Kentucky Department of Highways

Stability Investigation

of

Bituminous Pavements

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Preliminary Report

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Bituminous Division of the
Highway Materials Research Laboratory
Lexington, Kentucky

March 5, 1945

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SYNOPSIS

1. This stability investigation was started by the Bituminous Division of the Highway Materials Research Laboratory, Lexington, Kentucky, during the month of October, 1944, and was completed the first of March, 1945. The purpose of this investigation was to develop information on the design and control of asphalt pavements. The data presented may be used to compare mixes made from commercial aggregates with mixes containing local aggregates. It is believed that sufficient amount of reliable data is presented in this report to enable the design engineer to use the Marshall stability equipment and testing procedure to select the best available aggregate combination, gradation and bitumen content.

2. This investigation includes a series of tests conducted on commercial aggregates now being used by the Department of Highways for bituminous pavements. The following commercial aggregates were included in this series of tests; river gravel and sand, limestone and sand, slag, and limestone. Three gradations were used for all aggregate combinations. These three gradations were selected to represent the minimum, average, and maximum per cent passing each sieve size designated by the Department of Highways Class I, Type B, Specification.

3. Stability tests were made with the Marshall stability equipment and testing procedure. The test specimens are four inches in diameter and two and one-half inches thick. The stability is the maximum load in pounds required to fail the specimen when compressed between two segments of a semi-confined

compression ring. Water permeability tests were conducted on all test specimens. Water permeability is the pounds of water that flows through a 4-inch diameter by 25-inch thick specimen in 24 hours. Other tests and calculations were made on all test specimens, including specific gravity, flow value, per cent of voids in the mix, per cent of solid volume density, and unit weight in pounds per cubic foot.

4. The type, gradation, and general physical characteristics of any given aggregate determine the exact bitumen content required in order for the mix to have the desired resistance to shear, flow, and rutting. At present the engineer in responsible charge of a project determines whether or not the pavement has three properties by visual inspection. One of the basic benefits to be derived by the adoption of a stability test would be the elimination of personal judgment and substituting a scientific method for the design and control of asphalt pavements. Data included in this report will demonstrate that the correct gradation and per cent of asphalt can be established and accurately controlled by the use of this testing equipment; and also, enable the engineer to determine when sufficient rolling has been completed. There is a considerable variation in the physical characteristics, gradation, and quality of the various types of aggregates available throughout the state. Specifications cover all types of aggregate for general use and contain restrictions which prevent the use of acceptable materials which are available for certain localities. The adoption of a stability test would give the

Department a comparison of the qualities of mixes containing commercial aggregates, and those containing local materials. A test of this type would enable the Design Department to know definitely in advance if satisfactory pavements could be constructed from the local available aggregates. This information would be valuable to the Design Department in deciding whether or not special specifications would be desirable from the standpoint of quality or economy for any specific project.

5. An analysis of the data presented in this report indicated that the following conclusions could be made. The correct bitumen content and aggregate gradation may be determined by stability and flow tests. When stability tests are conducted both in air and water gradations and type of materials can be selected which would be the least effected by the action of water on the pavement. Open gradations were not satisfactory when the aggregates in the mixes were composed of river gravel and sand, or limestone and sand. The open gradation was satisfactory when the aggregates were composed of slag or limestone. The medium and fine gradations were satisfactory for all types of aggregate. The per cent of asphalt, and grading of the aggregate, are the two principal factors effecting both stability and water permeability. Asphalt mixes containing more than 5% voids have unsatisfactory water permeability qualities. Data included in this report indicated that the types of aggregate should be considered when selecting an aggregate gradation for an asphalt mix.

PART I: INTRODUCTION.

Purpose

6. The purpose of this investigation was to conduct a sufficient number of stability and other related tests on asphalt paving mixes to supply data on the following:

a. To determine what effect bitumen content has on the stability and other properties of an asphalt mix.

b. To determine what effect gradation of the aggregate has on the stability, flow, and permeability of bituminous mixes.

c. To determine what effect various types of gravel, crushed stone, slag, and sand aggregate combinations have on stability, flow, and permeability and voids in asphalt mixes.

d. To determine the minimum stability value required for satisfactory pavement performance.

e. Establish a correlation between laboratory and field densities.

f. To determine the effect of temperature on the compaction of various types of aggregates.

Scope

7. The scope of this investigation may be briefly stated as follows:

a. Conduct a sufficient number of tests to supply adequate data on stability and other related tests for all types of aggregates used by the Department in bituminous pavements.

b. To determine by stability and other types of tests whether or not the Department's present aggregate grading requirements for bituminous mixes are satisfactory for all types of aggregate.

Definition of terms

8. Certain terms used in this report are defined as follows:

Stability. The resistance of an asphalt pavement to stresses produced by wheel loads.

Flow. The amount of deflection required to produce failure of the test specimen.

Bulk Specific Gravity. The ratio of the weight in air of a given volume of a permeable material at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature.

Theoretical Solid Volume Specific Gravity. This term refers to the theoretical specific gravity of a unit volume composed of aggregate and asphalt in the proportions used in the mix excluding all air voids.

Water Permeability. The pounds of water that flows through a compacted asphalt specimen 2-1/2" high and 4" in diameter in 24 hours.

Voids in the Compacted Aggregate. The amount of voids in the compacted aggregate including the space occupied by the asphalt cement.

Voids in the Asphalt Mix. The amount of air voids in the compacted mix which represents the space not occupied by aggregate or asphalt cement in a given volume.

Adhesion of Bitumen to Aggregate. The resistance of the bituminous mix to the removal of asphalt from the aggregate by the action of water.

Stripping. The removal of asphalt from the aggregate particle by the action of water on the mix.

Optimum Asphalt Content. The per cent asphalt required to produce a maximum stability for a definite aggregate gradation.

River Gravel and Sand Aggregate. This term applies to mixes composed of river gravel and sand aggregates only.

Limestone and River Sand. This term applies to mixes composed of limestone (+16) and river sand (-16) aggregates only.

Slag Aggregate. This term applies to mixes composed of slag aggregate (100% slag) only.

Limestone Aggregate. This term applies to mixes composed of limestone aggregate (100% limestone) only.

Gradation No. 1. Gradation one is the coarsest grading and contains the minimum per cent passing all sieve sizes permissible under the Class I, Type B, grading composition.

Gradation No. 2. Gradation two has a gradation exactly in the middle of the Class I, Type B, grading requirements.

Gradation No. 3. Gradation three is the finest grading and contains the maximum per cent passing all sieve sizes permissible under the Class I, Type B, grading requirements.

PART II: DESCRIPTION OF MATERIALS USED

Aggregates

Description

9. Limestone. All limestone used in this investigation was obtained from the Central Rock Company's Quarry located at Lexington, Kentucky. This was a very fine grained limestone, having a smooth texture on all fractured faces. The bitumen adhesive qualities of this aggregate were very poor. Physical tests conducted on this aggregate were as follows:

Per Cent of Wear	28.6
Sodium Sulphate Soundness Loss	2.5
Specific Gravity	2.68
Per Cent Absorption	0.3

10. Gravel. Commercial gravel used in this investigation was obtained from Portsmouth Sand & Gravel Company's plant located at Portsmouth, Ohio. This gravel contained better than 50% limestone particles, approximately 10% quartz, 10% chert, and less than 10% sandstone. The texture of most of the gravel particles had a rough surface and only a small percentage of the particles had a polished surface. The majority of the particles were angular in shape and had fairly good bitumen adhesive qualities. Most of this gravel originated from a glacial deposit and has only been carried in the river approximately 100 miles. Laboratory physical tests conducted on this material were as follows:

Per Cent of Wear	29.1
Sodium Sulphate Soundness Loss	7.8
Specific Gravity	2.57
Per Cent Absorption	1.0

11. River Sand. The river sand used in this investigation was obtained from the Portsmouth Sand & Gravel Company's plant located at Portsmouth, Ohio. This is a good quality quartz sand containing a very small amount of impurities. The shape of most of the particles was semi-angular. This sand had fairly good bitumen adhesive qualities. The laboratory physical tests conducted on this sand were as follows:

Specific Gravity	2.55
Per Cent Absorption	0.8

12. Slag. The blast furnace slag used in this investigation was obtained from the Standard Slag Company's plant at Ashland, Kentucky. It is a good quality material, having a very small amount of glassy particles. This aggregate had very good bitumen adhesive qualities. Laboratory physical tests conducted on this aggregate were as follows:

Per Cent of Wear	31.5
Sodium Sulphate Soundness Loss	1.0
Specific Gravity	2.38
Per Cent Absorption	8.4

Gradation of aggregates

13. All aggregates were processed in the laboratory and separated into individual sieve sizes, in order that they could be accurately proportioned in the asphalt mixes.

14. The Department's Specifications for Class I, Type B Surface, was selected for use in this work. This specification has the following aggregate grading composition:

% Passing	1/2"	Sieve	100%
% "	3/8"	"	90-100
% "	#4	"	50-65
% "	#8	"	35-50
% "	#16	"	20-40
% "	#50	"	2-20
% "	#100	"	0-10
% "	#200	"	0-5

15. In order to show the effect of these grading limits on stability and other related tests three gradations were selected. Gradation No. 1 was selected as being the coarsest material permissible under this specification. Gradation No. 2 was selected to represent the grading limits exactly in the middle of this specification. Gradation No. 3 was selected to contain the maximum per cent of fine material permissible under this specification. These three gradations are illustrated graphically on a semi-log chart in Plate No. 1. The exact grading limits used in these three gradations were as follows:

			Gradation No. 1	Gradation No. 2	Gradation No. 3
% Passing	1/2"	Sieve	100	100	-
% "	3/8"	"	90	95	65
% "	#4	"	50	57	50
% "	#8	"	35	42	50
% "	#16	"	20	30	40
% "	#30	"	10	20	30
% "	#50	"	2	11	20
% "	#100	"	-	5	10
% "	#200	"	-	2-1/2	5

Asphalts

16. Only 85-100 penetration grade asphalt cement was used in this investigation. This material was obtained from the Shell Petroleum Company's plant at St. Louis, Missouri. Tests on this material were as follows:

Specific Gravity	1.00	Ductility 25°C.	100+
Penetration 25°C.	.90	Bitumen Solution CS2	99.8
Loss 163°C.	0.04%		

PART III: EQUIPMENT, LABORATORY TESTS, AND PROCEDURE

Equipment and Testing Procedure

17. The stability equipment used in this investigation was developed by Bruce G. Marshall of the Mississippi Highway Department, who cooperated in furnishing photographs and other details concerning the construction of this equipment.

18. The stability machine was constructed by the University Machine Shop, and conforms to the information furnished this Department by Mr. Marshall, except that some minor changes were made. Photographs 1 to 5 are views of this equipment.

19. The testing procedure used in this investigation follows Mr. Marshall's method in practically all details except that a higher compactive effort was used, and some other slight modifications have been made.

Laboratory Tests

Stability Tests

20. All stability tests conducted during this investigation were performed with the Marshall Stability Equipment and testing procedure. Stability tests on all types of commercial aggregates covered by this investigation were conducted on three gradations conforming to the grading requirements outlined in Paragraph 15. Stability tests were

conducted at 140°F. in water on all samples, also at 140°F. in air on the majority of specimens.

21. River gravel and sand aggregates. Test results on mixes made from river gravel and sand aggregate are presented in Tables 1, 2 and 3. Stability and flow tests versus bitumen per cent are illustrated graphically in Plate 2. A study of this data revealed the following:

a. Gradation No. 1 had a maximum stability at 140°F. of 212 pounds in water and 230 pounds in air. This data showed that there was a considerable loss in stability due to the action of water on this open graded mix. It should be noted that this gradation did not have stability value high enough either in air or water to meet the minimum requirements of 300 pounds.

b. Gradation No. 2 had a maximum stability at 140°F. of 432 pounds in water and 524 pounds in air. An analysis of this data indicates that there was approximately 20% deduction in stability due to the action of water on this medium graded mix.

c. Gradation No. 3 showed a maximum stability at 140°F. of 487 pounds in water and 550 pounds in air. This data indicates that there was only a slight reduction of stability due to the action of water on this closed gradation.

d. It should be pointed out that Gradations 1, 2 and 3 showed a maximum stability of 125, 432 and 487 pounds respectively at 140°F. in water. These values demonstrate the effect of gradation on stability.

22. Limestone and river sand aggregates. Gradations 1, 2 and 3, composed of limestone and sand aggregates contained 20, 30 and 40% sand respectively. Test results on these mixes are presented in Tables 3, 4 and 5. Stability and flow tests vs. bitumen content are illustrated graphically in Plate 3. A study of this data revealed the following:

a. Gradation No. 1 had a maximum stability at 140°F. of 212 pounds in water and 320 pounds in air. This data illustrates that open grade mixes having grading requirements similar to Gradation No. 1 are effected considerably by the action of water and did not develop a satisfactory minimum stability value.

b. Gradation No. 2 showed a maximum stability at 140°F. of 770 pounds in water and 800 pounds in air. This data indicates that there was practically no loss on this gradation due to the action of water on the compacted mix.

c. Gradation No. 3 showed a maximum stability at 140°F. of 890 pounds in water and 895 pounds in air. This data shows that there is no difference in the stability values obtained in water and air on these fine graded mixes. Also, that there was very little increase in stability over Gradation No. 2.

d. Gradations 1, 2 and 3 showed a maximum stability in water of 212 pounds, 770 and 890 pounds respectively. This data indicates that mixes containing these types of aggregates can be improved considerably by a small addition of fine sized aggregates.

23. Slag aggregates. Test results on mixes made from slag aggregates are presented in Tables 7, 8 and 9. Stability and flow tests versus bitumen per cent are illustrated graphically in Plate 4. A study of this data revealed the following:

a. Gradation No. 1 had a maximum stability at 140°F. of 539 pounds in water and 555 pounds in air. This data showed that there was no loss in stability due to the action of water on this open graded mix. Also, that mixes containing this aggregate and conforming to Gradation No. 1 had stability values considerably above the minimum satisfactory requirements of 300 pounds.

b. Gradation No. 2 showed a maximum stability at 140°F. of 900 pounds in water. Stability tests on this gradation were not conducted in air since Gradation No. 1 did not show any loss in stability due to the action of water.

c. Gradation No. 3 had a maximum stability of 967 pounds in water. Stability tests were not conducted in air on this gradation.

d. Gradations 1, 2 and 3 had maximum stabilities in water at 140°F. of 539, 900, and 967 pounds respectively. This data indicates that considerable improvement in stability may be gained by using Gradation No. 2 instead of Gradation No. 1. However, very little increase was shown in Gradation No. 3 over Gradation No. 2.

24. Limestone aggregates. Test results on mixes containing limestone aggregates are presented in Tables 10, 11 and 12. Stability and flow tests versus bitumen per cent are illustrated graphically in Plate 5. A study of this data indicated the following:

a. Gradation No. 1 showed a maximum stability at 140°F. of320 pounds in water and 420 pounds in air. This data indicates that there was considerable loss in stability due to the action of water on this open graded mix. However, this open graded mix does meet the minimum stability requirement of 300 pounds.

b. Gradation No. 2 showed a maximum stability at 140°F. of 1108 pounds in water and 1147 in air. This data demonstrated that there was no loss in stability due to the action of water on this gradation.

c. Gradation No. 3 showed a maximum stability at 140°F. of 1365 pounds in water and 1360 in air. This data demonstrates that there was no loss in stability due to the action of water on this gradation.

d. Gradations 1, 2 and 3 showed a maximum stability at 140°F. in water of 320, 1108 and 1365 pounds respectively. These stability values demonstrate the effect of gradation on stability. It should be pointed out that Gradation No. 1 showed approximately one-third as high stability as Gradation No. 2 and one-fourth as high as Gradation No. 3

Flow value and bitumen content

25. Flow values recorded in this report are expressed

in 1/32 of an inch. Bituminous concrete mixes are considered satisfactory when their flow values range from 4 to 8. However, flow value ranging from 4 to 6 is recommended for pavements carrying extremely heavy traffic.

26. River gravel and sand aggregate. Data on flow value and bitumen per cent on mixes containing these aggregates are presented in Tables 1, 2 and 3. Flow value versus bitumen per cent is illustrated graphically in Plate 2. A study of this data indicates the following:

a. Gradation No. 1 showed satisfactory flow values for both 5 and 6% bitumen. The stability values obtained on this gradation indicate that the optimum asphalt content should be 5%.

b. Gradation No. 2 showed a satisfactory flow value for 6% bitumen only. The optimum content indicated by stability tests for this gradation was also 6%.

c. Gradation No. 3 had a satisfactory flow value for mixes containing 5 and 6% bitumen. The optimum asphalt content indicated by stability tests was 6%. Considering both flow values and stability tests this data would indicate that 6% bitumen should be used for pavements carrying heavy traffic and 7% bitumen for pavements subjected to light traffic only.

27. Limestone and river sand aggregates. Data on flow value and per cent bitumen on mixes containing these gradations is presented in Tables 4, 5 and 6. Flow value versus per cent bitumen is illustrated graphically in Plate 3. A study of this data indicated the following:

a. Gradation No. 1 showed satisfactory flow values for 4, 5 and 6 per cent bitumen. This data indicates that mixes containing these aggregates are not very sensitive to flow value. The stability values obtained on this mix indicate that the optimum asphalt content was 5%.

b. Gradation No. 2 showed satisfactory flow values for 5, 6 and 7% bitumen. It should be noted that 7% bitumen had a flow value of 7, which is near the maximum, and the 8% bitumen content was considerably above the maximum. Stability values indicated an optimum asphalt content of 7%. A study of both flow values and stabilities would indicate that 6% should be used for pavements carrying heavy traffic and 7% for pavements subjected to light traffic.

c. Gradation No. 3 showed satisfactory flow values for 6, 7 and 8% bitumen. However the 6 and 8% bitumen contents showed flow values on the minimum and maximum respectively. Stability values obtained on these mixes indicated an optimum asphalt content of 7%.

28. Slag aggregate. Data on flow value and per cent bitumen on mixes containing slag aggregate are presented in Tables 7, 8 and 9. Flow values versus per cent bitumen is illustrated graphically in Plate 4.

a. Gradation No. 1 had satisfactory flow values for 6, 7, 8 and 9% bitumen, which indicates that this aggregate and gradation is not very sensitive to bitumen content. The stability values also indicated the same.

b. Gradation No. 2 showed satisfactory flow values for 7, 8, 9 and 10% bitumen. Flow value and stabilities indicated that this aggregate and gradation are not sensitive to bitumen content.

c. Gradation No. 3 showed satisfactory flow values for 7, 8, 9 and 10 per cent bitumen. The data on flow values and stability indicated that this aggregate and gradation was not sensitive to a change in bitumen content.

29. Limestone aggregate data. Data on flow value and bitumen content on mixes containing limestone aggregate are presented in Tables 10, 11 and 12. Flow value versus per cent bitumen is illustrated graphically in Plate 5. A study of this data indicated the following:

a. Gradation No. 1 showed satisfactory flow values for 5 and 6% bitumen. Stability values obtained on this same mix indicated that the optimum asphalt content was 5%.

b. Gradation No. 2 showed satisfactory flow values for 6 and 7% bitumen. Stability values indicated that the optimum asphalt content for these same mixes was 8%. However, the flow value on this per cent of bitumen is on the maximum, and by considering stability and flow values together the optimum asphalt content of 7% would be selected for this aggregate and gradation.

c. Gradation No. 3 showed satisfactory flow values for 6 and 7% bitumen. Stability values obtained on this same mix indicate an optimum asphalt content of 7%.

Permeability and voids

30. Permeability. Data on water permeability for all aggregate combinations and bitumen contents are presented in Tables 1 to 12, inclusive. Permeability versus bitumen content is illustrated graphically in Plate 6, for all aggregate combinations. This data revealed the following:

a. Gradation No. 1 showed water permeabilities in excess of 30 pounds per 24 hours for all aggregate combinations. This data indicated that Gradation No. 1 would not be satisfactory from the standpoint of water permeability unless an excess bitumen content was used.

b. Gradation No. 2 showed a satisfactory water permeability for a 24 hour period for all aggregates when the mix contained the optimum asphalt content. Mixes containing bitumen contents one or two per cent less than optimum were not satisfactory.

c. Gradation No. 3 showed a satisfactory water permeability for all aggregates when the mix contained the optimum asphalt content. Gradation No. 3 also showed a satisfactory water permeability for bitumen contents one or two per cent below optimum.

d. A study of the data on water permeability included in this report indicated that the gradation of the aggregate and per cent of asphalt are the two factors controlling water permeability of asphalt mixes.

31. Voids in the compacted mix. Data on voids in the compacted mix are presented in Tables 1 to 12, inclusive, for all aggregate combinations. A study of this data revealed the following:

a. Asphalt mixes containing voids in excess of 5% did not have satisfactory water permeability qualities.

b. Asphalt mixes containing less than 5% voids had satisfactory permeability qualities for all aggregate tested.

PART IV: DISCUSSION

Stability

32. All stability tests were made with the Marshall Stability Equipment. This method is a semi-confined, compression type test in which a 4-inch diameter by 2-1/2 inch thick specimen is compressed between two segments of a ring. The stability value is the total maximum load required to produce failure of the test specimen. The minimum satisfactory stability is 300 pounds. All tests were conducted at 140°F. Data on stability tests for the various commercial aggregate combinations was presented in Paragraphs 21 to 24, inclusive.

33. Data on mixes composed of river gravel and sand aggregates are presented in Tables 1, 2 and 3. Mixes containing these aggregates and conforming to Gradation No. 1

showed stability values below the minimum requirement when specimens were tested in air or water. It should be noted that a considerably higher stability was obtained in air than in water, which showed that mixes containing this aggregate lost a large part of their durability and strength due to the stripping of the asphalt from the aggregate when the mix was exposed to water. Due to this fact Gradation No. 1 would not be satisfactory for gravel and sand aggregates. The stability values obtained on Gradation No. 2 composed or river gravel and sand aggregates showed stability values of 432 pounds in water and 524 pounds in air. This indicates that there was a slight reduction in stability due to the action of water on this medium graded mix. It should be noted that the stability values obtained on Gradation No. 2 were more than double those obtained on Gradation No. 1. This data would indicate that Gradation No. 2 would make a much more durable pavement than Gradation No. 1. Mixes conforming to Gradation No. 3 and containing river gravel and sand aggregates showed stability values of 487 pounds in water and 550 pounds in air. This data indicates that there was very little loss in stability due to the action of water on this closed graded mix. It also indicates that Gradation No. 2 had stability values almost equal to those obtained on Gradation No. 3. This would indicate that mixes containing the additional fines required by Gradation No. 3 were probably not justified over Gradation No. 2 from the standpoint of increasing the stability.

34. Data on mixes composed of limestone and river sand aggregates are presented in Tables 3, 4 and 5. Mixes conforming to Gradation No. 1 showed stability values of 212 pounds in water and 320 pounds in air. This data demonstrates that mixes composed of this aggregate and conforming to the requirements of Gradation No. 1 were effected considerably by the action of water and would not conform to the minimum stability requirements, except where the pavement would not be exposed to water. Since all pavements are exposed to considerable water it is evident that this gradation is not satisfactory for use in asphalt pavements, when the aggregates are composed of limestone and river sand. Mixes composed of limestone and river sand aggregates conforming to Gradation No. 2 showed a maximum stability of 770 pounds in water and 800 pounds in air. This data indicates that there was practically no loss in stability due to the action of water on this medium graded mix. It is also evident that this gradation would be entirely satisfactory from the standpoint of stability since it is more than twice the minimum requirement. Gradation No. 3 composed of limestone and river sand aggregates had stability values of 890 pounds in water and 895 pounds in air. This data indicated that there was no loss in stability due to the action of water on this mix. A comparison of the stability values obtained on Gradation 1, 2 and 3 showed that Gradation No. 2 had stability values almost four times that of Gradation No. 1. Also that Gradation No. 3 showed slightly higher stability than Gradation

No. 2. This data indicates that mixes conforming to Gradation No. 2 would be entirely satisfactory and that the additional fines required for Gradation No. 3 are not justified from the standpoint of increasing the stability.

35. Data on mixes composed of slag aggregate are presented in Tables 7, 8 and 9. Mixes containing slag aggregate and conforming to Gradation No. 1 showed maximum stability values of 539 pounds in water and 555 pounds in air. This data showed that there was no loss in stability due to the action of water on this open graded mix. Also that mixes composed of slag aggregate and conforming to Gradation No. 1 have satisfactory stability values. It should be pointed out that Gradation No. 1 did not have satisfactory stability values when the mixes contained river gravel and sand aggregates, or limestone and river sand aggregates. Gradations Nos. 2 and 3 had maximum stability values of 900 and 967 pounds respectively for tests conducted in water. Stability tests were not conducted in air on Gradations 2 or 3. A study of the data indicates that there was only a slight increase in the stabilities obtained on Gradation No. 3 over those obtained on Gradation No. 2, which would indicate that the additional fines required by Gradation No. 3 are not justified from the standpoint of stability. It should be pointed out that mixes containing this aggregate are not very sensitive to changes in bitumen content which indicates that satisfactory stability values can be obtained with this aggregate when the bitumen contents vary as much as 4%.

36. Data on mixes composed of limestone aggregates are presented in Tables 10, 11 and 12. Mixes conforming to Gradation No. 1 showed a maximum stability due to the action of water on this open graded mix. However, mixes containing this aggregate and conforming to this open graded mix did meet the minimum stability requirement. It should be mentioned that this same gradation containing slag aggregate showed stability values of 539 pounds, while the stability values obtained on mixes containing river gravel and sand aggregates, or limestone sand aggregates were below the minimum requirement of 300 pounds. Gradation No. 2 had a maximum stability of 1108 pounds in water and 1147 pounds in air. This data illustrates that there was very little loss in stability due to the action of water on the mixes conforming to this gradation. Gradation No. 3 had a maximum stability of 1365 pounds in water and 1360 pounds in air. These stability values showed that there was no loss in stability due to the action of water on this gradation. A comparison of the stability values obtained on Gradations Nos. 1, 2 and 3 will show that Gradation No. 2 had stability values three times as great as Gradation No. 1. Gradation No. 4 had stability values approximately four times greater than Gradation No. 1.

37. A comparison of the stability values obtained on the various aggregate combinations will show that the river gravel and sand aggregates had the lowest stability values, and that the limestone and river sand aggregates were second, slag

aggregates third, and the limestone aggregates showed much higher stability values than any of the other aggregates used.

Flow Value

38. The flow meter measures the amount of deflection that takes place in the specimen to the point of failure. Flow values are expressed in units of 1/32 of an inch. Mixes having flow values ranging from 4 to 8 are considered satisfactory. The main purpose of this test is for controlling the asphalt content in the field when testing mixes produced by asphalt plants. This test will indicate a slight change in gradation of the aggregate or bitumen content. In designing an asphalt pavement, stability and flow values should be each considered since the asphalt mix may have a satisfactory stability value, but have an asphalt content below the maximum required for durability. This would be indicated by flow values of 4 or less. The mixes may also contain an excess of asphalt which would be indicated by flow values above 8.

Bitumen Content

39. The optimum asphalt content for any gradation or type of aggregate may be selected by making a number of test specimens containing a range of asphalt contents. The maximum stability value obtained is selected as the optimum asphalt content providing the flow values are within the range that is considered satisfactory. Plates 2 to 5, inclusive, indicate

that gradation of the aggregate and types of aggregate are the two principal factors effecting bitumen content.

Water Permeability

40. Permeability tests were run on compacted specimens four inches in diameter and two and one-half inches in thickness. These samples were placed in a metal funnel and sealed around the sides with paraffin wax so that water could only flow through the top four inch diameter. The permeability was recorded in pounds for a 24 hour period. Data on permeability for all aggregate combinations used in this investigation are presented in Tables 1 to 12, inclusive. This data is illustrated graphically in Plate 6 for Gradations Nos. 1 and 2. Gradation No. 3 showed zero permeability at optimum asphalt content for all aggregate combinations included in this series of tests. A study of this data indicated that Gradation No. 1 was not satisfactory for any of the aggregates used since it had a water permeability in excess of 30 pounds, except where the bitumen contents were in excess of optimum. Gradation No. 2 showed a satisfactory water permeability for all aggregate combinations at optimum asphalt content. This grading was not satisfactory when the asphalt content was 1 or 2 per cent below optimum. Gradation No. 3 also showed a satisfactory water permeability at optimum asphalt content for all the aggregate combinations used. Most of the aggregates

had satisfactory permeabilities when the content was 1 or 2 per cent below optimum. It should be pointed out that gradation of the aggregate and the per cent of asphalt are the two principal factors controlling water permeability.

Voids in the Compacted Mix

41. Voids in the compacted mix were calculated by dividing the actual bulk specific gravity of the compacted specimens by the theoretical solid volume specific gravity of compacted specimen which gives the per cent of solid volume density. This value subtracted from 100 per cent is equal to the voids in the compacted mix. Tables 1 to 12, inclusive, present data on the voids, in the compacted mix for all aggregate combinations. A study of this data revealed that mixes containing more than 5 per cent voids had an unsatisfactory water permeability. Also mixes containing less than 5 per cent voids had satisfactory water permeability qualities.

The Effect of Temperature on Compaction

42. Data on the effect of temperature on compaction is not included in this report, but through observations of the behavior of the various mixes it is believed that the following will apply. Mixes composed of river gravel and sand aggregate compacted to a greater density when the temperature of the mix was around 220°F. Mixes containing limestone and river sand aggregates compacted to the greatest density when the

temperature of the mixes was approximately 240°F. Mixes composed of slag or limestone aggregate compacted to greatest density when the temperature of the mixes was between 260 and 270°F.

Laboratory and Field Densities

43. One of the purposes of this investigation was to establish a correlation between laboratory and field densities. Sufficient work has not been completed on this part of the program to warrant its inclusion in this report. From the limited amount of work completed so far the densities obtained in the field under standard roller practices are about 95 per cent of those obtained by the laboratory method of compaction.

PART V: CONCLUSIONS

44. From the data presented in this report the following conclusions were made.

a. The correct bitumen content for any specified aggregate gradation may be determined by stability and flow tests.

b. The best aggregate gradation may be selected by stability tests.

c. By conducting stability tests in air and water the best aggregate combination and gradation may be selected to resist the action of water on the pavement.

d. Gradation No. 1 was not satisfactory from the standpoint of water permeability or stability when the aggregates in the mix were composed of river gravel and sand, or limestone and sand.

e. Gradation No. 1 had a satisfactory stability when the aggregates in the mix were composed of slag or limestone.

f. Gradations Nos. 2 and 3 had satisfactory stabilities and water permeabilities for all aggregates used in this investigation.

g. Gradation No. 3 did not show a sufficient increase in stability over Gradation No. 2 to justify the extra cost of the additional fine sizes.

h. Asphalt mixes containing more than 5 per cent voids had unsatisfactory water permeabilities.

i. Asphalt mixes containing less than 5 per cent voids had satisfactory water permeabilities.

j. When asphalt mixes were composed of limestone or slag aggregates and subjected to the action of water no loss in strength or stability was obtained.

k. When asphalt mixes were composed of river gravel and sand or limestone and sand aggregates, and subjected to the action of water considerable loss in strength or stability was obtained.

TABLES

TABLE I
River Gravel and Sand Aggregate Data
Gradation No. 1

Tests on Compacted Mix		Per Cent Bitumen 4	5	6	7
Stability in Pounds 140°F. in Water		60	95	145	70
		60	85	120	80
		60	105	120	90
		55	115	110	70
	Ave.	60	100	125	78
Stability in Pounds 140°F. in Air		125	230	145	100
		115	220	160	90
		135	240	120	80
		125	235	140	90
	Ave.	125	230	140	90
Flow Value 1/32 inch		4	4	6	9
		4	5	6	9
		4	5	7	10
		4	6	8	11
	Ave.	4	5	7	10
% Voids in Compacted Aggregate		19.8	19.3	19.2	20.2
		19.3	19.7	18.9	19.8
		19.8	20.0	18.4	19.4
		20.1	19.3	19.2	19.1
	Ave.	19.8	19.6	18.8	19.6
% Solid Volume Density		88.8	91.6	94.0	95.2
		89.3	91.2	94.4	95.7
		88.8	90.8	94.9	96.0
		88.4	91.6	94.0	96.5
	Ave.	88.8	91.2	94.3	96.1
Bulk Specific Gravity		2.15	2.18	2.20	2.20
		2.16	2.17	2.21	2.21
		2.15	2.16	2.22	2.22
		2.14	2.18	2.20	2.23
	Ave.	2.15	2.17	2.21	2.22
Theoretical Solid Volume Sp. Gr.		2.42	2.38	2.34	2.31
	Ave.	2.42	2.38	2.34	2.31
Weight in Pounds per cu. ft.		134.2	136.0	137.3	137.8
		134.8	135.4	137.9	137.9
		134.2	134.8	138.5	138.5
		133.5	136.0	137.3	139.2
	Ave.	134.1	135.4	137.9	138.5
Water Permeability Pounds in 24 hours		32.6	13.9	4.8	2.4
	Ave.	32.6	13.9	4.8	2.4
% Voids in Compacted Mix		11.2	8.4	6.0	4.8
		10.7	8.8	5.6	4.3
		11.2	9.2	5.1	3.9
		11.6	8.4	6.0	3.5
	Ave.	11.2	8.8	5.7	4.1

TABLE II
River Gravel and Sand Aggregate Data
Gradation No. 2

Tests on Compacted Mix	Per Cent Bitumen 5	6	7	8
Stability in Pounds 140°F. in Water	270	430	335	
	245	430	355	
	255	450	345	
	265	432	341	
Ave.	258	432	341	
Stability in Pounds 140°F. in Air	390	535	360	
	380	525	340	
	375	515	350	
	385	520	345	
Ave.	382	524	348	
Flow Value 1/32 inch	3	3	8	
	3	4	7	
	3	4	9	
	3	5	8	
Ave.	3	4	8	
% Voids in Compacted Aggregate	17.4	17.0	16.9	
	16.8	17.0	17.3	
	17.1	16.3	17.6	
	17.4	16.6	17.6	
Ave.	17.2	16.7	17.3	
% Solid Volume Density	93.8	96.6	99.1	
	94.5	96.6	98.7	
	94.1	97.4	98.3	
	93.8	97.0	98.3	
Ave.	94.1	96.9	98.6	
Bulk Specific Gravity	2.23	2.26	2.29	
	2.25	2.26	2.28	
	2.24	2.28	2.27	
	2.23	2.27	2.27	
Ave.	2.24	2.27	2.28	
Theoretical Solid Volume Sp. Gr.	2.38	2.34	2.31	
Ave.	2.38	2.34	2.31	
Weight in Pounds per Cu. Ft.	139.2	141.0	142.8	
	140.0	141.0	142.3	
	139.8	142.2	141.6	
	139.2	141.6	141.6	
Ave.	139.5	141.5	142.1	
Water Permeability Pounds in 24 hours	1.8	0.0	0.0	
Ave.	1.8	0.0	0.0	
% Voids in Compacted Mix	6.2	3.4	0.9	
	5.5	3.4	1.3	
	5.9	2.6	1.7	
	6.2	3.0	1.7	
Ave.	5.9	3.0	1.3	

TABLE III
River Gravel and Sand Aggregate Data
Gradation No. 3

Tests on Compacted		Per Cent Bitumen			
		5	6	7	8
Stability in Pounds 140°F. in Water		280	485	385	140
		230	465	395	150
		255	505	380	135
		265	495	390	130
	Ave.	257	487	385	138
Stability in Pounds 140°F. in Air		315	545	410	140
		350	555	420	145
		330	560	415	135
		340	540	425	155
	Ave.	333	550	417	143
Flow Value 1/32 inch		4	5	5	11
		3	5	7	13
		5	5	6	12
		4	5	6	12
	Ave.	4	5	6	12
% Voids in Compacted Aggregate		16.7	15.5	17.3	18.2
		16.7	15.5	16.5	18.3
		17.2	15.2	16.9	18.5
		17.5	15.8	16.9	18.5
	Ave.	17.0	15.5	16.9	18.4
% Solid Volume Density		94.6	98.3	98.7	100.0
		94.6	98.3	99.6	100.4
		94.0	98.7	99.1	99.6
		93.8	97.9	99.1	99.6
	Ave.	94.2	98.3	99.1	100.0
Bulk Specific Gravity		2.25	2.30	2.28	2.28
		2.25	2.30	2.30	2.29
		2.24	2.31	2.29	2.27
		2.23	2.29	2.29	2.27
	Ave.	2.24	2.30	2.29	2.28
Theoretical Solid Volume Sp. Gr.		2.38	2.34	2.31	2.28
	Ave.	2.38	2.34	2.31	2.28
Weight in Pounds per cu. ft.		140.0	143.5	142.3	142.3
		140.0	143.5	143.5	142.9
		139.6	144.1	142.9	141.6
		139.0	142.9	142.9	141.6
	Ave.	139.8	143.5	142.9	142.1
Water Permeability Pounds in 24 hours		0.0	0.0	0.0	0.0
	Ave.	0.0	0.0	0.0	0.0
% Voids in Compacted Mix		5.4	1.7	1.3	0.0
		5.4	1.7	0.4	0.4+
		6.0	1.3	0.9	0.4
		6.2	2.1	0.9	0.4
	Ave.	5.8	1.7	0.9	0.2

TABLE IV
Limestone and River Sand Aggregate Data
Gradation No. 1

Tests on Compacted Mix		Per Cent Bitumen 4	5	6
Stability in Pounds 140°F. in Water		145	220	170
		175	200	170
		175	200	180
		190	230	160
	Ave.	170	212	170
Stability in Pounds 140°F. in Air		260	310	250
		255	330	240
		265	315	255
		270	325	235
	Ave.	262	320	245
Flow Value 1/32 inch		4	4	5
		4	5	5
		4	4	6
		4	4	5
	Ave.	4	4	5
% Voids in Compacted Aggregate		21.9	21.2	21.5
		21.2	21.5	22.2
		21.6	21.9	21.8
		21.6	21.5	21.8
	Ave.	21.6	21.5	21.8
% Solid Volume Density		86.5	89.6	91.6
		87.3	89.2	90.8
		86.9	88.8	91.2
		86.9	89.2	91.2
	Ave.	86.9	89.2	91.2
Bulk Specific Gravity		2.11	2.16	2.18
		2.13	2.15	2.16
		2.12	2.14	2.17
		2.12	2.15	2.17
	Ave.	2.12	2.15	2.17
Theoretical Solid Volume Sp. Gr.		2.44	2.41	2.38
	Ave.	2.44	2.41	2.38
Weight in Pounds per Cu. Ft.		131.7	134.8	136.0
		132.9	134.2	134.8
		132.3	133.5	135.4
		132.3	134.2	135.4
	Ave.	132.3	134.2	135.4
Water Permeability Pounds in 24 hours		30.0	15.8	4.5
	Ave.	30.0	15.8	4.5
% Voids in Compacted Mix		13.5	10.4	8.4
		12.7	10.8	9.2
		13.1	11.2	8.8
		13.1	10.8	8.8
	Ave.	13.1	10.8	8.8

TABLE V
Limestone and River Sand Aggregate Data
Gradation No. 2

Tests on Compacted Mix	Per Cent Bitumen 5	6	7	8
Stability in Pounds 140°F. in Water	355	540	780	415
	335	580	760	405
	350	560	775	400
	345	580	765	420
Ave.	346	565	770	410
Stability in Pounds 140°F. in Air	410	610	765	420
	400	600	825	425
	390	590	800	410
	380	615	810	405
Ave.	395	604	800	415
Flow Value 1/32 inch	4	5	6	11
	3	5	7	12
	4	6	7	10
	4	5	8	11
Ave.	4	5	7	11
% Voids in Compacted Aggregate	17.5	17.9	18.7	19.5
	18.3	18.4	18.7	19.9
	18.0	18.4	18.4	20.2
	18.0	18.7	19.0	19.9
Ave.	18.0	18.4	18.7	19.9
% Solid Volume Density	93.9	95.9	97.5	99.1
	93.0	95.4	97.5	98.7
	93.4	95.4	97.9	98.3
	93.4	95.0	97.1	98.7
Ave.	93.4	95.4	97.5	98.7
Bulk Specific Gravity	2.29	2.31	2.32	2.33
	2.27	2.30	2.32	2.32
	2.28	2.30	2.33	2.31
	2.28	2.29	2.31	2.32
Ave.	2.28	2.30	2.32	2.32
Theoretical Solid Volume Sp. Gr.	2.44	2.41	2.38	2.35
Ave.	2.44	2.41	2.38	2.35
Weight in Pounds per Cu. Ft.	142.9	144.1	144.8	145.6
	141.6	143.5	144.8	144.8
	142.3	143.5	145.4	144.1
	142.3	142.9	144.1	144.8
Ave.	142.3	143.5	144.8	144.8
Water Permeability Pounds in 24 hours	1.8	0.0	0.0	0.0
Ave.	1.8	0.0	0.0	0.0
% Voids in Compacted Mix	6.1	4.1	2.5	0.9
	7.0	4.6	2.5	1.3
	6.6	4.6	2.1	1.7
	6.6	5.0	2.9	1.3
Ave.	6.6	4.6	2.5	1.3

TABLE VI
Limestone and River Sand Aggregate Data
Gradation No. 3

Tests on Compacted Mix		Per Cent Bitumen 6	7	8	9
Stability in Pounds 140°F. in Water		525	885	605	380
		575	910	650	360
		560	880	680	400
		540	890	640	410
	Ave.	550	890	644	387
Stability in Pounds 140°F. in Air		580	905	625	415
		560	870	650	425
		600	890	660	390
		540	915	675	370
	Ave.	570	895	655	400
Flow Value 1/32 inch		4	6	8	13
		4	5	8	14
		4	7	9	12
		4	5	7	10
	Ave.	4	6	8	12
% Voids in Compacted Aggregate		16.5	16.9	19.0	21.0
		16.5	17.6	19.4	21.4
		16.1	17.2	19.7	21.0
		16.8	17.2	19.0	20.7
	Ave.	16.5	17.2	19.4	21.0
% Solid Volume Density		97.5	99.6	99.6	99.6
		97.5	98.7	99.1	99.1
		97.9	99.2	98.7	99.6
		97.1	99.2	99.6	100.0
	Ave.	97.5	99.2	99.1	99.6
Bulk Specific Gravity		2.33	2.35	2.32	2.29
		2.33	2.33	2.31	2.28
		2.34	2.34	2.30	2.29
		2.32	2.34	2.32	2.30
	Ave.	2.33	2.34	2.31	2.29
Theoretical Solid V olume Sp. Gr.		2.39	2.36	2.33	2.30
	Ave.	2.39	2.36	2.33	2.30
Weight in Pounds per Cu. Ft.		145.4	146.6	144.8	142.9
		145.4	145.4	144.1	142.3
		146.0	146.0	143.5	142.9
		144.8	146.0	144.8	143.5
	Ave.	145.4	146.0	144.1	142.9
Water Permeability Pounds in 24 hours		0.0	0.0	0.0	0.0
	Ave.	0.0	0.0	0.0	0.0
% Voids in Compacted Mix		2.5	0.4	0.4	0.4
		2.5	1.3	0.9	0.9
		2.1	0.8	1.3	0.4
		2.9	0.8	0.4	0.0
	Ave.	2.5	0.8	0.9	0.4

TABLE VII
Slag Aggregate Data
Gradation No. 1

Tests on Compacted Mix	Per Cent Bitumen			
	6	7	8	9
Stability in Pounds 140°F. in Water	370	460	535	490
	370	470	550	470
	400	480	510	460
	380	490	560	440
Ave.	380	475	539	465
Stability in Pounds 140°F. in Air	390	460	570	365
	355	480	550	360
	410	450	540	390
	430	440	560	375
Ave.	396	456	555	372
Flow Value 1/32 inch	4	5	5	6
	4	5	5	7
	4	6	5	7
	4	5	6	7
Ave.	4	5	5	7
% Voids in Compacted Aggregate	21.1	21.0	21.4	21.7
	21.5	21.5	22.2	22.6
	21.1	21.5	21.8	22.2
	20.8	21.9	21.8	22.2
Ave.	21.1	21.5	21.8	22.2
% Solid Volume Density	90.9	93.1	94.8	96.6
	90.4	92.6	93.9	95.7
	90.9	92.6	94.4	96.2
	91.3	92.1	94.4	96.2
Ave.	90.9	92.6	94.4	96.2
Bulk Specific Gravity	2.00	2.02	2.03	2.05
	1.99	2.01	2.01	2.03
	2.00	2.01	2.02	2.04
	2.01	2.00	2.02	2.04
Ave.	2.00	2.01	2.02	2.04
Theoretical Solid Volume Sp. Gr.	2.20	2.17	2.14	2.12
Ave.	2.20	2.17	2.14	2.12
Weight in Pounds per Cu. Ft.	124.8	126.0	126.7	127.9
	124.2	125.4	125.4	126.7
	124.8	125.4	126.0	127.3
	125.4	124.8	126.0	127.3
Ave.	124.8	125.4	126.0	127.3
Water Permeability Pounds in 24 hours	33.3	15.7	7.3	2.1
Ave.	33.3	15.7	7.3	2.1
% Voids in Compacted Mix	9.1	6.9	5.2	3.3
	9.6	7.4	6.1	4.3
	9.1	7.4	5.6	3.8
	8.7	7.9	5.6	3.8
Ave.	9.1	7.4	5.6	3.8

TABLE VIII
Slag Aggregate Data
Gradation No. 2

Tests on Compacted Mix	Per Cent Bitumen			
	7	8	9	10
Stability in Pounds 140°F. in Water	725	790	930	725
	640	780	820	730
	700	760	940	680
	650	740	910	660
Ave.	679	768	900	698
Stability in Pounds 140°F. in Air				
Ave.				
Flow Value 1/32 inch	5	5	6	6
	5	5	6	7
	4	5	7	7
	5	5	6	7
Ave.	5	5	6	7
% Voids in Compacted Aggregate	21.5	20.6	21.4	21.8
	21.5	21.0	21.0	21.4
	21.0	21.0	21.0	21.4
	21.9	21.4	20.6	21.0
Ave.	21.5	21.0	21.0	21.4
% Solid Volume Density	92.6	95.8	97.1	99.0
	92.6	95.3	97.6	99.5
	93.1	95.3	97.6	99.5
	92.1	94.8	97.6	100.0
Ave.	92.6	95.3	97.6	99.5
Bulk Specific Gravity	2.01	2.05	2.06	2.08
	2.01	2.04	2.07	2.09
	2.02	2.04	2.07	2.09
	2.00	2.03	2.08	2.10
Ave.	2.01	2.04	2.07	2.09
Theoretical Solid Volume Sp. Gr.	2.17	2.14	2.12	2.10
Ave.	2.17	2.14	2.12	2.10
Weight in Pounds per Cu. Ft.	125.4	127.9	128.5	129.8
	125.4	127.3	129.2	130.4
	126.0	127.3	129.2	130.4
	124.8	126.7	129.8	131.0
Ave.	125.4	127.3	129.2	130.4
Water Permeability Pounds in 24 hours	6.0	0.45	0.0	0.0
Ave	6.0	0.45	0.0	0.0
% Voids in Compacted Mix	7.4	4.2	2.9	1.0
	7.4	4.7	2.4	0.5
	6.9	4.7	2.4	0.5
	7.9	5.2	1.9	0.0
Ave.	7.4	4.7	2.4	0.5

TABLE IX
Slag Aggregate Data
Gradation No. 3

Tests on Compacted Mix		Per Cent Bitumen 7	8	9	10
Stability in Pounds 140°F. in Water		615	770	945	855
		690	880	955	865
		740	750	980	780
		720	760	990	790
	Ave.	691	790	967	822
Stability in Pounds 140°F. in Air					
Flow Value 1/32 inch		5	5	5	6
		5	5	6	5
		5	5	5	6
		4	5	5	6
	Ave.	5	5	5	6
% Voids in Compacted Aggregate		20.3	19.9	19.9	21.0
		20.0	19.9	19.5	21.0
		20.3	19.4	20.3	21.0
		20.3	20.3	19.9	21.0
	Ave.	20.3	19.9	19.9	21.0
% Solid Volume Density		94.0	96.7	99.0	100.0
		94.4	96.7	99.5	100.0
		94.0	97.2	98.5	100.0
		94.0	96.2	99.0	100.0
	Ave.	94.1	96.7	99.0	100.0
Bulk Specific Gravity		2.04	2.07	2.10	2.10
		2.05	2.07	2.11	2.10
		2.04	2.08	2.09	2.10
		2.04	2.06	2.10	2.10
	Ave.	2.04	2.07	2.10	2.10
Theoretical Solid Volume Sp. Gr.		2.17	2.14	2.12	2.10
	Ave.	2.17	2.14	2.12	2.10
Weight in Pounds per Cu. Ft.		127.3	129.2	131.0	131.0
		127.9	129.2	131.7	131.0
		127.3	129.8	130.4	131.0
		127.3	128.5	131.0	131.0
	Ave.	127.4	129.2	131.0	131.0
Water Permeability Pounds in 24 hours		1.6	0.0	0.0	0.0
	Ave.	1.6	0.0	0.0	0.0
% Voids in Compacted Mix		6.0	3.3	1.0	0.0
		5.6	3.3	0.5	0.0
		6.0	2.8	1.5	0.0
		6.0	3.8	1.0	0.0
	Ave.	5.9	3.3	1.0	0.0

TABLE X
Limestone Aggregate Data
Gradation No. 1

Tests on	Per Cent Bitumen		
Compacted Mix	4	5	6
Stability in Pounds 140°F. in Water	260	315	270
	245	335	300
	235	310	260
	240	320	280
Ave.	245	320	277
Stability in Pounds 140°F. in Air	290	410	290
	300	425	280
	320	415	300
	310	430	270
Ave.	305	420	285
Flow Value 1/32 inch	4	5	5
	4	5	6
	4	4	6
	4	6	7
Ave.	4	5	6
% Voids in Compacted Aggregate	25.1	25.1	25.1
	24.7	25.4	24.8
	25.1	25.8	24.8
	25.5	25.4	24.4
Ave.	25.1	25.4	24.8
% Solid Volume Density	83.3	85.5	87.7
	83.7	85.1	88.1
	83.3	84.7	88.1
	82.9	85.1	88.5
Ave.	83.3	85.1	88.1
Bulk Specific Gravity	2.10	2.12	2.14
	2.11	2.11	2.15
	2.10	2.10	2.15
	2.09	2.11	2.16
Ave.	2.10	2.11	2.15
Theoretical Solid Volume Sp. Gr.	2.52	2.48	2.44
Ave.	2.52	2.48	2.44
Weight in Pounds per Cu. Ft.	131.0	132.3	133.5
	131.7	131.7	134.2
	131.0	131.0	134.2
	130.4	131.7	134.8
Ave.	131.0	131.7	134.2
Water Permeability Pounds in 24 hours	34.8	15.3	4.7
Ave.	34.8	15.3	4.7
% Voids in Compacted Mix	16.7	14.5	12.3
	16.3	14.9	11.9
	16.7	15.3	11.9
	17.1	14.9	11.5
Ave.	16.7	14.9	11.9

TABLE XI
Limestone Aggregate Data
Gradation No. 2

Tests on Compacted Mix	Per Cent Bitumen			
	6	7	8	9
Stability in Pounds 140oF. in Water	825	1000	1110	690
	849	975	1100	720
	900	995	1090	725
	910	1010	1130	750
Ave.	869	995	1108	721
Stability in Pounds 140oF. in Air	950	990	1150	720
	920	940	1130	740
	900	1020	1170	710
	880	1040	1140	730
Ave.	912	997	1147	725
Flow Value 1/32 inch	5	6	8	12
	5	5	8	12
	6	6	9	13
	5	6	8	11
Ave.	5	6	8	12
% Voids in Compacted Aggregate	22.2	20.6	19.5	21.2
	22.2	21.0	19.2	20.9
	22.2	21.0	19.5	20.9
	22.0	21.3	19.5	21.2
Ave.	22.2	21.0	19.4	21.1
% Solid Volume Density	91.8	95.4	99.2	99.6
	91.8	95.0	99.6	100.0
	91.8	95.0	99.2	100.0
	91.4	94.6	99.2	99.6
Ave.	91.7	95.0	99.3	99.8
Bulk Specific Gravity	2.24	2.29	2.34	2.31
	2.24	2.28	2.35	2.32
	2.24	2.28	2.34	2.32
	2.23	2.27	2.34	2.31
Ave.	2.24	2.28	2.34	2.32
Theoretical Solid Volume Sp. Gr.	2.44	2.40	2.36	2.32
Ave.	2.44	2.40	2.36	2.32
Weight in Pounds per cu. ft.	139.8	142.9	146.0	144.1
	139.8	142.3	146.6	144.8
	139.8	142.3	146.0	144.8
	139.2	141.6	146.0	144.1
Ave.	139.7	142.3	146.1	144.4
Water Permeability Pounds in 24 hours	1.4	0.7	0.0	0.0
Ave.	1.4	0.7	0.0	0.0
% Voids in Compacted Mix	8.2	4.6	0.8	0.4
	8.2	5.0	0.4	0.0
	8.2	5.0	0.8	0.0
	8.6	5.4	0.8	0.4
Ave.	8.3	5.0	0.7	0.2

TABLE XII

Limestone Aggregate Data

Gradation No. 3

Tests on Compacted Mix		Per Cent Bitumen			
		6	7	8	9
Stability in Pounds 140°F. in Water		915 935 875 900	1370 1340 1400 1350	1030 990 975 1015	795 825 840 810
	Ave.	906	1365	1002	817
Stability in Pounds 140°F. in Air		945 895 840 820	1360 1390 1295 1400	1050 980 1000 950	810 830 880 850
	Ave.	900	1360	995	842
Flow Value 1/32 inch		6 5 6 6	6 6 5 7	8 8 7 9	13 13 11 12
	Ave.	6	6	8	12
% Voids in Compacted Aggregate		16.3 16.3 16.0 16.8	16.8 17.1 17.1 17.1	18.5 18.9 18.9 18.8	20.9 20.9 20.9 20.9
	Ave.	16.3	17.1	18.8	20.9
% Solid Volume Density		98.0 98.0 98.4 97.5	100.0 99.6 99.6 99.6	100.4 100.0 100.0 99.6	100.0 100.0 100.0 100.0
	Ave.	98.0	99.6	100.0	100.0
Bulk Specific Gravity		2.39 2.39 2.40 2.38	2.40 2.39 2.39 2.39	2.37 2.36 2.36 2.36	2.32 2.32 2.32 2.32
	Ave.	2.39	2.39	2.36	2.32
Theoretical Solid Volume Sp. Gr.		2.44	2.40	2.36	2.32
	Ave.	2.44	2.40	2.36	2.32
Weight in Pounds per cu. ft.		149.1 149.1 149.8 148.5	149.8 149.1 149.1 149.1	147.9 147.3 147.3 146.6	144.8 144.8 144.8 144.8
	Ave.	149.1	149.1	147.3	144.8
Water Permeability Pounds in 24 hours		0.0	0.0	0.0	0.0
	Ave.	0.0	0.0	0.0	0.0
% Voids in Compacted Mix		2.0 2.0 1.6 2.5	0.0 0.4 0.4 0.4	0.4 0.0 0.0 0.4	0.0 0.0 0.0 0.0
	Ave.	2.0	0.4	0.0	0.0

PLATES

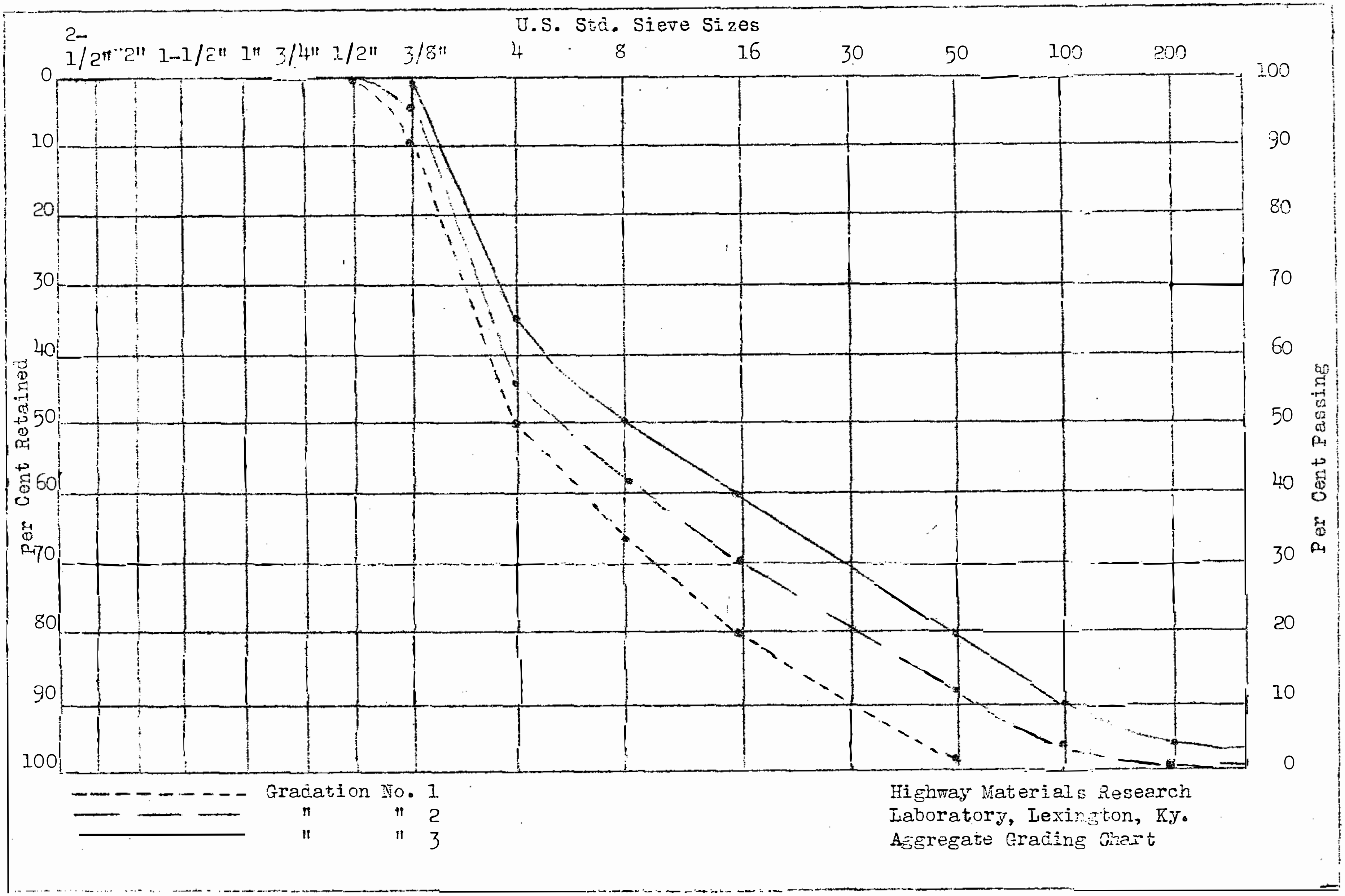
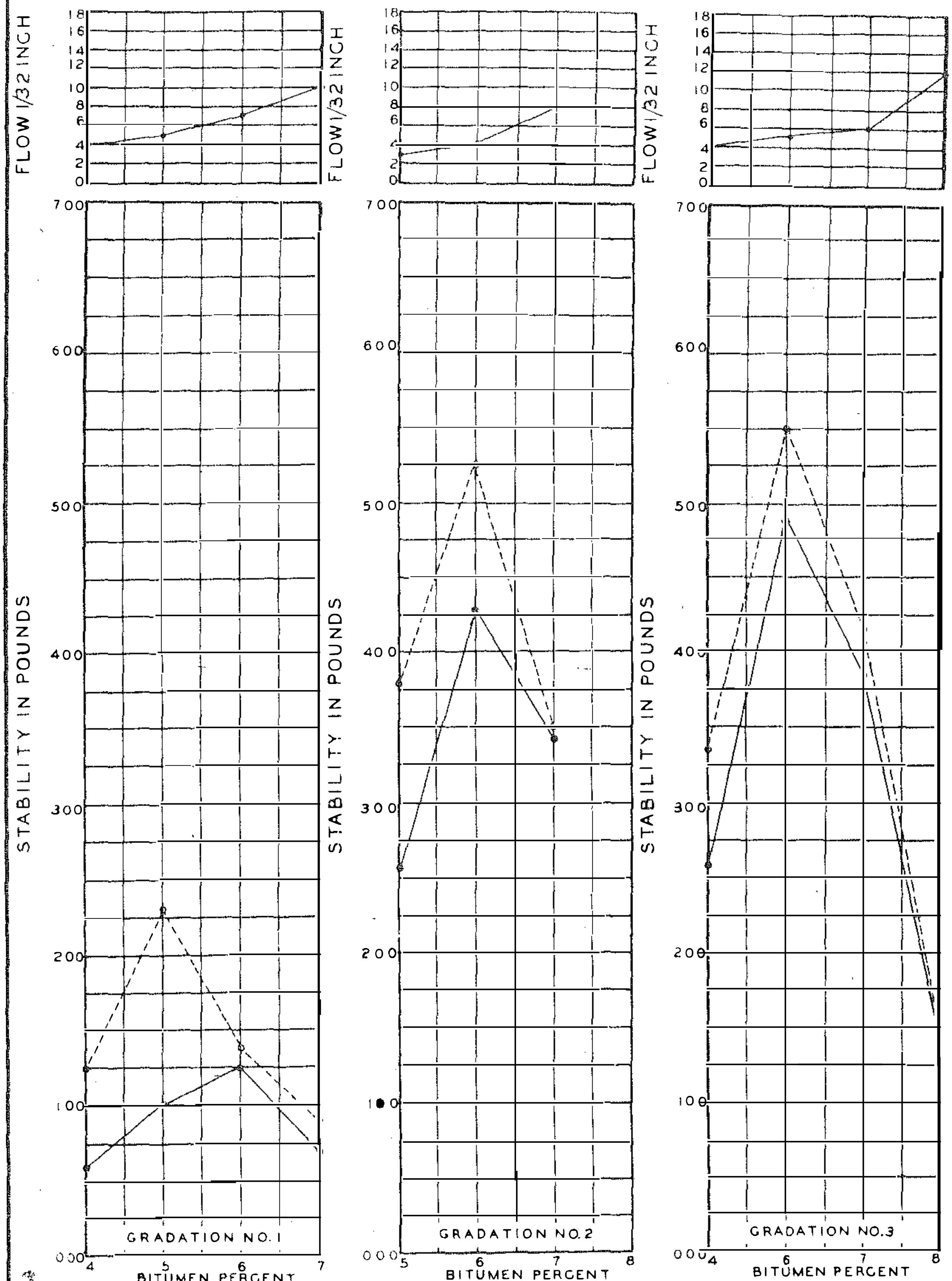
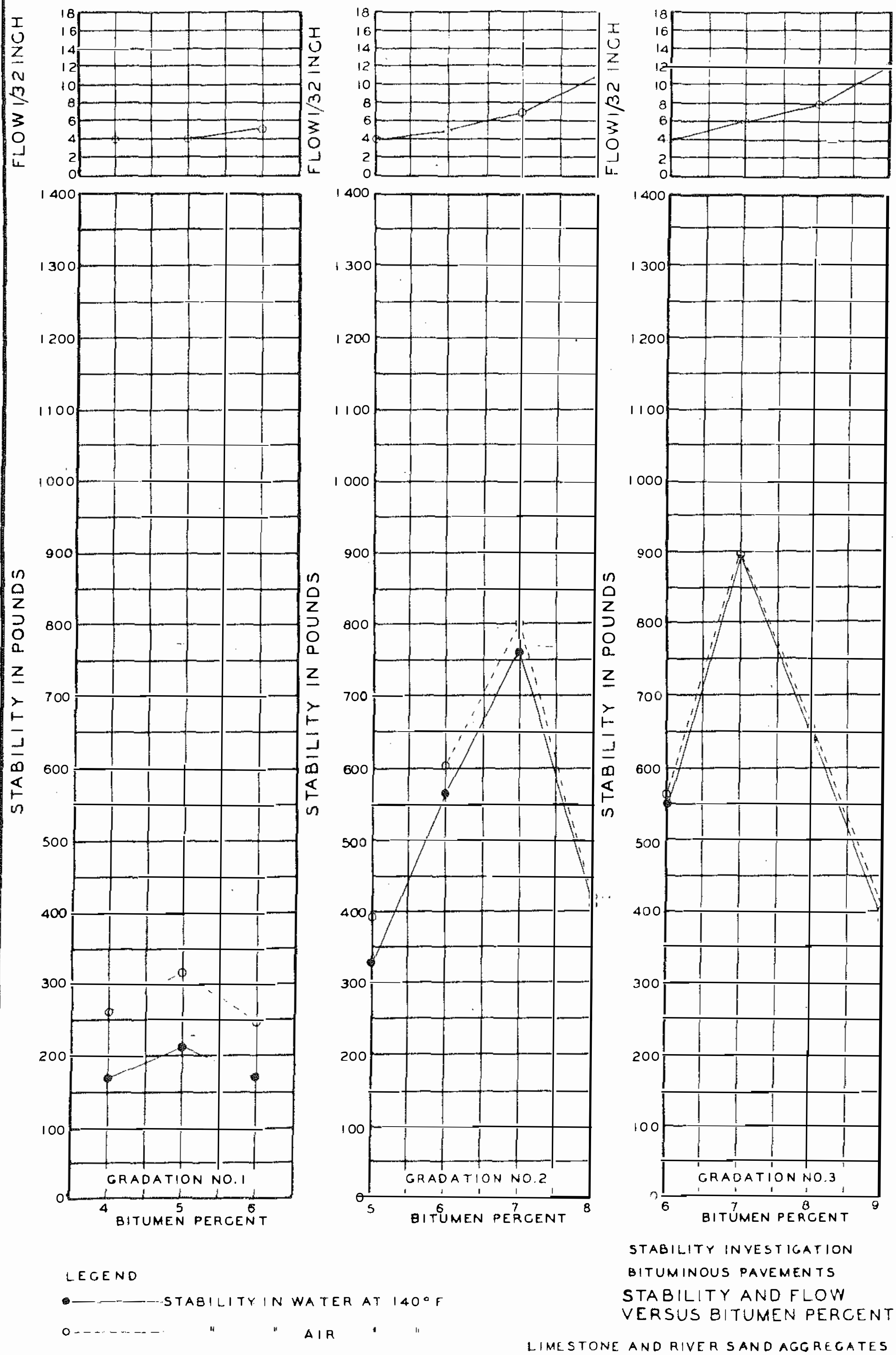

U.S. Std. Sieve Sizes
2-1/2" 2" 1-1/2" 1" 3/4" 1/2" 3/8" 4 8 16 30 50 100 200
0 10 20 30 40 50 60 70 80 90 100
Per Cent Retained
100 90 80 70 60 50 40 30 20 10 0
Per Cent Passing
Gradation No. 1
" " 2
" " 3
Highway Materials Research
Laboratory, Lexington, Ky.
Aggregate Grading Chart

Plate No. 1

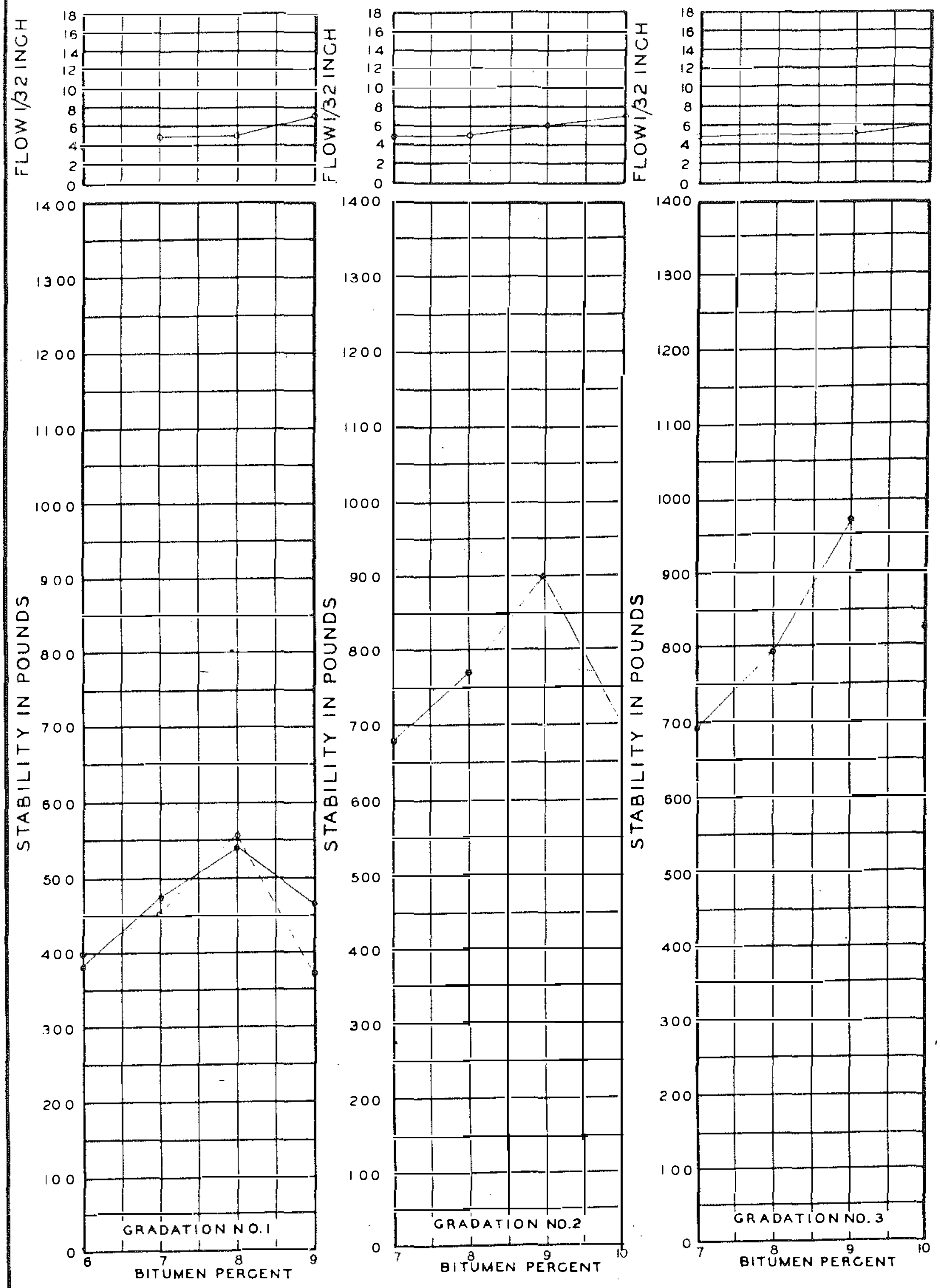


LEGEND
●——— STABILITY IN WATER AT 140°F
○- - - - - STABILITY IN AIR AT 140°F

STABILITY INVESTIGATION
BITUMINOUS PAVEMENTS
STABILITY AND FLOW
VERSUS BITUMEN PERCENT
RIVER GRAVEL AND SAND AGGREGATES



STABILITY INVESTIGATION
BITUMINOUS PAVEMENTS
STABILITY AND FLOW
VERSUS BITUMEN PERCENT
LIMESTONE AND RIVER SAND AGGREGATES



LEGEND

●———— STABILITY IN WATER AT 140°F

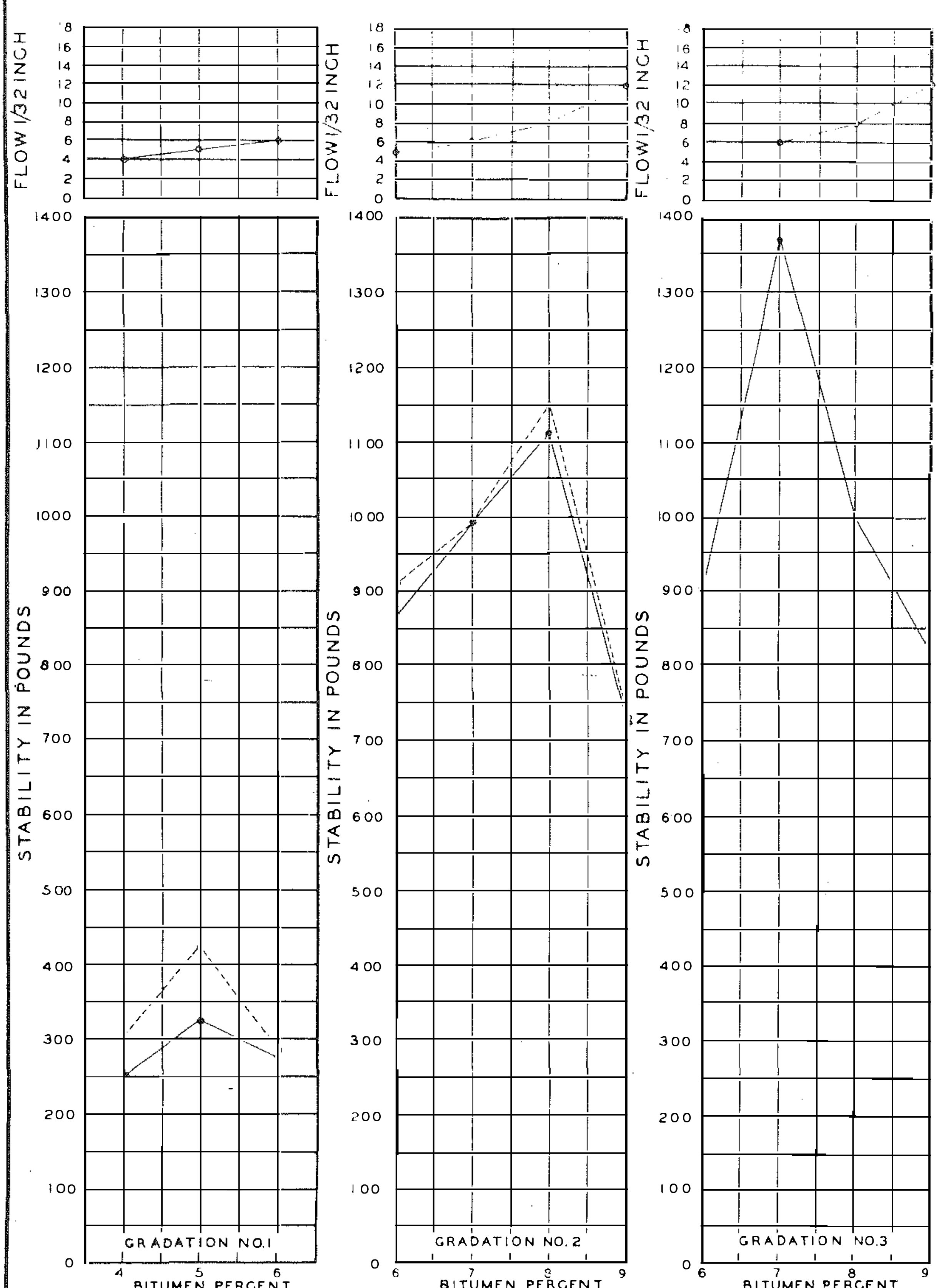
○- - - - - - " " AIR " "

STABILITY INVESTIGATION

BITUMINOUS PAVEMENTS

STABILITY AND FLOW VERSUS BITUMEN PERCENT

SLAG AGGREGATE



LEGEND

● STABILITY IN WATER AT 140°F

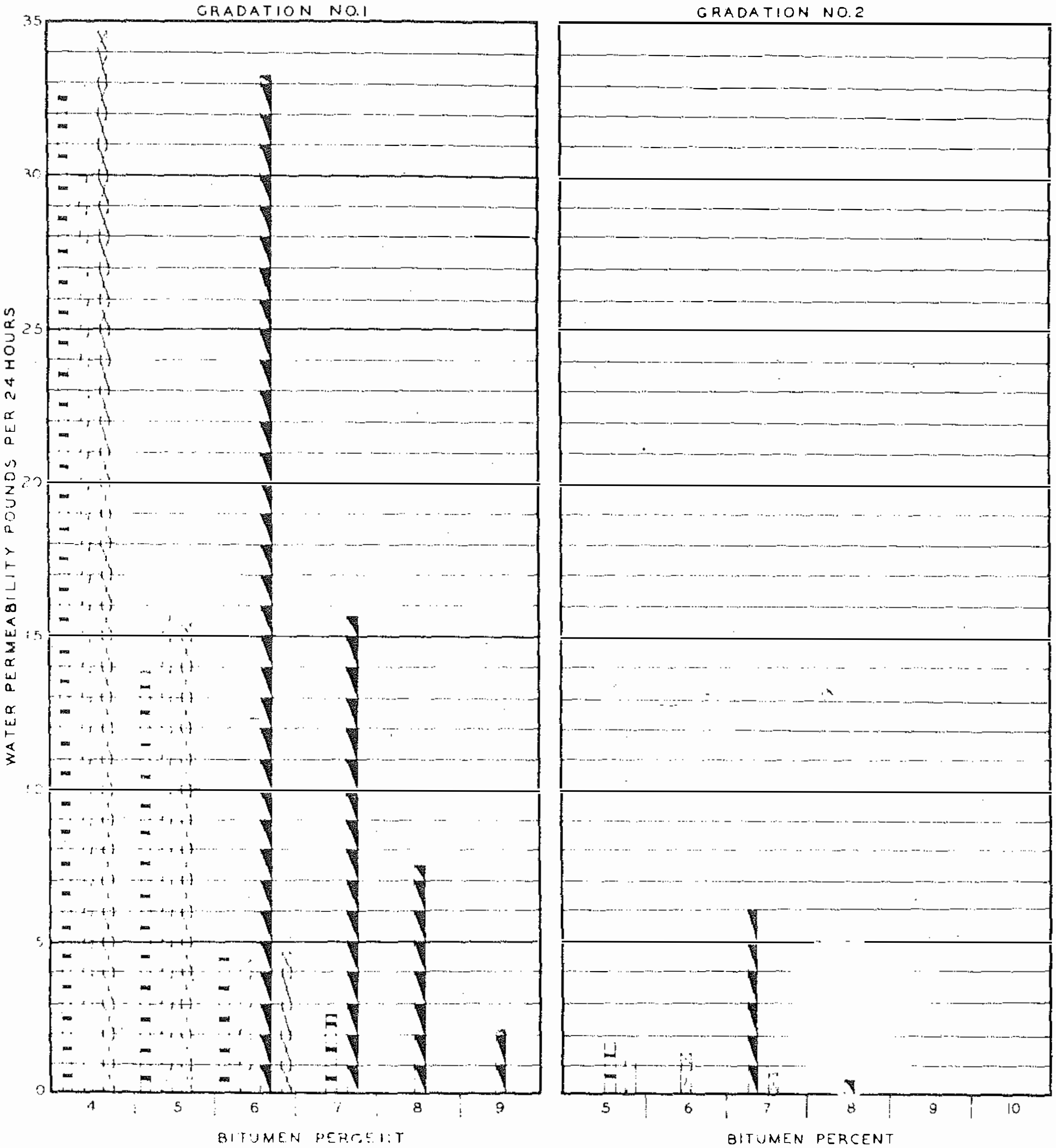
○ " " AIR " "

STABILITY INVESTIGATION

BITUMINOUS PAVEMENTS

STABILITY AND FLOW VERSUS BITUMEN PERCENT

LIMESTONE AGGREGATE



LEGEND

RIVER GRAVEL, SAND AGGREGATES

LIMESTONE & RIVER SAND "

LIMESTONE "

SLAG "

STABILITY INVESTIGATION
OF
BITUMINOUS PAVEMENTS

PERMEABILITY VERSUS
GRADATION AND BITUMEN PERCENT

Note:
Grading N° 3 showed 0.0 Permeability at optimum Asphalt on all aggregates –
Where the varios aggregate combinations are not illustrated the Permeability was 0.0 –