type of failure, and it was sudden like steel fracture failures.

(a) Diagonal Tension Failure in Concrete

(b) Tension Failure in Concrete Underload

(c) Steel Fatigue Fracture

PLATE NO II DIFFERENT MODES OF FAILURE

CHAPTER VII

SUMMARY AND CONCLUSIONS

7.1 Summary

An experimental study of the behavior of concrete slabs reinforced with welded wire fabrics under repeated loads is presented in this thesis. The experiments were limited to simply supported slabs loaded at the third points.

Seventeen under-reinforced concrete slab specimens were tested to examine the various types of failures, and to determine the fatigue strength of such specimens under repeated loading. Dynamic loading tests were made on the longitudinal wires of the fabric to find whether there was any correlation between failure of steel and concrete specimens reinforced with these fabrics.

The conclusions are based on tests on concrete specimens 8 in. wide, 5 in. deep and 51 in. long. They were tested on a 42.75 in. span. The specimens were made of concrete having 28-day compressive strength of approximately 4600 psi. All specimens were reinforced with welded wire fabric style 212-05 with yield strength of 65,000 psi and ultimate strength of 80,900 psi.

7.2 Conclusions

1. Based on 1,500,000 cycles, the fatigue strength of slabs is about 30 percent of the ultimate strength.

2. The slabs failed in three different ways, diagonal tension, steel fatigue fracture, and failure of concrete under load.

3. The ultimate static load capacity appears to remain unaffected by 1, 500, 000 applications of loads less than 30 percent of the ultimate load.

4. The longitudinal wires of the fabric are very susceptible to failure near a weld under repeated loads. In these concrete specimens using welded wire fabric as reinforcement, most of the failures were not due to failure of the steel but were due to diagonal tension failures.

5. The S-N curve established for these specimens is shown in Fig. 5-6.

7.3 Suggestions for Further Investigations

The study of fatigue of concrete slabs reinforced with steel is a broad area of study, one in which much work remains to be done. An immediate extension of this study would be the investigation of slab sections with shear reinforcements.

Further investigations of concrete slabs should be made to determine the effects that the fundamental properties such as aggregate bond, moisture, and curing will have on the behavior of slabs under repeated loads. The effects of these properties on the modes of failure should be studied. There is a need for additional research to investigate the effects of air entrainment, admixtures, and variations in specimen sizes on the fatigue of concrete slabs. Further investigations should be made to establish the modified Gooman diagram for the concrete slabs. More research is needed to study the effects that different percentages of steel, sizes, and spacings of transverse wires will have on the fatigue strength and the modes of failures.

BIBLIOGRAPHY

1. Design Manual, "Welded Wire Fabric for Building Construction, " Wire Reinforced . Institute, Inc., Washington, D. C.

2. ACI, Bibliography No. 3, "Fatigue of Concrete"

3. Nordby, G. M., "Fatigue of Concrete - A Review of Research, " Proc. ACI, V. 55, Aug., 1958, pp. 191-219.

4. Van Ornum, J. L., "Fatigue of Concrete, " Transaction, ASCE, V. 58, 1907, pp. 294-320.

5. Probst, E., "The Influence of Rapidly Alternating Loading on Concrete & Reinforced Concrete, " Structural Engineer (London), pp. 430-432, V. 9, No. 10, Oct. 1931, pp. 326-340, No. 12, Dec. 1931, pp. 410-429. Discussion. ✓

6. Saliger, R., "Austrian Fatigue Tests of Reinforced Concrete Beams, " Engineering News-Record, May 16, 1935, p. 697.

7. Lea, F. C., "Repeated Stresses on Reinforced Concrete," Structural Engineer (London), V. 18, No. 2, Feb. 1940, pp. 511-520.

8. Le Camus, B. "Recherches sur le comportement du be'ton et du beton armé soumis a des efforts repe'tes, " Annales de C'Institut Technique du Batiment et des Travaux Publics. Circulaire Serie F. No. 27 , July 1946, p. 24.

9. Valette, R., "Resistance des ponts sous rails en beton armé ; essais de poutres aux flexions répeteés, " (Endurance of reinforced concrete railway bridges; tests of beams with repeated bending); Publications, International Association for Bridge & Structural Engineering, V. 8, 1947, pp. 511-520.

10. Ros, M., "Festigkeit und Verformung von auf Biegung beanspruchten Eisenbeton-Balken, " (Strength & Deflection in Flexure of Reinforced Concrete Beams); Report No. 141, Eidgenossische Materialprufungs und Versuchsanstalt für Industrie (Published by Buwesen und Gewerbe) Zurich, Oct. pp. 84, (Abstract in Concrete & Constructional Engineering. V. 42, No. 7, July, 1947. pp.223- 238) .

11. Chang, T. S., and Kesler, C. E., "Static and Fatigue Strength in Shear of Beams with Tensile Reinforcement," ACI Journal, Proc., V. 54, June 1958, pp. 1033-1057.

12. Chang, T. S., and Kesler, C. E., "Fatigue Behavior of Reinforced Concrete Beams," ACI Journal, Proc., V. 55, Aug 1958, pp. 245-254.

13. Stelson, T. E., and Cernica, J. N., "Fatigue Properties of Concrete Beams," ACI Journal, Proc., V. 55, Aug 1958, pp. 255-259.

14. Verna, J. R., and Stelson, T. E., "Failure of Small Reinforced Concrete Beams Under Repeated Loads," ACI Journal, Proc., V. 59, Oct. 1962, pp. 1489 - 1504.

15. Ivanov-Diatlov, A. I., "Fatigue Limit of Reinforced Concrete Under Repetitive Loads," Beton i Zhelezobeton, Moscow, No. 9, Sept. 1958, pp. 353-356.

16. Bate, S. C. C., "The Strength of Concrete Members Under Dynamic Loading," Proceedings, Symposium on the Strength of Concrete Structures, Session D, Paper No. 2, Cement & Concrete Association, London, pp. 487-524. (Published 1958).

17. Ferguson, P. M., "Reinforced Concrete Fundamentals," John Wiley & Sons, Inc.

APPENDIX A

CALCULATION OF ULTIMATE LOAD

Available Data:

Slab dimensions - width, b = 8"
depth = 5", effective depth, d = 4"
length = 51", effective span, L = 42.75"

Slab Reinforcement: Long. 0 gage no. (0.3065"Ø), 2" spacing
Tans. 5 gage no. (0.2070"Ø), 12" spacing

Stresses: Yield strength of longitudinal steel, fy = 65,000 psi
Concrete strength at 28 days, f'_c = 4,500 psi

The typical cross-section of the slab is shown in Fig. 3-1.

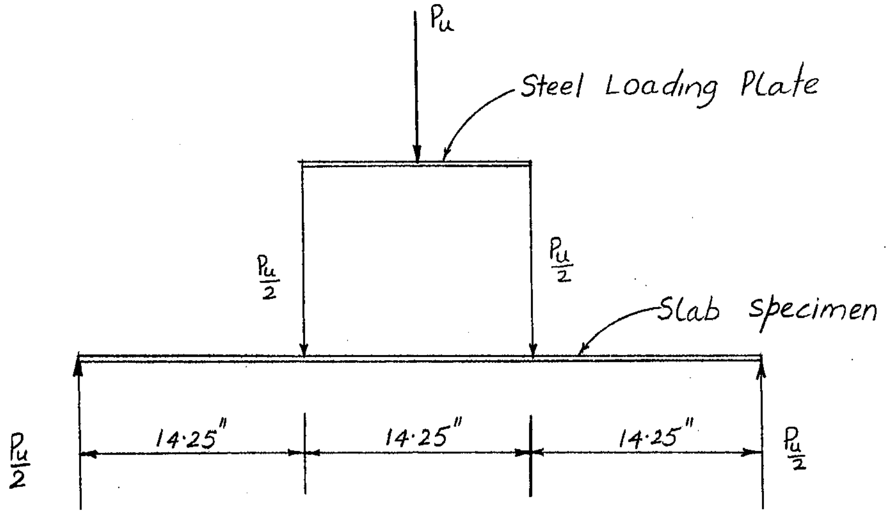


Fig. A-1 Loads on the Slab

Area of Longitudinal steel = 4 x 0.0738 = 0.2952 in^2

From Whitney's stress block* theory (See Fig. A-2), since $C = T$, $0.85\, f'_c\, ab = A_{sfy}$ or

$$a = \frac{A_s f_y}{0.85\, f'_c b}$$

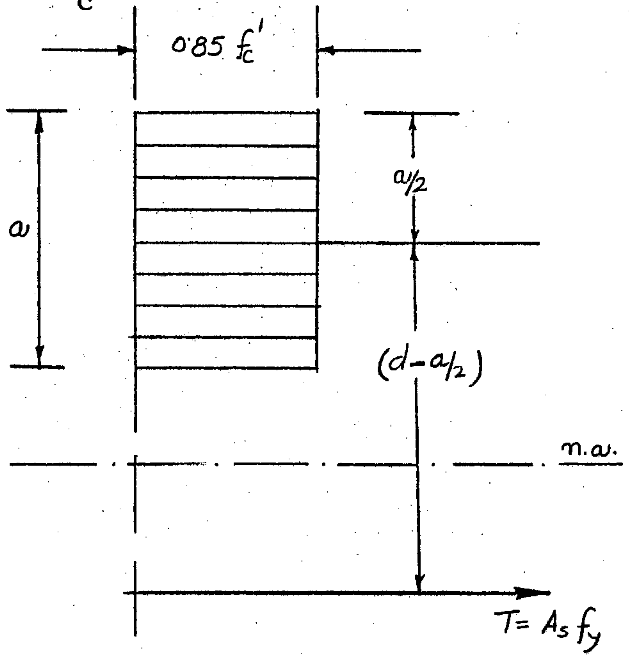


Fig. A-2 Whitney's Stress Block

Then, ultimate moment $M_u = A_s f_y (d - \frac{a}{2})$. Here,

$$a = \frac{0.2952 \times 65,000}{0.85 \times 4500 \times 8} = 0.627 \text{ in.}$$

and

$$M_u = 0.2952\ (65,000)\ (4 - \frac{0.627}{2}) = 70,600 \text{ in lbs}$$

---

* See Ferguson, P. M., "Reinforced Concrete Fundamentals," John Wiley & Sons, Inc., p. 50.

$= 5,900$ ft-lbs

Weight of specimen $= \frac{5}{12} \times \frac{8}{12} \times 150 = 41.6$ lb per ft

Moment due to its weight, $M_d = \frac{41.6(42.75)^2}{8 \times 144}$

$= 66.0$ ft. lb.

Moment $M = M_u - M_d$

$= 5900 - 66.0 = 5934.0$ ft. lb.

Ultimate Load, $P_u = \frac{6M}{L}$

$= \frac{6 \times 5934 \times 12}{42.75}$

$= 9820$ lbs.

Ultimate Load, $P_u = 4.91$ tons

Percentage of Steel:

For the designed Specimen

$p = \frac{As}{bd} = \frac{0.2952}{8 \times 4}$

$= 0.922\%$

According to Whitney for a balanced Section

$p_o = 0.456 \frac{f'_c}{fy}$

$= 0.456 \times \frac{4500}{65000}$

$= 3.16\%$

Hence, the slabs specimens used in this study are under-reinforced.

APPENDIX B

DESIGN OF STEEL LOADING PLATE

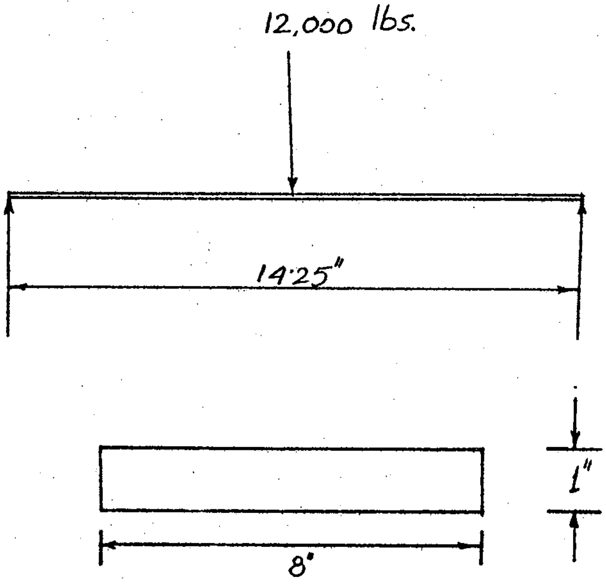


Fig. B-1 Loads on Steel Loading Plate

The steel loading plate was designed for an arbitrary load of 12, 000 lb. supported on a span of 14.25". The plate was so designed that the maximum stress in bottom fiber is less than one-half of yield stress of 65000 psi.

$$\text{Maximum moment} \quad M = \frac{(12000)(14.25)}{4}$$

$$= 42,750 \text{ in. lb.}$$

Also M = f. Z.

and Section modulus $Z = \frac{M}{f} = \frac{42,750 \times 2}{65,000}$

$$= 1.32 \text{ in}^3$$

i.e., $\frac{bd^2}{6} = 1.32$

or $bd^2 = 7.92$

Assuming $b = 8''$

$$d^2 = \frac{7.92}{8} = 0.99$$

$$d = 0.995 \text{ in}$$

Use a 8" x 1" x 18" rectangular plate.

APPENDIX C

FATIGUE FAILURE

Failure which occurs at stresses considerably lower than the ultimate strength of the material and less than the yield strength are referred to as fatigue failures.

Fatigue strength is the maximum stress which can be applied an indefinitely large number of times without danger of fatigue failure is called the fatigue strength.

S-N diagram is a diagram in which the stress S causing failure is plotted against the number of cycles N at failure.

Load factor is the ratio of ultimate design load to the working load.

VITA

Pyare Mohan

Candidate for the Degree of

Master of Science

Thesis: AN INVESTIGATION OF THE FATIGUE STRENGTH OF CONCRETE SLABS REINFORCED WITH WELDED WIRE FABRICS

Major Field: Civil Engineering

Biographical:

Personal Data: Born in Ajmer, Rajasthan (India), October 20, 1939, the son of Lalit M. and Shakuntla Simlote.

Education: Attended Agarwal High School in Ajmer, Rajasthan (India); graduated from Government High School in 1953; awarded Rajasthan State Government Merit Scholarship; received the Bachelor of Science degree from the Agra University in June, 1957; awarded Indian Institute of Technology Scholarship in Civil Engineering for four years; received the degree of Bachelor of Technology from the Indian Institute of Technology, Kharagpur, India, with honors in Civil Engineering, in June, 1961; graduate research assistant in Civil Engineering from September, 1962, to May, 1963; completed requirements for the Master of Science Degree in August, 1963.

Professional Organizations: Member Chi Epsilon, Honorary Civil Engineering Fraternity; Student Member of the American Society of Civil Engineers and Prestressed Concrete Institute; Junior Member American Concrete Institute; Member Engineering Gavel Club (Toastmasters International).