

THE POSSIBILITY OF USING UNCRUSHED RIVER GRAVEL FOR BITUMINOUS
PAVEMENTS AND SURFACINGS

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PREFACE

A great many of the standard specifications written for highways require the use of crushed aggregates for bituminous surfacings and pavements. The principle aim in this provision is the development of interlock or wedge-action between the aggregates in order to produce stable pavements to withstand the effects of vehicular traffic. This requirement will not be of a problem as long as crushed gravel, crushed stone and crushed rock are in abundance. Design mixtures can be easily made in the laboratory to satisfy requirements for gradation, wear and stability.

To some parts of the Philippines, the crushing requirement may be of a problem on account of insufficient crushers. Therefore, the eagerness of a district or city engineer to construct a bituminous surface is curtailed simply because the poor engineer can not produce specification requirements economically. The purpose of this report is to present facts actually studied, performed and managed wherein uncrushed gravel have been actually used to advantage and have shown substantial behavior under traffic.

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CHAPTER I

INTRODUCTION

Geographically, the Philippines is a group of islands and islets numbering 7,100, with an aggregate area of about 300,000 square kilometers. The two biggest islands, Luzon and Mindanao are divided into several provinces and cities while the Visayan group is composed of small islands each of which is divided into one, two or three provinces. There are about 53 provinces and 27 cities in the whole archipelago. The towns within the provinces and the cities are connected together by about 30,000 kilometers of all classes of roads about 15,500 kilometers of which belong to the first class group, passable throughout the year. The first class group are all paved with all-weather surfaces namely portland cement concrete, asphalt and crushed stones. These roads are presently serving about 110,000 motor vehicles.

Generally, every island has mountain ranges running about the middle of the island with wide valleys at the center and coastal plains along the coast. It is very evident, therefore, that the rain water washed away the mountain slopes and carried with it an enormous amount of sand and gravel which are deposited along rivers. These are good construction materials. Almost all the rivers and creeks are potential sources of sand and gravel for

highway purposes. Almost every province or city has an abundant supply of sand and gravel from rivers such that no further exploration inland would be necessary.

The asphalt pavements and surfacings itemized in the specifications require that the aggregate should be crushed stone with the control that at least 60 percent by weight must have at least one face fractured. The district and city engineers being guided by the pertinent provisions of the specifications can not simply utilize the available natural river gravel since it is not crushed.

Almost everybody would agree that the more angular the sides of the aggregates are, the more there will be interlock and hence better stability. The problem at hand is that there is not enough stationary or portable crushers available in each province to do the crushing of these aggregates. This crushing requirement is making the unit cost of the material prohibitive, like for example when it is done by hand, or when crushed material has to be hauled 50 to 100 kilometers away just to follow strictly the contents of the specifications. Also it costs much money and delay to ship crushers from one province to another.

Oftentimes, district and city engineers make representations to allow them the use of uncrushed gravel for asphalt pavements and surfacings, reasoning out that to adhere closely to the requirements of the specifications will amount to a prohibitive cost of the finished product, so long as strength requirements are maintained.

This approach may create unsavory reactions from other engineers working on the subject but situation is such as to make anything good for the purpose. This study is hard to develop as it seems to go on the wrong side of principles but the district and city engineers who could not economically produce the specification requirements are there waiting for any authority that will give them the go signal and deviate somewhat from accepted practice.

Studies related to this subject are difficult to encounter in recognized literatures on highway engineering. In answer to this, something has got to be done in order to solve the problem at hand.

This report, therefore, is being prepared to find ways and means of deviating slightly from the pertinent provisions of the specifications, to allow, if really necessary, the use of the natural or uncrushed gravel for asphalt surfacings and pavements without of course sacrificing stability, performance and available funds.

CHAPTER II

GENERAL DISCUSSION

Bituminous Pavements and Surfacing constructed by the Philippine Bureau of Public Highways are classified into three types depending on the amount of traffic the road under consideration is to carry within its economical and usable life. Table No. 1 shows the practice of the Bureau in recommending what type of surfacing or pavement to use for a given highway.

Table No. 1 - Recommended pavement types for various traffic volume.

Expected volume of traffic	Type of surfacing or pavements
Under 400 vehicles per day	Low-type surfacings
401 to 1,000 " " "	Intermediate-type pavements
Above 1,000 " " "	High-type pavements

Hereunder is the list of bituminous surfacings and pavements under each of the types given in the above table:

Low-Type Surfacing:

- 1) Bituminous Preservative Treatment
- 2) Single Bituminous Surface Treatment (Hot Asphalt Type)
- 3) Bituminous Surface Treatment (Hot Asphalt Type)
- 4) Bituminous Surface Treatment (Emulsified Asphalt Type)

Intermediate-Type Pavements

- 1) Bituminous Macadam Pavement (Hot Asphalt Type)
- 2) Bituminous Macadam Pavement (Emulsified Asphalt Type)

High-Type Pavements

- 1) Dense-graded Plant-mix Surface Course
- 2) Open-graded Plant-mix Surface Course
- 3) Bituminous Concrete

According to the Philippine Standard Specifications (6)* for Highways and Bridges only aggregates for blotter material of the Bituminous Preservative Treatment; aggregate for Single Bituminous Surface Treatment; the choker and the cover aggregates for Bituminous Surface Treatments; the choker, key and cover aggregates for Bituminous Macadam Pavements; the aggregates for dense-graded plant-mix surface course and the fine mineral aggregate for Bituminous concrete Surface Course can we possibly use the uncrushed or natural gravel. All the other aggregates have to be 60 percent crushed gravel, crushed stone, crushed rock or crushed boulders.

This requirement can be seen easily because it is believed that this property of the coarse aggregate will withstand the effects of the wheels of traffic thus making it stable, and prevent the shoving and creeping of the pavement.

In Table No. 1, it is very evident that there seems to be a wide tolerance in the traffic volume for anybody to

*Numbers in parenthesis indicates the number of reference at the last page.

recommend what pavement or surfacing is to be adopted for a certain highway under consideration. This means that for a traffic volume of say 100 or 400, we shall recommend the surfacing using the same aggregate requirement. Likewise, the intermediate type, where a highway is expected to carry 401 vehicles, will have the same materials for a pavement that will be constructed for 1,000 vehicles. It is obvious that a 1,000 traffic volume will give a more destructive effect on a certain pavement rather than a 200 traffic volume. Possibly, if we can compromise things and say that for the low-type group we can use natural uncrushed gravel for counts up to 200 and from 200 to 400 we should use crushed gravel or crushed stones. In like manner, both the intermediate and high-type groups should follow otherwise by saying that from 401 to 700 vehicles, use uncrushed gravel and from 701 to 1,000 use the crushed materials. For plant-mix materials either the crushed or uncrushed will do as has been proven from test that angularity of the aggregates does not affect much the stability of the pavements.

With this put into practice, it is believed that great savings in the cost of pavements will be realized by the Bureau and more highway kilometerage will be constructed instead of a few short ones just by following strictly the printed stipulations. This insistence on aggregates that they should meet a rigid set of specifications should not prevail at all times and conditions, but instead specifications should be written to make use of a wide variety of local materials.

CHAPTER III

PENETRATION SURFACE TYPES

The types of bituminous pavement construction are the penetration types which are mixed on the road surface and the plant-mix types which are mixed in a central plant and delivered to the road ready for paving.

1. Surface Treatments

Reference is made to the article entitled "Study of Some Variables Affecting Retension of Aggregate By Asphalt Surface Treatment" written by Fred J. Benson and Bob M. Gallaway, Research Engineers at the Texas A & M College, wherein it was proven from tests that the three essential requirements for a successful surface treatment construction ⁽⁵⁾ are the following:

(a) The bituminous material shall be controlled to such quantity to hold the stone but not to submerge the stone, so that there will be too much asphalt present which will bleed during hot temperatures.

(b) Enough stone of one layer must cover the asphalt, because more than this quantity will just not stick to the asphalt and therefore will be thrown by the wheels of traffic.

(c) The bond between the stone and the bituminous material shall be such as not to allow dislodging by the action of the wheels of traffic.

Two asphalt cement penetration of 120-150 and 210-250, RS-2 and RC-2 were used as the binders and the aggregates were washed rounded river gravel (pea gravel) and a crushed limestone. This test has verified that the proper quantity of a given aggregate for one-course surface treatment should be the optimum quantity required to cover one square yard one stone thick, plus an allowance of 10 percent for spreading inaccuracies. The use of more aggregates shows no useful advantage. About 15.4 pounds per square yard of pea gravel will be the optimum quantity. The binder requirement is .15 gallon per square yard for pea gravel and .21 gallon per square yard for crushed limestone. This test also reveals that dust, even in small particles is a source of reduction in aggregate retention.

With asphalt cements and cutbacks, the results of test when the aggregate was applied wet, then rolled and brushed showed a marked reduction in the quantity of retention. On the other hand, with the use of RS-2 emulsion, the presence of water in the aggregate had a beneficial effect on the retention of aggregates. But on all asphalts, the presence of dust reduced the aggregate retention by about 1/2 lb. per square yard. For all asphalt an increase of the fine fraction from 0 to 30 percent of the aggregate caused 1.2 lbs. reduction in aggregate retention. To obtain a better retention, it is required to have a gradation as uniform as possible.

On a gallon to gallon basis the asphalt cement has more aggregate retention than the RC-2 or the RS-2, but the difference is of no material importance. For asphalt cements it is important that immediate spreading of the aggregate is required after the application of asphalt for more aggregate retention. While the harder or low penetration asphalt cement holds the aggregate better, it seems difficult to obtain the initial retention.

In this test nothing was mentioned as to the variation in the behavior of the uncrushed river aggregate compared to crushed limestone. It is very likely that both aggregates proved satisfactory because all that were emphasized are the amount of aggregates, gradation, presence of dust and the quality of the asphalt binder. The booklet entitled "Material Details of the Standard Specifications for Road and Bridge Construction" of the Mississippi State Highway Department showed that for a double bituminous surface treatment⁽⁷⁾ the first course of uncrushed gravel with a gradation according to the specifications may be permitted. The maximum size for this is 1 inch to 1-1/4 inch. The State of Mississippi has found this construction satisfactory, and no doubt it would prove successful in any part of the country as long as the right amount of binder is applied.

2. Penetration Macadam Gravel Pavements

The "Textbook on Highway Engineering" written by Arthur H. Blanchard and Henry B. Drowne, recalled a bituminous gravel pavement⁽⁸⁾ constructed in Longview, Texas, under the direc-

tion of P.E. Green. Mr. Green noted that the washed gravel depends on the bituminous binder for its bond or strength as a pavement. The reason being that due to the lack of keying effect, the strength of the wearing surface is dependent almost entirely on the bond of the asphalt.

The washed rounded gravel was the only material economically available at the site and expenses that will be within the limits of available funds, so he decided to use the gravel and utilized every effort and energy to bond the aggregate by rolling. As a first trial he specified that the gravel shall all passed a 2 inch diameter ring and retained on the 1/2 inch diameter ring. These materials were spread and there was no evidence of bond between the stones, and plus the addition of bituminous materials, only a little strength was obtained. This stretch was removed and a change in gradation was made by specifying that only materials retained on the 3/4 inch diameter ring should be used. This gradation then was spread and rolled to the satisfaction of the inspector and about 1-1/2 gallons of asphalt cement was applied per square yard. Immediately pea size aggregate was lightly spread over the surface and the whole surface rolled. Then 1/2 to 3/4 gallon per square yard of asphalt was applied after rolling and brooming and over this application, coarse sand was spread and then rolled, furnishing the seal coat.

Mr. Green concluded that due to the much care needed in handling gravel as to screen it and eliminate the small pebbles that prevented the interlock between individual stones, it would have been cheaper to purchase crushed

limestone. Gravel can be made to offer a keying effect but only after a great deal of labor and control are associated with it. It was emphasized here that the use of gravel in the construction of bituminous pavements by penetration methods should be limited only to those localities where the cost of broken stone is very much in excess of the cost of gravel.

Labor and control will not be too much of a problem in the Philippines as there will be in crushing. There is plenty of labor for use. The fact that natural gravel could be used as an aggregate on penetration problems is sufficient enough to authorize constructions especially in remote areas where crushed gravel or crushed stone is uneconomically available.

CHAPTER IV

PLANT-MIX PAVEMENT TYPES

For quite a long time it has been established that the shape of the aggregates in composite bituminous aggregate mixtures affected the stability and strength of the mixtures, in that sharp-angular and roughly-textured aggregates developed more stability than rounded aggregates. It is true and has been accepted in practice, but nobody has made actual comparison of the strength and how much the natural aggregates are deficient. The trend toward a more stable mix is always the goal of a designer, so whenever possible the crushed stone is always specified within the limits of economical means. So that for the control of the mixture, it will require a certain percentage of the aggregate to be broken stones or crushed gravel noted in most state highway specifications.

There was lack of study and test of the stability behavior of bituminous mixes as affected by different aggregate shapes. So investigations were made by Dr. M. Herrin and W. H. Goetz, at Purdue University as to the effects of aggregate shape to the stability of bituminous mixtures.⁽¹⁾ In their study, three variables were adopted, namely the shape of the coarse aggregate, the shape of the fine aggregate and the gradation of the aggregates. Variation in the shape of coarse

aggregates was made by using crushed limestone, rounded uncrushed gravel and crushed gravel. For the fine aggregate, natural sand and crushed limestone were used to give a distinct contrast desired in the shape of the aggregate particles. This study was made on three gradations, namely dense, open and one-size gradings. All mixtures were hot using asphalt cement and a fix asphalt content for any particular gradation.

For evaluating the stability, the triaxial-compression method was used because the results gave the basis for analysis of the various factors affecting the stability of the bituminous mix. It was believed that this test will produce data that is analyzed in terms of properties of the cohesive granular mix which is in accordance with the Mohr's strength theory. The theory of failure is more observed in this test than the others and it provides some basic and logical approach in finding the stability or shear strength of the bituminous mix. This study was purely laboratory and was never tried in actual performance on the roads. Mohr's theory of failure recognizes two factors contributing to the ability of bituminous-aggregate mixture to carry moving loads. These are internal friction (ϕ) and cohesion (c). Internal friction is frictional resistance to sliding and resistance due to aggregate interlock. Cohesion is resistance to shear develop by the binding material. Price devised the method of least squares to obtain the vertical

intercept (a) and slope (b) of the best straight line plot of the confining pressure against maximum compressive strength. These values of (a) and (b) are used to compute the angle of internal friction and cohesion of the mix from the following formula:

$$\sin \phi = \frac{b - 1}{b + 1} ; \quad C = \frac{a}{2 \sqrt{b}}$$

The coarse aggregate material used in this investigation are of three types all retained on the No. 4 sieve, namely rounded uncrushed gravel, crushed gravel and angular crushed limestone. The crushed and uncrushed gravel were mixed in varying percentages of crushed gravel as 0, 55, 70 and 100 percent. Variation in fine aggregate all passing the No. 4 sieve, was done by using the natural sand and crushed limestone. Three gradings of aggregate were used to give a wide range of gradation. The dense graded mixture was represented by the Corps of Engineers, U. S. Army, called Surface course Asphalt Mix with maximum aggregate size of 3/4 inch. The two other gradations are the open graded and the one-size grading corresponding to the requirements of Hot Asphaltic Concrete Binder Course and Bituminous Coated Aggregate Surface of the Indiana State Highway Department specifications.

One type of asphalt was used in this investigation. It has a penetration of 66, with a specific gravity of 1.015 and a ductility of over 150 cm. at 77°F. The asphalt content used was based on the corresponding specifications. All types of coarse aggregates under one gradation and with one

type of fine aggregate, the asphalt content was made constant. The asphalt contents of the mixtures made from different gradings were as follows:

Dense Grading

Natural Sand Fine Aggregate	6.0 percent
Crushed Stone Fine Aggregate	5.5 percent

Open Grading

Natural Sand Fine Aggregate	5.0 percent
Crushed Stone Fine Aggregate	5.0 percent

One Size Grading 5.0 percent

All mixtures were hot where corresponding amount of aggregate and asphalt were heated separately to about 300°F and 275°F, respectively, combined in a mechanical mixer for two minutes. Specimens four inches high were molded by the double-plunger compaction method in a hydraulic compaction device with a static axial load of 2,160 psi. for about one minute. All specimens were tested in the triaxial-compression cell. The testing speed was maintained at 0.05 inch per minute.

Effect of Coarse Aggregates

The results of test as to the effect of coarse aggregates showed that generally there was no general trend of increased compressive strengths with larger amounts of crushed gravel in the mixture. There was no difference in the strength lines of the mixture containing gravel. The average of the test results shows that the strength of all the four gravel mixtures could be considered to be the same. There was an increase in compressive strength above the

strengths of the gravel mixes by using crushed stone coarse aggregate in the mixture. The observed values of cohesion and angle of internal friction for dense-graded mixture containing natural sand indicated that there was very little change in the values for friction angle and cohesion as the amount of crushed gravel was increased in the mixtures. Based on the fact that there is not much difference in the strength curves for all the prepared combinations of crushed and uncrushed gravel, all gravel mixtures of the same fine aggregate could be considered to have the same values of cohesion and angle of internal friction. However, there was a marked increase in the values of cohesion when crushed stone coarse aggregate was used with either type of fine aggregate. The angle of internal friction was practically the same when crushed stone coarse aggregate was used compared to the gravel mixture when the fine aggregate used was the natural sand. Using both crushed stone for coarse and fine aggregate, it had lesser friction angle than when crushed stone fine aggregate with gravel coarse aggregate. There was also no increase in compressive strengths by any increase in the amount of crushed gravel with any of the two types of fine aggregate. There was a slight increase in strength when crushed stone was used instead of gravel for coarse aggregate. However, this increase was very slight and therefore has not much significance.

Effect of Fine Aggregate

Whatever grading was used, the strength of the mixtures were increase when crushed stone fine aggregate was used instead of natural sand. The strength remains the same regardless of the amount of crushed gravel used. Using uncrushed gravel, the strength was increased about the same amount when there was a change in the type of fine aggregate as that of the same mixture using pure crushed gravel. Both increases in strength of the dense or open-graded mixture was due to the shape of fine aggregate rather than the shape of the coarse aggregates.

Effect of Open Grading

As the amount of crushed gravel was increased from 0 to 55 percent, there was a corresponding increase in compressive strengths of the open-graded mixtures. The increase in strength although significant was less than 10 percent and may be considered as without practical importance. Further increase from 55 to 100 percent of the crushed gravel did not show any increase in strength. However, when crushed stone coarse aggregate was used instead of gravel, greater compressive strength was produced.

Effect on the One-Size Grading

The compressive strength of the one-size mixture was affected by the shape of the aggregate.

The more angular the aggregate is, the more is the developed compressive strength. The strength developed of mixtures containing crushed limestone coarse aggregate was greater than mixtures containing any type of angularity of gravel.

Effect of Aggregate Grading

While the angularity in the coarse and fine aggregate affects the strength of the mixture, the more pronounced change in strength is affected by gradation. For the three gradations used the dense-graded was the highest in strength, next was the open-graded and the lowest of the three was the one-size gradation. These differences in strength were due primarily in the values of cohesion rather than the angle of internal friction.

It was concluded that the grading of the aggregate is an important factor affecting the strength of the mixtures than the shape of the aggregate. This study has conclusively established that on plant-mixes the use of uncrushed gravel may be substituted for crushed gravel as long as the gradations are controlled and if possible sharp angular fine aggregates are used.

Since emphasis was given on the gradation of the composite aggregate, then for a given gradation of coarse, fine aggregate and filler, what would be the composite gradation to have a stable mix?

CHAPTER V

GRADATION OF MINERAL AGGREGATES FOR DENSE-GRADED BITUMINOUS MIXTURES

It might seem strange to find areas of pavements that hold traffic while other areas would not behave with traffic under the same conditions of terrain, materials, and specifications. It was found by Mr. F. N. Hveem that pavement failures may be attributed to improper gradation⁽²⁾ of the mineral aggregates that composed the mix. It was then disturbing to note that when samples were taken from the failure areas and good areas, the gradations of the aggregates in the good areas did not conform to the regular curves while gradations in the failure areas were the ones that adhered to conventional gradation curves. This discovery of Mr. F. N. Hveem seems a shock and tends to destroy the faith on accepted principles. We oftentimes spoke of good and poor grading and it is quite evident that there is what we call as ideal grading. In order to know about this gradations, samples were taken on various localities and comparison was made to find out any common property which might exist relative to the good performance of bituminous pavements. His study covered a wide field to include also the gradations of portland cement concrete with the several bituminous mixtures.

After all this study, he indicated that it is necessary for the designer to know the individual items and properties which are needed to accomplish the purpose. One can possibly devise the ideal grading from the aggregate available. It is not a simple matter to arrive at an ideal grading because in practice the best gradation of aggregate that can be secured is, most of the time, a "compromise". This selection then implies allowance for diverse elements, namely workability, permeability and economy. A desirable property of a mixture is one that possesses plasticity and mobility which sum up to workability. All bituminous mixtures must be workable depending on the type of equipment used.

Permeability is another factor that influenced gradation and should not be confused with density. Paving mixtures may be impermeable under conditions that the subgrade on which it stands are such as not to allow surface water to enter through underneath the pavement. It is an admitted fact that subgrade saturation is due some to capillary moisture and some from surface water. Placing a very tight pavement prevents evaporation and may result to failure due to accumulation of moisture underneath the pavement. It would then be proper to have a pavement of some degree of porosity, to allow the moisture to evaporate rapidly, enough to avoid concentration of water thereby to maintain equilibrium.

Economy is one factor which affects the choice of gradations so that if possible, the ideal grading chosen should be one very desirable and economical to secure out of the aggregates available.

The present trend in skid resistance for traffic safety is one minor factor that influenced the grading of aggregates. Mr. Hveem also indicated that the important property which is slightly or indirectly affected by variation of aggregate size within gradation limits, is the stability of the bituminous mixture.

He concluded that on all bituminous mixtures, the trend towards the selection of aggregates would be toward the use of rougher aggregates and a reduction of the fine aggregate to the lowest amount possible so as to maintain a high internal friction. Inasmuch that stability is also affected by cohesion, any attempt to reduce the amount of fines reduces the cohesive strength as well as an increase in permeability, so that we are again back to the need of a compromise.

He further concluded that the best grading in a mixture is one that takes into consideration the available aggregate to satisfy as many of the desired factors. Inasmuch that natural aggregates vary throughout the country and that its utilization is local in character due consideration should be given to the nationalization of standards of gradings. On the other hand, manufactured aggregates are not transported to a far distance so there is no reason why control should be made so that crushed stones, sand, or gravel, in one place should meet the grading requirements of a distant place.

CHAPTER VI

THE RELATION BETWEEN LOS ANGELES ABRASION TEST RESULTS AND THE SERVICE RECORDS OF COARSE AGGREGATES

There exists a distinct relation between the loss in the Los Angeles Rattler Test⁽⁴⁾ and the service record of materials used in bituminous pavement construction and surface treatments. From the data submitted by several road organizations, it appeared that the percentages of wear suitable for use in highway specifications to control the quality of coarse aggregates are the following:

Surface Treatments	40 percent
Bituminous Pavements	40 percent
Portland cement concrete	50 percent

Results of a circular tract roller test, showed that the Los Angeles Abrasion Test gives an accurate evaluation of materials under test and the lower the percent of wear the better is the composite mixture.

In the year 1935 the committee on Correlation of Research in Mineral Aggregates of the Highway Research Board, headed by R. R. Litehiser, recommended that study of this feature be made. A request from various highway engineering organizations was solicited. That same year and the following year, some information was received by the Board and additional data, secured by the Bureau of Public Roads, was supplemented.

The information given are classified under two headings:

A. Comparison between the Los Angeles Test result and the service record of the material, and

B. Comparison between the Los Angeles Test result with wear test of aggregates which simulates the action of traffic.

All the gathered data comparing the Los Angeles Abrasion Test result with service records were obtained from several state highway departments and a highway board in Australia. Service records were reported of the material when used in concrete, bituminous pavements and surface treatments. The Florida State Road Department service records show that natural gravel was used and that with the Los Angeles percent of wear from 41.2 to 48.5, they were found to be satisfactory for use in concrete and bituminous construction.

The service record furnished by the Ohio Department of Highways revealed that whether the gravel is uncrushed or crushed, as long as the Los Angeles Abrasion Test result is above 50 percent, the pavement behavior is questionable, which goes to show that angularity of the aggregate does not affect to a great extent the performance of bituminous pavement constructions.

The service records of the Texas State Highway Department showed that gravel with less than 42.8 percent of wear had satisfactory performances in both concrete and bituminous constructions.

The data submitted by the County Roads Board, State of Victoria, Australia, showed that all rock and gravel with a percent of wear of 35 percent or less are found to have from excellent to fair service records. They concluded that a maximum loss of 20 percent should be used for the best surfacing materials.

All of these information or findings of the different highway authorities were summed up and grouped in accordance with the type of construction and it was concluded generally that the Los Angeles Abrasion for bituminous pavements are lower than those for concrete and even lower for surface treatment.

The Michigan State College conducted tests comparing the loss in the Los Angeles Abrasion Test with the loss observed in a circular track roller test. In this test, the materials were prepared to conform to the following gradations:

Passing 1-1/2 inch sieve, percent	100
Passing 1-1/4 inch sieve, percent	80
Passing 1 inch sieve, percent	60
Passing 3/4 inch sieve, percent	40
Passing 1/2 inch sieve, percent	0

The material passing the No. 10 sieve after each test was considered the loss and was expressed as a percentage of the original weight of the material. This roller test subjected the material to a maximum of 500 passes of a cast iron roller loaded to 200 pounds per inch of width. It was interesting

to note that the 500 passes of the iron roller approaches the loss obtained from the Los Angeles Abrasion Test. It was concluded that there really exist a definite relation between the loss in the Los Angeles Abrasion Test and the service record of materials used in concrete, bituminous construction and surface treatment. Basing his conclusions on the data available, the following percentage of wear are recommended for use in the specifications to control the quality of aggregates:

Concrete	50 percent
Bituminous Pavements	40 percent
Surface Treatments	40 percent

It was revealed that in the control of coarse aggregates for bituminous pavements and surfacings, the Los Angeles Abrasion Test is a good measure and an accurate indication for quality of the coarse aggregate. As long as the aggregate has its proper gradation and has passed the abrasion test, there simply is every reason to use natural gravel in bituminous constructions where crushing would be a problem of cost.

CHAPTER VII

THE ROLE OF ANGULAR AGGREGATES IN THE DEVELOPMENT OF STABILITY IN BITUMINOUS MIXTURES

Engineers are lucky who work in areas where crushed gravel, crushed stone or crushed rock are in abundance. They can easily design mixtures which will produce high stabilities that will counteract any shoving or creeping effect. But to engineers who happened to work in regions where only rounded and smooth-faced materials are available, they will find it hard to design mixtures that satisfy requirements.

Mr. W. H. Campen and J. R. Smith⁽³⁾ both of the Omaha Testing Laboratory, happened to be practicing in an area where the most and abundant source of aggregates consist of river sand and gravel. This sand and gravel are very sound except that they are rounded and smooth. Bituminous pavements constructed of these materials are known to be durable with the only objection of having the tendency to creep and shove. Due to this problem of aggregate procurement, they conducted an intensive laboratory experiment for the purpose of determining the required mixture so as to increase the relative stability of the resulting bituminous mixture.

Three types of bituminous mixtures were studied, namely, sheet asphalt, stone-filled sheet asphalt and asphaltic concrete where the maximum size of aggregate ranges from 1/2 inch to 1-1/4 inch. From the results of test, it was shown that the stability of the mixtures made with the local sand and gravel ranges from 850 to 410 pounds as the asphalt content varied from 9 to 10 percent. With the addition of crushed sand, the stability was increased. The most important thing to note is the fact that satisfactory stability can be attained by replacing from 20-40 percent of the local rounded sands with angular sands. With this it was possible to use about 70 percent of the available local sands.

On the stone-filled sheet asphalt, each of the five aggregates wherein one was the local natural gravel, was mixed with both the weak and strong mortars to produce 35 percent coarse aggregates. It was found that mixtures with strong mortar and 6.2 to 6.6 percent of asphalt cement were from 3 to 7 times as strong as those with the weak mortar of the same asphalt content. The angularity and smoothness of the aggregates also affected the stability but to a lesser extent than does the strength of the mortar. Mixtures containing natural gravel with weak mortar show no adequate stability.

With respect to the asphaltic concrete, they all behave like in the stone-filled sheet asphalt, except the natural gravel with weak mortar, all other mixtures showed adequate stability. So that natural gravel with strong mortar will

be just as substantial as any other crushed aggregate. The same tests were made on 3/4 inch and 1-1/4 inch maximum size of aggregate using about 60 to 67 percent coarse aggregate and the results were all identical giving more stability when strong mortar is used. With the results of the test, they were able to conclude that:

A. With any type and percentage of coarse aggregate, the stability is higher when strong mortar is used;

B. Regardless of the type of mortar, the stability increases for a corresponding increase in the amount of coarse aggregate;

C. Crushed aggregates produced more stability than round or angular smooth-faced aggregates; and

D. All asphaltic concrete aggregates when mixed with strong mortar possessed adequate stability regardless of crushed or uncrushed.

CHAPTER VIII

CONCLUSION

Results of recent tests have indicated that the stability of pavements depends more on the roughness, characteristics of aggregate's surface rather than angularity. This may be true in some respects because even if crushed gravel were used, it is possible that in spreading of the aggregates, the fractured face of one may not fit in with the fractured face of the other so that interlock between the aggregates may not be fully developed. On the other hand, deep fitted surfaces of natural aggregate in contact with another may develop a wider area of contact, and with the right amount of asphalt binder will increase the stability of the mixture. It may be also added that uncrushed gravel may fit its way better than a crushed gravel with regards to interlock, because what actually happens is that the edges of the uncrushed gravel being rounded has the ability to adjust itself unlike crushed material, which if not properly fitted will eventually crush under rolling operations.

The following is a summary of the findings of those men mentioned in this report who made extensive studies of the behavior of various aggregates in bituminous surfacings and pavements:

1. Aggregates used for surface treatment do not necessarily have to be crushed. The only considerations are amount and gradation of aggregates, presence of dust and the quality of asphalt binder;

2. Washed river gravel was found to satisfy stability requirements in a penetration macadam pavement as long as the materials used were retained on the 3/4 inch sieve. About 1-1/2 gallons of asphalt binder was applied per square yard and then followed by a thin layer of pea size gravel to fill the voids. Rolling and brooming followed and then 1/2 to 3/4 gallon per square yard of asphalt was applied. Coarse sand was the last layer spread and then rolled as a seal coat to satisfaction.

3. The strength in a bituminous plant-mix pavement depends to a larger extent on the gradation than in the angularity of the coarse aggregates. However, sharp angular fine aggregates should be utilized in the mortar to increase the internal friction and cohesion of the mix. The angularity and smoothness of the aggregates affect the stability only to a small extent. A larger gain in strength can be obtained by the use of a strong mortar of sharp angular sands which increases the strength 3 to 7 times.

In the light of all the materials presented in this report, it is believed that as long as angular sands are used, and the correct gradation and the right percentage of wear are possessed by any natural gravel, same can be used as a bituminous paving aggregate where crushed aggregate could not be economically obtained.

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VITA

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Scope of Study: The standard specifications for highways in the Philippines require that aggregates for bituminous surfacings and pavements shall be crushed, just as any other specification of highway organizations in the United States. There is an abundant supply of natural river gravel and unless this is crushed same can not be used as an asphalt paving aggregate. Remote projects in the Philippines which are considerably small can not produce specification requirements economically due to insufficient crushers available. The use of a rented crusher or crushing by hand may prove prohibitive in some places. Reference to past laboratory test and actual construction procedures were compiled using uncrushed river gravel to advantage and satisfactory behavior was observed on the mixtures.

Findings and Conclusions: Laboratory tests have shown that the stability of pavement mixtures depends more on the roughness characteristics of the aggregate rather than angularity. For surface treatments, considerations only on quantity, type of binder, amount of moisture and presence of dust are the ones emphasized. For macadam gravel pavements, gradation was the most important and only materials passing the 2 inch sieve and retained on the 3/4 inch should be used. A great deal of labor and control are required for a successful result. On the plant-mix surface types, comparisons on strength were made and that there was no difference in strength whether gravel or crushed gravel was used. The two important properties of an asphalt mix are the angle of internal friction and cohesion whose values can be increased by the use of strong mortars. This strong mortar is produced by using angular sands as fine aggregate. It was determined that the strength of the mixtures responded to the shape of the fine aggregate rather than the shape of the coarse aggregate. There should be no standard for gradation but it should be one that utilizes the available aggregates to give as many of the desired properties. The Los Angeles percentage of wear for all bituminous aggregates shall not be more than 40.

ADVISER'S APPROVAL _____