ness. (In this symposium the subsection designation is combined with the section number and the combined symbol used to designate a section of the test track.)

Unit - A division of a subsection in which the aggregate gradation is uniform but the asphalt content may vary.

Item - The smallest subdivision of a test lane in which all factors are constant.

Coverage - A single wheel application over all points in a given traffic lane.

DISCUSSION

V. R. SMITH, *California Research Corporation* - The work undertaken by the Army Engineers and the data presented in this symposium, (including the reports frequently referred to) probably represents the most extensive study of asphalt paving mixtures yet undertaken. A great deal can be said concerning the merits of this work and much less concerning its faults. These comments are intended as constructive criticism in the interest of developing better methods for the design and control of asphalt paving mixtures which is the purpose of this symposium.

Selection of the Marshall Test - It was emphasized in the papers by Messrs. Mc Fadden and Ricketts and by Mr. Griffith that for military reasons a test method of utmost simplicity and portability is desired. The Marshall test meets these requirements. However, in achieving these ends the Marshall test procedure sacrifices an extremely important property; namely, it does not give due weight to the frictional resistance properties of bituminous mixes. These frictional resistance properties are fully as important as the tensile strength characteristics which are the predominant influence in the Marshall test. Messrs. McFadden and Ricketts stated "that the Hubbard-Field machine was typical of those that satisfactorily measured the pertinent properties of an asphalt paving mixture." Because the Marshall test gave good correlation with Hubbard-Field results, it was chosen as the basic laboratory tool for all subsequent studies. There is a large and rapidly growing group of highway engineers that has become convinced that the Hubbard-Field test does not measure all the "pertinent properties of an asphalt paving mixture" but instead is primarily affected by the tensile strength or cohesion properties of a mixture with frictional resistance characteristics influencing the test results to a minor degree. Other tests which fall in the same category are the unconfined compression test, the several extant punching shear tests, direct shear tests, and the Hveem Cohesiometer. All of these tests measure tensile strength (cohesion) predominantly. Although they are valuable tools in establishing the cohesive properties of a bituminous mix, they provide only limited indications of the frictional resistance properties, the latter being of paramount importance in withstanding compressive stresses.

We have all learned that any test method which has been widely used and with which we are personally experienced is a valuable tool for guiding our thinking when new and untried situations develop. On the other hand, we are inclined to allow our experience and understanding to influence the meaning of numerical test results obtained from an emperical test. Thus a given numerical test result does not always mean the same nor is it handled the same by the neophyte as by the experienced engineer. The Marshall test appears to suffer from this shortcoming as some engineers now becoming acquainted with the test are having difficulty in interpreting the test results in the light of their field experience. It is the writer's opinion that the Marshall test must be complemented by a test which measures frictional resistance properties before the former can be widely employed. Other than the fact that the Marshall test can readily handle cored specimens of any reasonable thickness, it does not offer any advantages, nor does it provide any information, which cannot be developed from a simple unconfined compression test.

Shortcomings of Marshall Test - This test does not adequately measure frictional resistance toward compressive stresses primarily because the specimen is unconfined on two sides. The test is made at a rate of strain which is excessive in that it will not indicate the true cohesive properties of a mixture subjected to static loads, which are recognized as the most severe stress conditions encountered. The fact that eight "identical" specimens are prepared for each test indicates that the test does not possess as high a degree of reproducibility or preciseness as would be desirable.

The accompanying Figure 1 illustrates the effects of asphalt content upon friction and cohesion (interlock plus tensile) properties of a typical well-graded asphaltic concrete mixture. These particular data were obtained from triaxial tests using a closed system triaxial cell. Load was applied in static increments. However, it is of special significance that the "cohesion" curve has exactly the same shape and peaks very close to the same asphalt content as do "stability" vs. asphalt content curves derived from Marshall tests, unconfined compression tests, Hubbard-Field tests and similar tests which measure predominantly the cohesive or tensile properties of a mix. It will be observed that, for this particular aggregate, at the asphalt content which is optimum for "cohesion," the frictional resistance properties of the aggregate have been seriously reduced due to lubrication by the bituminous binder. The calculated unit vertical pressures which these mixes will withstand without undergoing plastic shear deformation are shown. Whether these calculated values are correct or not, it is still significant that internal friction is often greatly reduced at the asphalt content which is optimum for "cohesion," or optimum by Marshall test, or optimum by Hubbard-Field. Thus mix design by Marshall test, Hubbard-Field, unconfined compression, or like test will often yield pavements on the "rich side" and likely will result in shoving or rutting distress.

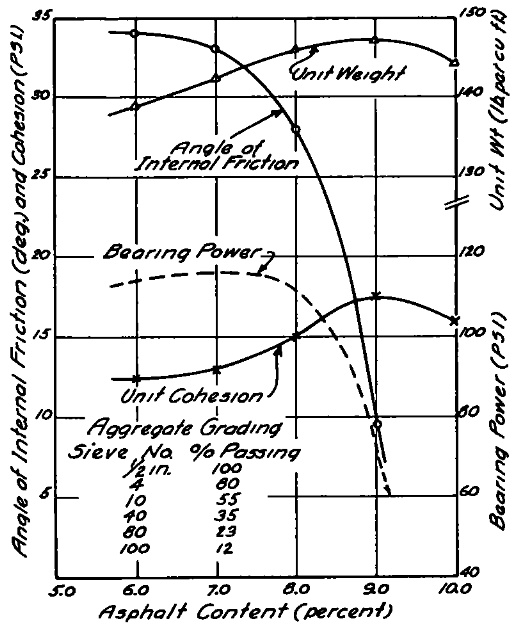

Figure A.

It has been found that certain mixes are less critical of asphalt content than the mix shown in Figure 1. In these cases, internal friction remains at a relatively high value at "optimum cohesion." In such cases maximum stability will occur at or near the Marshall optimum asphalt content. However, many mixes (particularly the dense, uncrushed, high surface area type) will be reduced in internal friction on increase of binder content even more rapidly than the mix of Figure 1. In these cases, design by Marshall Test is likely to yield a very unstable overly rich mix. The asphaltic concrete mixes employed in the field studies reported by Mr. Foster have been tested for both internal friction and "cohesion" at various asphalt contents and have been found less critical of binder content than the mix represented by Figure 1. Had "critical mixes" been included in the field studies, poorer correlation with laboratory test results would have been expected.

While frictional resistance properties are being discussed, mention should be made of the results obtained on testing road-mix asphaltic surfaces by the Marshall test or similar tests. Many road mixes made with the lighter liquid paving asphalts such as SC-2 or MC-2 fall far short of meeting the Marshall stability design criteria of 500 + discussed in Mr. Griffith's second paper of this symposium. However, these mixes are exhibiting ample load carrying capacity in many locations of severe traffic. The reason such mixes often perform so satisfactorily in spite of their low tensile strength as measured by Marshall test, Hubbard-Field, or unconfined compression test is because they possess relatively high internal friction properties. Many road oil mixtures which possess extremely low unconfined compression strength, low Marshall strength, and low Hubbard-Field strength, but which are giving completely adequate service performance have been investigated. It has been found without exception, when these mixes are tested for triaxial stability, that they possess excellent frictional resistance properties although very low in "cohesion."

A further indication that design based on Marshall test results may sometimes yield erroneous conclusions is found in Figure No. 9 of Mr. Boyd's first paper. In this figure it is shown that an aggregate with size distribution approximating aggregate number 10 shown in the same paper, Figure 5 (76 percent coarse aggregate with 3/4 inch maximum, and 24 percent minus 10 mesh with about 4 percent 200 mesh fines) possesses a very low Marshall Stability at Marshall optimum asphalt content. Yet asphaltic concrete mixes of precisely this grading were adopted in Pacific Coast shipyards and subsequently for extensive airport and highway construction in the Pacific Northwest. In the case of the "shipyard pavements," it was necessary to find asphaltic concrete mixes which would withstand unit surface loads several times greater than are applied by the heaviest aircraft in order to withstand the effects of armor plates standing on edge, and similar loads. Crushed rock (3/4 inch maximum) graded precisely according to curve No. 10, Figure 5, of Mr. Boyd's paper was found by trial and error to possess adequate stability to withstand these excessive contact pressures, yet such a mix shows a Marshall test stability of only about 250 lbs. In the "shipyard pavements" an asphalt content of about 5.1 percent is used, a mix containing about 16 percent voids results, and an asphaltic binder of 200/300 penetration or harder is satisfactory.

Mr. Boyd's first paper states, "Increased Marshall stability can be secured by using a lower penetration asphalt." This assertion is supported by Figure 11 of the same paper. The tremendous increase in Marshall stability derived by using harder asphalts (280 lbs. stability with 120 penetration binder as compared to 440 lbs. with 54 penetration binder) has not been observed in actual service within the scope of the writer's experience. Instead it has been found that a mix employing 120 penetration binder which shoved and corrugated at boulevard stops acted virtually the same when a binder of less than 50 penetration was employed. Similarly a desert sand mix which ruts when bound with SC-2 or SC-3 also ruts when bound with 200/300 penetration asphalt. The pronounced effect of asphalt grade on Marshall stability is due to the relatively high rate of strain (2 in. per minute) employed in making the test. A mix showing 500 lbs. Marshall stability will probably show less than half that stability if tested at 0.2 in. per minute. If tested at 0.002 in. per minute its stability may well be less than 20 pounds. Likewise the changes in stability resulting from changes in penetration grade of binder as illustrated in Figure 11 of Mr. Boyd's first paper will disappear to a large extent if testing is conducted at a much lower rate of strain or at near static conditions. The reason for this can be traced to the viscous nature of asphalt and/or asphalt-filler mixtures. Fifty penetration asphalt offers an exceedingly high resistance when deformed at a noticeable rate, whereas it offers virtually no resistance to deformation at extremely low rates of strain. Indeed we all have seen a chunk of 50 penetration asphalt flow out into a puddle when left at room temperature for several weeks. The rate of strain employed in the Marshall test lies between these two extremes. For this reason the resistance offered to deformation in the Marshall apparatus approximates the cohesive resistance which the mix will offer to moving wheel loads. It has little relation to the resistance which the mix will offer to static loads (parked aircraft, parked automobiles) which have been proven to represent the most severe loading condition insofar as an asphalt mixture is concerned. Therefore, good correlation between Marshall test results and service behavior of taxiways or city pavements should not be expected.

The need for using eight test specimens to assure adequately accurate test data is discussed in Mr. Griffith's second paper. The fact that such a large number of specimens of a specific mix are required indicates that the reproducibility of the test is not as high as might be desired for simplicity, economy, and expeditiousness. It is the writer's belief that this poor reproducibility is due mainly to the effects of temperature on the viscosity of the asphalt binder, and the effects of oxidation of the asphalt during preparation of the specimens. Figure 11 of Mr. Boyd's first paper shows that a reduction of several points in asphalt penetration results in a sizeable increase in Marshall stability. A difference of several points in the penetration of the asphalt binder will often result even though mixes are prepared strictly according to the very specific procedures and temperature tolerances outlined in the test method. Similarly slight differences in the actual temperature of the briquet being tested can result with changes in room temperature, use of cold testing heads as compared to testing heads that have become warm due to contact with previous specimens, etc. Any slight change in the temperature of the specimen will greatly affect the viscosity of the asphaltic binder and will be reflected in erratic stability results when testing is conducted at a high rate of strain. It is suggested that the Army Engineers further explore the effects of very low testing speeds in order to improve test reproducibility.

Army Engineers Proposed Design Criteria - In Mr. Griffith's second paper very specific design criteria are listed for establishing the suitability of a proposed paving mix. For asphaltic concrete these criteria are given as:

Marshall Stability	-	more than 500
Flow	-	less than 20
Percent Voids, Total Mix	-	3 to 5
Percent Voids filled with Asphalt	-	75 to 85

The need for a Marshall stability of over 500 to satisfactorily carry heavy aircraft or other traffic has been questioned above. Field observations have demonstrated that many road-mixes of extremely low Marshall stability or unconfined compressive strength perform quite satisfactorily because they possess high frictional resistance characteristics, a property which does not influence the Marshall test results to the proper degree.

The "flow test" introduces a new empirical measure of the plasticity characteristics of bituminous mixtures. Undoubtedly, it measures the same property as is obtained from an unconfined compression test when the percent strain at maximum load is measured. The writer has been unable to apply the results of such tests to any specific characteristic observed in the field. However, this property may be useful in wearing surface design. It will be quite interesting to determine how certain road-mixes, asphalt macadams, and high voids content mixes react to this determination.

The limitation percent voids total mix of 3 percent to 5 percent will probably be questioned in many quarters. Samples of unstable wearing-courses taken from various locations on the Pacific Coast have shown percent voids total mix of 4 percent or less. This is in substantial agreement with the Vicksburg findings that instability results at percent voids total mix of 3 percent or less. The measured voids content is subject to some variations depending upon the methods used for measuring specific gravity of the constituents and other factors. There is no apparent justification for a 5 percent maximum percent voids total mix, as many surfacing mixes having voids contents considerably in excess of 5 percent are being used today after many years' satisfactory service. Extremely high voids content mixes (above 10 percent) are likely to leak water and therefore must be used over foundations relatively unaffected by moisture or they must be provided with a seal coat. However, from a stability standpoint and from a flexibility standpoint (lack of brittleness) there is no reason for establishing 5 percent voids total mix as the maximum allowable. The brittleness characteristics of an asphaltic mixture are dependent upon the thickness of the binder films on the surfaces of the mineral particles which is only indirectly related to the voids content of the compacted mix. In support of this argument, the accompanying Table 1 is presented. The so-called "open-graded" mix of Table 1 represents a somewhat radical type of asphaltic concrete and one which might leak water if not sealed. However, from a stability standpoint this type of mix has demonstrated the ability to withstand surface stresses greatly in excess of those imposed by the heaviest aircraft. Likewise this type of mix has demonstrated the capacity to deform over 1 inch in a radius of 12 inches without visible signs of cracking or loss of soundness. Yet field specimens of this surfacing show voids contents of 16 percent or slightly more. Of course, this flexibility results from the relatively thick films of binder which can be employed with this aggregate gradation without introducing excessive lubrication. Mix No. 11 of the Vicksburg experiments represents a more "normal type" of asphaltic concrete. Comparing it with the open-graded mix of Table 1, it is apparent that on a surface area basis the binder films in the high voids content mix are 65-85 percent thicker than those of Mix No. 11. Many similar cases can be cited which substantiate the contention that 5 percent voids total mix is entirely unreasonable as a design criterion. In fact, it appears that voids content per se has little relation to the suitability of an asphaltic mixture. If this is correct, the proposed limitation of 75 percent to 85 percent voids filled with asphalt is also irrevelent.

Preparation of Marshall Test Specimens - Mr. Foster's paper emphasizes that compactive effort has a considerable influence upon the measured stability properties of an asphaltic mix. He states that "if values are to be established for the test properties, they must be made with respect to a very definite compactive effort which must be specified and used to qualify such values." This matter deserves maximum emphasis. In support of the Army Engineers' findings the data of Table 2 are presented. These data illustrate the differences in measured stability values resulting from different types of compaction. Mix A contains 7.0 percent binder and its measured stability properties are little affected by type of compaction. Mix B and Mix C, the same aggregate with 8.0 percent binder exhibit widely different stability properties depending upon the method of compaction employed. In this case, double plunger compaction gives a much higher stability at a given mix density than does the mechanical (kneading type) compaction. The reason for this difference lies in the fact that extreme pressures (2000 psi or more) must be employed in plunger compaction to achieve the densities that are obtained with a kneading action or with a roller in the field at relative low compaction pressures (200-400 psi). These extreme pressures result in puncturing of binder films between particles, films which are not punctured but continue to act as lubricants under field compaction conditions. Also these extreme pressures result in excessive fracturing of the aggregate particles. It is not known how well the impact method recommended for preparing specimens in Mr. Shockley's paper will approximate the particle orientation obtained during field rolling. However, since a compaction foot covering

TABLE A

COMPARISON OF PROPERTIES OF ASPHALTIC CONCRETE MIXES

Size Distribution	Vicksburg Mix 11	Pacific Northwest Open-Graded Mix (Shipyard Mix)
Passing 3/4 in. sieve, %	100	100
Passing 1/2 in. sieve, %	95	77
Passing 3/8 in. sieve, %	73	67
Passing No. 4 mesh sieve, %	58	40
Passing No. 10 mesh sieve, %	52	21
Passing No. 20 mesh sieve, %	46	17
Passing No. 40 mesh sieve, %	32	11
Passing No. 80 mesh sieve, %	13	6
Passing No. 200 mesh, sieve, %	6	4
Asphaltic Binder, %	5.4-6.0[a]	5.1
Voids Total mix, approximate, %	2-7	16
Approximate Surface Area, sq. ft. per lb.[b]	37.3	19.2
Thickness of Asphaltic Binder Films, microns	6.2-6.9	11.4

[a]Considered optimum range.
[b]According to California Division of Highways Method.

the entire specimen is employed, it would appear that little opportunity is provided for the aggregate particles to orient themselves as they will under rolling or kneading compaction. In other words, it is likely that some critical mixes, such as Mix B or Mix C of Table 2, will give high Marshall stabilities and yet exhibit shoving distress in service. Likewise, it would be expected that such critical mixes will yield Marshall stabilities on laboratory specimens greatly in excess of the stabilities obtained on cored specimens.

The data of Table 2 together with voluminous additional data from a variety of sources prove that density, per se, has little meaning in the design and testing of bituminous mixtures. It is the method employed in achieving density which is most important insofar as the load carrying properties of the resulting mix are concerned. This matter certainly deserves further study and such studies now are being undertaken by various interested groups.

Vicksburg Traffic Tests and Evaluations - The construction and testing of the traffic sections at Vicksburg undoubtedly represented a tremendously difficult problem because of the ramifications involved and the completeness and accuracy desired. All who have had experience in the construction and testing of field sections realize the problems involved and will praise the manner in which field tests were conducted by the Waterways Experiment Station and the thoroughness and preciseness achieved. It is difficult to assimilate and evaluate quickly all of the data presented in Mr. Foster's paper and the Waterways Experiment Station reports to which he refers. Certain test results and conclusions highlight themselves when they serve to confirm or to contradict one's experience or other laboratory or field test results. It is those conclusions which do not seem to be supported by the actual data and those which seem to contradict previous experience that are discussed below.

In order to eliminate the possibility that surface distress resulted from improper foundation support these remarks are confined to results observed on sections 1A, 1B, 1C, 2A, 2B, and 2C which consisted of asphaltic concrete mixtures placed on thick, high bearing power bases (80 + CBR) on a strong subgrade (20 CBR).

In the accompanying Table 3 pertinent data have been tabulated for Mix 12 and Mix 15 which comprised the high Marshall stability (550 lbs.) mixes composed of crushed limestone and uncrushed gravel, respectively. The data of Table 3 were copied from tables C-1, D-1, D-9, D-12, D-13, and D-14 of the Waterways Experiment Station Technical Memorandum No. 3-254, and are typical of the voluminous data which appear in this memorandum.

faint upheaval occurred. The optimum binder content for Mix 15 is reported as 5.0-5.5 percent. The behavior of this mix within this binder range parallels that of Mix 12 within its so-called optimum binder content range.

An appraisal of the suitability of these mixes for the heavy wheel loads applied, depends upon the minimum standard of quality considered essential, Most paving engineers consider that any indication of rutting, shoving, or upheaval within the surfacing mix is indicative of unsatisfactory stability and high maintenance requirements in the future. By these standards neither Mix 12 nor Mix 15 would be considered suitable for heavy aircraft loads or unlimited highway traffic. Incidentally, Mix 12 has been tested by the triaxial stability method and was found to fall somewhat below the stability requirements

TABLE B

EFFECTS OF COMPACTION PROCEDURE ON MEASURED STABILITY

Mix No [a]	Method of Compaction [b]	Asphalt Binder %	Asphalt Binder Grade	Unit Weight Total Mix lb per cu.ft	Voids Total Mix %	Stability Constants [c] ϕ	Stability Constants [c] C	Calculated Supporting Power psi
A	M C	7 0	120/150	146 7	4 6	38 3	12 1	132
	D P	7 0	120/150	146 4	4 7	39 0	14 2	160
B	M C	8 0	60/70	145 8	3 9	10 8	9 0	38
	D P	8 0	60/70	145 7	3 9	39 4	15 7	180
C	M C	8 0	200/300	146 0	3 8	21 6	12 3	72
	D P	8 0	200/300	145 2	4 0	37 4	13 0	137

[a] All mixes prepared from crushed basalt and graded according to middle of limits of Asphalt Institute Specification A-2-b

[b] M C - signifies mechanical compaction according to method presented in "Journal Asphalt Technology," January 1944 D P - signifies double plunger compaction according to Asphalt Institute Specification A-2-b

[c] According to method of test described in Asphalt Institute Specification A-2-b

It will be noted from Table 3 that the 550 Marshall stability expected for mixes 12 and 15 was achieved in most cases during construction of the test sections and this stability was obtained in all cases after traffic compaction of several hundred passes of the wheel loads. From these and other field test results the Army Engineers conclude that for Mix 12 the optimum binder content is 4.8 percent to 5.4 percent. However, it will be noted that faint or well-defined rutting and shoving occurred in many instances at binder contents of 4.8 percent. At 5.4 percent rutting and shoving was more pronounced in general, and in some cases,

employed in many areas (Asphalt Institute Specification A-2-b).

The data of Table 3 show a trend toward poorer stability as thicker asphaltic surfaces are employed. This phenomenon agrees with theoretical principles, in that a mix having insufficient shearing strength to resist imposed stresses should show greater resistance to movement when it is employed in thinner layers.

The data of Table 4 also were copied from the previously mentioned tables of Technical Memorandum 3-254. These data are typical of tests on traffic sections employing asphaltic concretes of different Marshall stabilities. It can be seen

TABLE C

SUMMARY OF VICKSBURG RESULTS WITH HIGH STABILITY ASPHALTIC CONCRETE MIXES ON HIGH SUPPORTING POWER FOUNDATION

Section	Unit	Item	Asphalt Content Wearing Surface %	Thickness (Inches) Wear Surface	Thickness (Inches) Binder Course	Marshall Stability - Lbs As Placed	Marshall Stability - Lbs At 500 ± Coverages	Service Behavior Noted
					Mix 12 - Crushed Limestone[a]			
1A	3	1	4 8	1 5	0	426-590	912-1250	Well defined tire-printing 15M lane, Faint tire-printing 60B lane
		2	5 4	1 5	0	774-1006	1062-1387	Faint rutting and shoving 37M and 60M lanes Well defined tire-printing 60M lane
		3	6 0	1 5	0	448-740	737-966	Faint rutting and shoving 15M and 60M lanes Well defined tire printing all lanes
1B	3	1	4 8	1 5	1 5	386-558	960-1257	Well defined rutting 15M lane, faint upheaval 60M lane, faint rutting and shoving 37 M lane
		2	5 4	1 5	1 5	583-802	1170-1250	Well defined rutting 15 M lane, faint rutting and shoving 37M and 60M lanes
		3	6 0	1 5	1 5	610-893	988-1160	Well defined rutting 15 M and 37M lanes, faint rutting shoving 60M lane
1C	3	1	4 8	2 0	3 0	543-733	852-1066	Well defined rutting and faint upheavel 37 M lane Faint rutting and shoving other lanes
		2	5 4	2 0	3 0	294-476	902-1342	Well defined rutting all lanes, faint upheaval 15M and 37M lanes
		3	6 0	2 0	3 0	702-834	716-1335	Well defrned rutting all lanes, faint upheaval 15M and 37M lanes
					Mix 15 - Uncrushed Gravel[b]			
2A	3	1	4 5	1 5	0	319-427	663-973	Faint rutting and shoving all lanes
		2	5 0	1 5	0	727-736	1043-1148	Well defined rutting 15M lane, faint rutting and shoving 37M lane
		3	5 5	1 5	0	466-535	866-1173	Faint rutting and shoving 37M and 60M lanes
2B	3	1	4 5	1 5	1 5	336-462	846-1162	Faint rutting and shoving all lanes
		2	5 0	1 5	1 5	484-705	693-1058	Faint rutting and shoving all lanes, well defined tire printing 15M lane
		3	5 5	1 5	1 5	652-747	982-1181	Faint rutting and shoving all lanes, well defined tire printing 15M lane
2C	3	1	4 5	2 0	3 0	302-489	737-1072	Faint rutting and shoving all lanes
		2	5 0	2 0	3.0	348-523	673-1182	Faint rutting and shoving all lanes
		3	5 5	2 0	3 0	534-670	817-1104	Well defined rutting 15M and 37M lanes with faint upheaval 25M lane Faint rutting 60M lane

[a]Designed for 550 Marshall Stability - From traffic results 4 8% - 5 4% is considered optimum binder content range
[b]Designed for 550 Marshall Stability - From traffic results 5 0% - 5 5% is considered optimum binder content range

from these data wearing surfaces of widely varying Marshall stabilities exhibited virtually the same service behaviors. In fact, in many cases the low Marshall stability mixes out-performed the high stability mixes. Certainly the minimum requirement of 500 lbs. Marshall stability cannot be justified on the basis of these results. This lack of correlation is believed by the writer to be due entirely to the fact that the Marshall test does not measure adequately the frictional resistance of bituminous mixes toward slow-moving or static compressive stresses.

Conclusions - The traffic tests conducted by the Waterways Ecperiment Station provide a wealth of information which merits detailed review by all highway engineers. Additional laboratory work should be undertaken wherein other stability tests are correlated against the results obtained in accelerated traffic tests. As the Marshall test is influenced predominately by the tensile or cohesive properties of bituminous mixtures under dynamic loading conditions, the results reported to date represent mainly a study of the effects of tensile properties upon mix performance.

At asphaltic binder contents considered optimum in the Vicksburg studies appreciable shearing distress took place in most of the surfacing mixes. These data and a few tests made on some of the mixes by

TABLE D

SUMMARY OF VICKSBURG RESULTS WITH ASPHALTIC CONCRETE MIXES OF VARIOUS MARSHALL STABILITIES ON HIGH SUPPORTING POWER FOUNDATION

Section	Unit	Item	Asphalt Content Wearing Surface	Marshall Stability As Placed	Marshall Stability At 500 ± Coverages	Service Behavior Noted
			%		Mix 10[a]	
1A	1	1	5 4	172-210	353-449	Faint tire printing
		2	6 0	203-343	462-647	Faint rutting and shoving 37M and 60M lanes
		3	6 6	361-495	738-796	Faint rutting and shoving, faint upheaval in 37M lane
					Mix 11[b]	
1A	2	1	4 8	349-447	809-887	Faint rutting and shoving 37M lane
		2	5 4	375-738	846-1019	Faint rutting and shoving 37M and 60M lanes
		3	6 0	407-603	618-1111	Faint rutting 60M lane, well-defined tire printing 15M and 60M lanes
					Mix 12[c]	
1A	3	1	4 8	426-590	912-1250	Well-defined tire printing 15M lane, faint printing 60M lane
		2	5 4	774-1006	1062-1387	Faint rutting and shoving 37M and 60M lanes, well-defined printing 60M lane
		3	6 0	448-740	737-966	Faint rutting and shoving 15M and 60M lanes, well-defined printing all lanes
					Mix 13[d]	
2A	1	1	6.0	216-259	495-570	Faint rutting and shoving 37M and 60M lanes, well-defined printing 15M lane
		2	6 8	369-415	339-707	Approximately same as above
		3	7 5	337-400	357-625	Approximately same as above
					Mix 14[e]	
2A	2	1	5 7	276-314	719-801	Faint rutting and shoving 60M lane, tire printing other lanes
		2	6 4	398-463	825-859	Faint rutting and shoving all lanes
		3	7 1	357-414	473-514	Well-defined rutting 15M lane, faint shoving with well-defined printing other lanes
					Mix 15[f]	
2A	3	1	4 5	319-427	663-973	Faint rutting and shoving all lanes
		2	5 0	727-736	1043-1148	Well-defined rutting 15M lane, faint rutting and shoving 37M lane
		3	5 5	466-535	866-1173	Faint rutting and shoving 37M and 60M lanes

[a]Mix 10 Crushed limestone - Designed for 150 Marshall Stability - Optimum Binder Range reported as 6 3-7 0
[b]Mix 11 Crushed limestone - Designed for 350 Marshall Stability - Optimum Binder Range reported as 5.4-6.0
[c]Mix 12 Crushed limestone - Designed for 550 Marshall Stability - Optimum Binder Range reported as 4 8-5.4.
[d]Mix 13 Uncrushed gravel - Designed for 150 Marshall Stability - Optimum Binder Range reported as 6 0-6.8
[e]Mix 14 Uncrushed gravel - Designed for 350 Marshall Stability - Optimum Binder Range reported as 5 7-6 4
[f]Mix 15 Uncrushed gravel - Designed for 550 Marshall Stability - Optimum Binder Range reported as 5 0-5 5

other test methods indicate that at "optimum binder content" most of the Vicksburg mixes possessed stability qualities below the standards required in many areas.

The Marshall test possesses the simplicity and portability desired for use during military operations. As it measures predominantly the tensile characteristics of a bituminous mix, it should be complemented with another test which measures the other important stress resisting factor, frictional resistance. The need for testing eight specimens to determine Marshall stability indicates that a more reproducible and precise test would be desirable. This lack of reproducibility is believed to result primarily because the test is made at an extremely high rate of strain. That is, small differences from specimen to specimen in the viscosity of the bituminous binder result in relatively large changes in the measured stability due to the nature of viscous resistance of asphalts.

The design criteria suggested by the Army Engineers do not appear to be justified on the basis of traffic test results. Likewise these criteria would eliminate as unsatisfactory many types of asphaltic paving mixes which have proven themselves suitable through many years of service.

J. T. PAULS[1]. - A tremendous amount of work has been done in this investigation. The data presented indicates the usefulness of the Marshall stability test as a tool in the design of bituminous mixtures. This test, unlike other stability tests in current use, provides direct information on the plastic properties of such mixtures. The same type of information, of course, is obtainable from the simple compression test when load-deformation curves are plotted.

The principal consideration leading to the selection of this particular test method was the portability of the test equipment required and its adaptability in conjunction with bearing test apparatus which has been adopted by the Army for field testing by advance engineer units. The weight of this consideration in connection with this special military problem is no doubt important. In most civilian highway work, however, design of bituminous mixtures is done in a central laboratory considerably in advance of the construction. Once the job formula has been established, frequent checkups by the plant inspector on aggregate gradation and asphalt proportioning are believed to be the most effective means of insuring uniform agreement with the design.

The Marshall test, like the compression test, the Hubbard-Field test, and the Hveem stability test is an empirical test, and like the others mentioned it measures cohesion and to some extent internal friction. Although these tests do not permit separate evaluation of these two forces, the test results reflect the influences of both forces in varying degrees. The influence of friction on the test values obtained by either the Hubbard-Field test or the Hveem stability test is probably greater than those obtained by the compression test or the Marshall test. In the two latter tests the principal force acting to resist displacement is cohesion.

[1]Principal Highway Engineer, Division of Physical Research, Public Roads Administration.

The importance of stability is recognized. Stability test provides valuable information on such factors as grading, bitumen content, and density. At the same time stability should not be considered the sole element of design. There are many other important factors that effect the durability and surface characteristics of bituminous highway pavements not brought out by determining the stability alone. For example the resistance of the pavement to the action of moisture might be of vital importance. Improvement of this resistance might necessitate the use of a particularly dense mixture, the use of aggregate of small particle size resulting in reduced pore size in the compacted pavement, the selection of a particular type of filler, or the elimination from consideration of certain aggregates because of their hydrophilic properties.

The hardness and toughness of the coarse aggregate is another important factor affecting the behavior of a bituminous pavement that is not brought out by a test for stability. Aggregate degradation under rolling and later under traffic may alter the particle size and gradation to such an extent that failure of the pavement due to revelling, bleeding, or instability results.

The durability of an asphaltic pavement is also greatly affected by the ability of the binder to resist alteration of its physical and chemical characteristics caused by exposure to air and sunlight. Depending on source and refining processes, asphalts differ considerably in this respect. Stability tests made on a mixture at the time of construction fail to provide reliable indication of the service behavior of some of the bituminous binders, due to their tendency to harden rapidly. When such materials must be used, bitumen contents somewhat higher than are indicated by stability tests may be selected, with a view to retarding the effects of the aging process by providing greater film thickness.

Much work has been done recently to develop a test to differentiate asphalts with respect to their resistance to alteration with age. The thin film oven test and the Hveem weathering test are noteworthy results of this work and are recognized as having considerable value.

In conclusion, necessarily hasty examination of the data lead to the following observations.

1. The apparent sensitiviey of the Marshall stability test to such variables as bitumen content, density, type of aggregate, grading, etc. demonstrates its usefulness as a tool for designing bituminous mixtures with respect to the property of stability.
2. Substantially all of these papers emphasize the property of stability, to the exclusion of other equally essential properties.
3. The tentative design limits suggested in the papers were based on correlation with accelerated test tracks. The essential difference between the effects induced by the intensive test conditions and those obtained in normal service should be borne in mind in evaluating these limits.

HARRY M. REX[1]. - The greater part of this symposium is devoted to the development of design procedure for bituminous wearing course mixtures based on the use of the Marshall stability test, and to the correlation of tentative design limits with results obtained on test sections subjected to accelerated traffic effects. The value of any laboratory method for testing bituminous mixtures rests on

testing bituminous mixtures rests on its ability to predict the service behavior of such mixtures, and in the present instance the decision to use accelerated field tests to furnish data that would allow selection of laboratory test values in the design procedure in the shortest time possible is wholly understandable.

A consideration tending to qualify somewhat the findings of investigations of bituminous mixtures based on accelerated traffic tests is, of course, the time element. The binder in a bituminous wearing course is in its most plastic condition at the time of construction. Thereafter, throughout its service life, aging of the pavement is accompanied by gradual alteration of the bitumen, evidenced by decreasing penetration and ductility. As the viscosity of the binder increases, the resistance to consolidation under traffic increases. It is conceivable, then, that the degree of consolidation noted for some of the mixtures in the test sections might never obtain in actual service, where repeated loadings might be spread out over relatively long periods of time, during which the bituminous cement would be becoming less plastic and the wearing course becoming progressively more resistant to compaction. Many of the mixtures that were designated as "plastic" or "border plastic" under the test conditions might therefore, under actual service conditions, prove to be entirely satisfactory and in some cases superior to those rated as "satisfactory."

Likewise, this consideration should, and doubtless will, be taken into account in making final selection of certain details in the laboratory compaction procedure. Density correlation between laboratory specimens and samples taken periodically from actual service installations will probably be found to be more significant than correlation based on samples from accelerated test tracks. While it may be held that design based on the latter type of correlation will be conservative, at the same time there is the possibility that such procedure may eliminate mixtures having bitumen contents in the higher ranges that would prove to be satisfactory in actual service. It is assumed that the studies will be extended to include correlation of the design limits suggested in the symposium with the service behavior of additional airfield wearing courses.

Good correlation between the density obtained by field compaction and the density obtained in the laboratory compacting procedure is important in the satisfactory use, for design purposes, of any type of stability test. In the Marshall test,

[1] Materials Engineer, Division of Physical Research, Public Roads Administration.

this correlation would appear to be especially important, since the selection of bitumen content is based upon the stability, unit weight of total mix and aggregate only, percent of voids aggregate only and total mix, and percent voids filled with asphalt.

It is believed that, whenever possible, the laboratory work in studies intended to correlate laboratory and field densities should be started at the time of constructing the field jobs, at which time samples of the fresh uncompacted mixture can be used for laboratory compaction. Densities of samples taken in the field from the finished work may then be compared to those of original laboratory-compacted specimens, thus avoiding the necessity to reheat and recompact.

One of the authors makes an observation with respect to specifications governing the compaction to be attained by rolling during construction that is particularly worthy of emphasis. He points out that many engineers have used specifications requiring compaction that will result in pavement densities equivalent to from "90 to 95 percent of the theoretical density without realizing that they were neither specifying a definite amount of compaction nor obtaining sufficient compaction in many cases."

Expanding on this point, it should be noted that similarly expressed requirements may sometimes result in over-compaction, accompanied by excessive crushing of the aggregate. If the theoretical density of a voidless mass is used as the reference specific gravity in such requirements, care must be exercised in selecting the numerical relative density to be required on individual jobs, giving consideration to the volume requirements of the bitumen content selected, and the void content of the mineral aggregate when compacted to its densest condition. Use of the observed specific gravity of laboratory-compacted specimens of the mixture that is to be used on a particular job, as the reference density with which the density of construction samples will be compared, is a much more realistic and logical practice. Whether laboratory compaction is accomplished using the procedure described in the symposium or by other laboratory procedures is a matter of choice, provided that the results may be correlated with field compaction.

RAYMOND C. HERNER, *Civil Aeronautics Administration* - The vast amount of laboratory and field work so ably summarized in this symposium has given us a valuable tool for use in the design of bituminous mixtures and flexible pavements. It is a tool, however, which must be used with a proper regard for its limitations.

First, we must recognize the fact that the approach is strictly empirical and that the resulting conclusions can be considered valid only within the limits of the test conditions. The Marshall test does not measure any fundamental quality of the asphaltic mixture or pavement, but indicates a composite result of several qualities when a specimen is tested under certain arbitrary test conditions. It is entirely possible that these qualities are not given the same comparative weights in the test results as they are under service conditions.

In this connection we should note that the word "stability", when applied to the Marshall test, is somewhat of a misnomer. This is brought out clearly in the symposium, from which the following quotations are made:

> "Referring to both the stability and flow curves, it can be seen that values of equal stability can be selected both below and above the optimum asphalt content. The flow curve shows that such values do not represent equally stable mixtures." (Paper No. 1. Underlining added).

> "The stability value is not a satisfactory indication of the ability of a mix to resist displacement under traffic ---." (Paper No. 4. Underlining added).

This is shown also in the field tests where we find instances of asphaltic concrete mixes with Marshall "stability" values greater than 500 and initial flow values less than 20 which still were rated as plastic.

As indicated in the symposium, accelerated traffic tests do not permit any evaluation of durability. Both experiments and experience have shown that a comparatively high asphalt content will contribute materially to achievement of this desirable quality. In the proposed method of mixture design the asphalt content is determined by averaging the results obtained from certain laboratory tests. It would appear more desirable to set the asphalt content at the maximum amount which would satisfy the limiting values set up for the various criteria.

For instance, in Paper No. 6 a design example was worked out by the averaging method which gave a value of 5.7 percent for the selected asphalt content. If this percentage is increased to 6.6 the mixture still will meet the limiting requirements for Marshall stability, flow, voids total mix, and voids filled with asphalt. The unit weight will be reduced only one pound per cubic foot. If the criteria are valid such a mix should be satisfactory for resistance to traffic, and it should be superior to the 5.7 percent mixture from the standpoint of durability.

W. H. CAMPEN, *Manager*, Omaha Testing Laboratories - One of the major conclusions reached in this symposium states that asphaltic content and density are the principal controlling factors in the development of stability. My own observations in the laboratory and field confirm this conclusion in a general way. However, the type of aggregate is most important also. I wish to elaborate on this phase because in my opinion the symposium does not cover it adequately.

On this point the symposium states that the type of coarse aggregate is not important in mixtures of sheet asphalt and coarse aggregate unless the percentage of coarse aggregate is 40 or more. I agree that the effect of coarse aggregate is not pronounced until the percentage exceeds about 40 regardless of whether it is round or angular and I also agree that when the percentage of coarse aggregate is high enough to produce interlocking the angular aggregates are more effective in developing stability than rounded ones. But, the effect of angular aggregates in bituminous mixtures is not confined to coarse aggregate sizes.

For instance, we find that we can more than double the Hubbard-Field stability in sheet asphalts by replacing about 40 percent of the natural sands with angular ones. Furthermore, stone-filled sheet asphalt mixtures in which the minus No. 10 portion contains about 40 percent angular material possess from 300 to 700 percent as much stability as do those in which the minus No. 10 material is all natural sand.

Furthermore, asphaltic concretes containing about 50 percent uncrushed coarse aggregate are three times as strong when about 40 percent angular aggregate is included in the minus No. 10 material as when natural sands only are used in the minus No. 10 portion. Even when the coarse aggregate consists of angular aggregate the stability increases from 50 to 100 percent when about 40 percent angular material is included in the minus No. 10 portion.

All these examples show the important part played by angular fine aggregate. They also show that coarse angular aggregates are more effective in producing stability when used in conjunction with strong mortars than with weak ones.

This brief analysis shows definitely that the role of angular aggregates in the development of stability is of utmost importance. A complete study will show that a wide range of stabilities can be produced in all types of mixtures by including angular aggregates which may be found in natural deposits or which may be produced by crushing durable rocks or gravels. A rather comprehensive study of the effects of both fine and coarse angular aggregates is included in a paper entitled: "A Study of the Role of Angular Aggregates in the Development of Stability in Bituminous Mixtures" by W. H. Campen and J. R. Smith, and published in the proceedings of the Association of Asphalt Paving Technologists, Vol. 17, 1948.

The symposium also attaches importance

to a flow test. It is used as a measure of plasticity. I certainly agree that we need a test to measure the wetness of bituminous mixtures because many of us are wondering if in designing for stability we are not sacrificing durability. However, the flow test as finally used in the symposium establishes upper values only. This is unfortunate because I believe it even more important to specify the lower limit than the upper one. My own experience in designing for stability leads me to conclude that the chances are much greater for producing dry, brittle mixtures than for producing wet, flexible ones.

That part which shows the effect of traffic on the density of bituminous mixtures is no doubt the most valuable contribution of the symposium. The laboratory compactive effort finally adopted for the preparation of test specimens is high enough to be equivalent to that of high wheel loads. For that reason the highest density which can be developed in the field will probably never be higher than that obtained in the laboratory and consequently the voids will not become lower than the minimum obtained in the laboratory.

I think it is good engineering to establish a compaction method which applies a specified amount of energy. All of us who make stability tests by other methods should take advantage of the data furnished by the U. S. Engineers and modify our compactive efforts accordingly.