INTRODUCTION

GAYLE McFADDEN[1] and WALTER C. RICKETTS[2]

During the latter part of November 1940, the responsibility for design and construction of military airfields and roads was assigned to the Corps of Engiieers.

It soon became apparent for many reasons that it would be necessary (1) to select a simple testing device suitable for design and field control of asphalt pavements; (2) to correlate the results obtained by the use of the selected device with field performance for various wheel loads; (3) to establish suitable criteria for asphalt pavements; and (4) to establish the thicknesses of asphalt pavements of known quality for various wheel loads.

Among these reasons were (1) the difference in character and magnitude of wheel loads of airplanes and military vehicles as compared with highway traffic; (2) military airplanes with ever increasing wheel loads were being planned and constructed; (3) axle loads of numerous military vehicles exceeded those adopted and used in the design of public highways; (4) the usual methods employed for design and control of asphalt paving mixtures were not readily adaptable to the preparation and construction of asphalt pavements to meet the requirements in Continental United States and in theaters of operation for rapid design and field control; and (5) asphalt pavements of high quality, adequate for various wheel loads without overdesign, must be provided.

Asphalt paving mixtures were usually designed and constructed following certain criteria and specifications which had proved satisfactory over a period of time. Each engineer or designer had his own empirical design method and employed in some cases various types of testing machines to check design. In most instances there was little or no correlation between the design and field performance of the pavement under traffic and there was little experience or engineering data available in connection with very heavy wheel loads. The engineer adjusted the designed paving mixture at the start of construction based on his knowledge of materials and traffic conditions. The compaction of the pavement was often left to the judgement of the roller operator.

During World War II a different condition developed. It became necessary to expeditiously design and construct asphalt pavements for airfields and cantonment areas to carry loads far in excess of those carried by highways and city streets. Also, the methods of field control usually employed for pavement construction and plant control were not considered adequate on jobs which required the use of one or more asphalt plants producing 2500 tons or more of paving mixtures a day to meet completion dates.

A method was needed which could be stated in terms of definite procedures and criteria correlated with traffic so that asphalt pavements adequate for the design load could be consistently constructed by the field engineer.

To obtain the necessary data for establishing design procedure, pavement criteria and field control, investigation-

[1]Gayle McFadden, Chief, Airfields Branch, Engineering Division (Military Construction), Office, Chief of Engineers, Washington, D. C.

[2]Walter C. Ricketts, Runways Section, Airfields Branch, Engineering Division (Military Construction), Office, Chief of Engineers, Washington, D. C.

al projects were initiated by the Office, Chief of Engineers. While the projects were directed toward the design of airfield pavements, the results obtained are equally applicable to the design of road and street pavements, particularly those which are to be subjected to considerable traffic of heavy vehicles.

INVESTIGATIONAL PROJECTS

The two initial projects consisting of a laboratory study and field investigation were authorized in September 1943 and in April 1944, respectively. These projects were assigned to the Corps of Engineers Flexible Pavement Laboratory, located at the U. S. Waterways Experiment Station, Vicksburg, Mississippi, for accomplishment. The overall objectives of the two initial projects were:

a. To select suitable test properties, develop laboratory techniques for their measurement, and by their use establish limiting criteria for satisfactory asphalt paving mixtures to meet the requirements of traffic for aircraft and heavy military vehicles.

b. To establish stability and thickness requirements of an asphalt pavement, adequate for the operation of single wheel loads of 15,000 and 37,000 lbs., and a dual wheel load of 60,000 lbs., when placed upon base course materials that range from low to high stability.

c. To fix gradation limits for asphaltic concrete, stone filled sand asphalt, and sand asphalt mixtures.

d. To investigate types of filler and select those considered best for asphalt paving mixtures.

e. To establish criteria for limiting the amount of filler that can be included in a satisfactory asphalt paving mixture for the herein specified use.

SCOPE

The scope of the overall investigation was to:

a. Study the existing methods of asphalt pavement design and select a method requiring testing apparatus adaptable to field design and control. Incorporate the selected testing apparatus with the military field CBR test kits, utilizing all the latter equipment, if practical, conduct a comprehensive laboratory investigation of the testing apparatus and perform such correlations with other existing apparatus as considered necessary or adviseable.

b. Conduct a comprehensive laboratory study utilizing the selected apparatus. Also compare the test properties of sand asphalt and asphaltic concrete mixtures in which such items as aggregate type and gradations and amount and type of filler are variables. Conduct studies to correlate laboratory compaction of asphalt paving mixtures with densities obtained in the field at the time of construction.

c. Construct a field test section of several qualities and thicknesses of asphalt pavements including surface treatments on three qualities of base and conduct accelerated traffic tests thereon.

d. Conduct final laboratory studies and analyze the data obtained from this investigation and establish satisfactory design criteria and control procedures.

LABORATORY STUDY

The first objective to be accomplished under the laboratory study was to select or develop, if necessary, a simple and highly portable testing machine. It was particularly desirable that the selected machine could be readily adapted to the existing California Bearing Ratio Testing equipment for field use by Engineer Troops.

A testing machine, which had been used by Mr. Bruce G. Marshall during his employment with the Mississippi State Highway Department, met the desired requirements and was tentatively selected. The final selection was to be based on the ability of the machine to satisfactorily measure properties of a paving mixture when compared to an existing machine known to be suitable for the purpose. Mr. Marshall, from whom the Marshall stability machine derived its name, was employed by the Flexible Pavement Laboratory during the initial laboratory study to further any desirable developments in the machine or test procedures.

A report of a study completed in 1943 by the Tulsa District of the Corps of Engineers of various types of testing machines in connection with the stability of rock asphalts and asphaltic concrete indicated that the Hubbard-Field machine was typical of those that satisfactorily measured the pertinent properties of an asphalt paving mixture.

Comparative laboratory tests were performed on a range of asphalt paving mixtures using both the Hubbard-Field and Marshall machines. This work indicated that the Marshall machine was satisfactory. The values obtained could be used for selecting proper asphalt content and reflected variations in gradation of aggregate, character of aggregate, variations in filler content, and penetration of asphalt.

The Marshall machine has been and is being used to measure the stability and flow of the paving mixtures used in connection with all phases of the overall investigation. However, it was necessary to redesign the compaction hammer and make revisions in the procedures originally used in designing paving mixtures by this method.

FIELD INVESTIGATIONS

In 1944 a test track was constructed on a well drained site at the Waterways Experiment Station, Vicksburg, Mississippi. The objectives of the test track were as follows:

a. To compare asphalt pavement mixtures which have a wide range of physical properties but equal stability values under traffic of 15,000, 37,000, and 60,000 lb. wheel loads (60,000 lb. load on dual tires).

b. To determine the stability values of asphalt pavement satisfactory for these wheel loads.

c. To establish the minimum thickness of asphalt pavements based on a specified stability for the three wheel loads outlined above on a high quality base course.

d. To determine the thickness of asphalt pavements of known stability necessary to support the wheel loads outlined above for bases of medium and low quality.

e. To compare the behavior of surface treatment on various type base courses under the three wheel loads.

f. To determine the relationship between the optimum asphalt content as determined by the Marshall method and the optimum required by traffic compaction of the three wheel loads listed above.

An additional objective formulated during the test program was to compare the effect of hot weather and cold weather traffic.

The reason for the selection of the above wheel loads was that in 1944 three types of airfields were being constructed based on their wheel loads.

TRAFFIC TESTS

Traffic testing was initiated on the 15,000 lb. lane in May 1945 and 3500 coverages were applied as of October 1945. Tests with the 37,000 lb. single wheel load were started in September 1945. Fifteen hundred coverages were applied to the 37,000 lb. lane in 1945 and summer of 1946. Tests using dual wheels (B-29 airplane) installed in the special constructed testing device and loaded to 60,000 lbs. were started in August 1945. Fifteen hundred coverages were applied to the 60,000 lb. lane in 1945 and summer of 1946. A coverage is defined as one load application over every point in a given area.

All traffic testing was conducted when the pavement temperature was 90 F. or higher. At times temperatures as high as 140 F. were recorded and most of the testing was conducted at temperatures ranging from 100 F. to 125 F. Some limited tests were conducted at much lower temperatures for comparison with the effect of hot weather traffic.

The experience obtained from the traffic testing indicated that 1500 coverages were sufficient for the purpose of the investigation. The physical properties did not change in the unfailed pavement by the application of additional coverages and as in the case of all accelerated tests, it is impossible to evaluate the effect of weather and time.

The tracking pattern was so arranged

as to eliminate effect of repeated coverage of one wheel on the same area. The direction of the traffic was reversed at regular intervals.

Pavement cores were taken at frequent intervals during the testing for laboratory examination and an accurate record supplemented with photographs was kept of all unusual conditions that developed in the pavements.

PAVEMENT CRITERIA

Using the data obtained from the laboratory study and the accelerated traffic tests, the following criteria have been established for asphaltic concrete surface course pavements for wheel loads between 15,000 lbs. and 37,000 lbs. on single wheels and 60,000 lbs. on dual wheels with gross tire pressures between 55 and 100 lbs. per sq. in. and net pressures as high as 140 lbs. per sq. inch.

Stability minimum	500 lbs.
Flow maximum	20
Percent voids, total mix	3 to 5
Percent voids, filled with asphalt	75 to 85

The pavement thicknesses conforming with the above criteria and considered suitable based on this investigation for the wheel loads used in the traffic testing, when placed on base courses of 80 CBR values or better, are as follows:

Wheel Loads Pounds	Total Pavement Thickness-Inches	Binder Course Thickness-Inches	Surface Course Thickness-Inches
15,000	2	-	2
37,000	3	1-½	1-½
60,000 (dual wheels)	3	1-½	1-½

As definite values were secured for mixes determined to be both on the rich and lean side of the optimum asphalt content, the above criteria are considered to be entirely valid. The criteria for sand asphalt, which will be discussed in a later paper, are considered to be less valid since mixes from the turnaround sections of the test track are included in the analysis and in general the sand asphalt mixes were on the rich side of optimum asphalt content.

All binder courses in asphaltic concrete sections of the test track performed in a satisfactory manner. Criteria were not established for binder courses as the present mold is too small to properly measure mixtures containing aggregate in excess of one-inch maximum.

Flow is the only property used in the criteria established for asphaltic concrete pavements suitable for heavy wheel loads which has not been generally used in connection with evaluating an asphalt pavement. It may be generally defined as the plasticity of the compressed mixture. However, the numerical values of flow do not vary a great deal until the mixture contains an excess of asphalt. Rich mixtures have higher flow values and the limiting values of flow have been established for satisfactory surface courses based on the results of the accelerated traffic testing with various wheel loads.

DESCRIPTION OF PAPERS

The papers composing this symposium were prepared with the view of making available in condensed form investigational data obtained to date which may be useful to the engineer engaged in the design and construction of roads or streets.

No attempt has been made to present all of the supporting data used in the development of the pavement criteria and the proper application of the Marshall machine to the design and control of asphalt paving mixtures. However, the comprehensive published report entitled, "Investigation of the Design and Control of Asphalt Paving Mixtures", (*1*)[1] consisting of three volumes, which contains all data, may be obtained from the Flexible

[1] Italicized figures in parentheses refer to the list of references at the end of the paper.

Pavement Laboratory, Waterways Experiment Station, Vicksburg, Mississippi.

The purpose of this paper is to briefly (1) review the activities of the Corps of Engineers in pavement design; (2) describe how the investigation fits into the over-all picture; (3) summarize the work completed; and (4) outline plans for future work.

In Paper No. 2, the preliminary analysis made to select test apparatus is summarized and in Paper No. 3, the results of the first laboratory study are reviewed. This study developed information on how various factors affect the characteristics of a paving mixture and resulted in a feasible design and control method based on the use of indicator tests. In Paper No. 4, the construction and testing of a field test section, together with analysis of the data, are presented. The purpose of the test section was to develop the design criteria for the proposed method. Paper No. 5 presents the adjustments that were made in the laboratory test procedures to insure that specimens on which designs would be based would closely approach field conditions. The final detailed test procedures for the method are presented in Paper No. 6. Paper No. 7 shows how the method is used in the actual design and construction of a pavement and the closing paper discusses the design as related to other features of a flexible pavement.

ADDITIONAL INVESTIGATIONAL WORK

Generally as an investigation progresses many items develop which merit further work. This investigation is no exception in this respect.

The present Marshall machine and procedures are applicable for conducting tests on paving mixtures containing aggregates of one-inch maximum size or less. Laboratory and field work are in progress to develop a mold and procedures suitable for use with the present Marshall machine capable of testing mixtures containing aggregates up to 2½-inch maximum size. The larger mold will be used primarily to establish test properties of asphaltic binder and base courses suitable for heavy wheel loads.

There are many opinions as to the exact percentage of material passing the No. 200 sieve that should be used to produce the most satisfactory pavements. Experience indicates that pavements containing excessive amounts of No. 200 mesh material tend to crack with age. The need to establish the most suitable percentages of No. 200 mesh material to use in producing pavements with long life as required for military installations is apparent.

The percentage of No. 200 mesh material in a runway pavement is particularly critical as the middle third of a runway receives most of the traffic. This leaves considerable areas which do not receive the beneficial kneading of concentrated traffic and may crack if not properly designed.

Some laboratory work has been accomplished towards the development of a machine that will measure the flexibility of an asphalt pavement. It is hoped that, with data obtained by the use of a flexibility machine, the most satisfactory limits for material passing No. 200 sieve, may be definitely established.

In order to further reduce the personal equation, decrease the amount of labor, and possibly cut the time required to produce a specimen, a machine for mechanically compacting test specimens is being developed. Laboratory work to date indicates such a machine will be available for use in the near future.

Since the start of this investigation, airplanes with wheel loads up to 150,000 lbs. have been designed and constructed and tires capable of being inflated to pressures up to 300 lbs. are distinct possibilities as standard equipment for future airplanes.

It is not known at this time whether or not the pavement criteria established as a result of the work performed in connection with this investigation are suitable for use in constructing pavements to be subjected to wheel loads in excess of 60,000 lbs. on dual wheels. The results obtained on a test track constructed and tested at Stockton, California may preclude the necessity of further investigational work to establish criteria suitable for pavements subjected to very heavy wheel loads. The Stockton test track consists of sections of flexible pavements of varying thicknesses and has been subjected to the accelerated traffic of wheel loads of 150,000 lbs. and greater.

It is to be pointed out that asphalt cement has been used as the binding agent in all the work completed to date. It is considered that the methods and probably the design criteria with some modifications are also applicable to the harder grades of tar. It is contemplated that a study of hot mix tar concrete will be initiated in the near future. It is also believed that with modification of the procedures, the method can be used for the design of paving mixtures using cut-backs or other liquid types of bituminous binders.

CONCLUSIONS

It is considered that based on the data presented in this symposium, the conclusions noted below are justified:

a. The Marshall machine measures in a satisfactory manner characteristics pertinent to an asphalt pavement, reflecting changes in type of aggregate, asphalt content, penetration of asphalt, plasticity, quantity of No. 200 mesh material and gradation.

b. The design procedures permit the determination of the "optimum" asphalt content for a given mixture.

c. The Marshall machine and procedures are equally adaptable to design and field control of asphalt paving mixtures.

d. The design criteria for asphalt pavements, particularly asphaltic concrete, has been validated by traffic testing and laboratory data.

e. The thickness of asphalt pavement of known characteristics required for wheel loads up to and including 60,000 lbs. (dual wheels) on base courses of varying quality are valid as the values were established as the result of traffic tests on actual pavements.

f. The use of the highly portable Marshall machine and the development of comparatively simple procedures permits adequate asphalt pavements to be designed and field controlled in an expeditious manner, a prime requisite in connection with the construction of military installations.

Detailed procedures for the use of the Marshall machine for the design and field control of asphaltic concrete paving mixtures are now being prepared for publication in the Engineering Manual of the Corps of Engineers, Department of the Army.

ACKNOWLEDGEMENTS

The work reported in this symposium represents the combined efforts of the engineers and laboratory technicians of the Flexible Pavement Laboratory, Messrs. W. J. Turnbull and S. M. Fergus, Waterways Experiment Station and the authors of this paper.

Mr. A. L. Beller, formerly with the Flexible Pavement Laboratory, was in direct Charge of the mixture design, construction of test section and a large portion of the traffic testing.

The Engineer Board (now Engineer Research and Development Laboratories) participated in the initial laboratory work and the construction of the test section.

The following have reviewed the analysis made of the investigational data in the capacity of consultants: Professor W. J. Emmons, Messrs. H. W. Skidmore, J. L. Land, O. J. Porter, and A. H. Benedict.