of the object on the right stage to form a composite image from portions of the two objects. The two objects are brought into focus through one eyepiece having a circular field which is divided in the center with a fine line separating the images from the two stages. The stages of the microscope are mechanical to permit manipulation and are provided with spindles for rotation of the specimens

This instrument may be used, for example, in the examination of fibers of clothing, or marks and striations on a fragment of metal which may have been broken from a hit-and-run car. Figure 8 is a photograph of two fibers being examined under the comparison microscope. In the examination of these two fibers it was found that the fiber found on the car, represented in the upper half of the photograph, compared in several respects with a fiber from the victim's coat. Both threads were found to be similar in size and type of fiber; both were composed of the same number of strands with like compositions. Tests indicated that the same type of dyestuff was present in both threads.

Scratches and marks which may be found on a broken radiator ornament may, for example, be examined under the comparison microscope to show whether or not the broken piece did or could have come from the car in question These and many other uses are made of the comparison microscope in the Laboratory.

This discussion will serve to illustrate some of the scientific developments which have been made in the laboratory and which are being applied daily in the field of law enforcement. Obviously, there has been much greater progress in the application of science to laboratory examinations than to the solution of problems arising in field operations. The progress which has been made in the laboratory is indicative of what progress can be expected in the handling of field problems as soon as the principles of science and other related professions are fully applied to the everyday problems of the police officer

DEPARTMENT OF SOILS INVESTIGATIONS

HAROLD ALLEN, *Chairman*

INVESTIGATION OF A SIMPLE METHOD OF IDENTIFYING BASE COURSE MATERIAL SUBJECT TO FROST DAMAGE

C. H. McDONALD, *Materials Engineer, Bureau of Public Roads, Phoenix, Arizona*

SYNOPSIS

This paper is concerned with the identification of base course materials that are subject to softening by supersaturation as a result of freezing and thawing conditions The necessary investigation was prompted by widespread damage to bituminous pavements, in northern Arizona, as a result of this phenomenon

The research was based upon accepted principles of excessive water accumulation in materials through frost action The principle here involved is that the capillary pores must be small enough to hold free water against the force of gravity and the expulsive action of traffic. It is reasoned that the above property can be determined by simply compacting the material at a moisture content in excess of optimum and observing whether it is firm, or soft by reason of excessive pore pressure

The test procedure adopted was based upon the standard AASHO density test, T 99, with certain modifications involving free drainage at the base of the mold and compaction at moisture contents above the optimum Observations and tests were made on the stability of the material, in its complete grading range, when compacted at relatively high moisture contents

The correlation with field performance was made by taking samples from eight projects that had a history of frost distress in the base, one project which had suffered no appreciable damage but on which there is evidence of borderline susceptibility to damage by frost and six projects which were unquestionably

free of frost troubles. These samples were subjected to the tests and observations outlined above and the results were then compared with field performance.

The results of this work indicate that, for Arizona conditions, the following tentative conclusions may be drawn.

1. A material that is capable of attaining a supersaturated state in the test described is apt to suffer instability under freezing and thawing conditions.
2. A "soft" reaction, accompanied by appreciable distortion of the surface, under blows of the rammer, when the material is at full water capacity, is indicative of a supersaturated state.
3. If the relative loss in stability exceeds 50 percent in the test, it is indicative of susceptibility to frost damage in the material.
4. Base materials containing in excess of 10 percent passing the No. 200 mesh sieve may lose stability under freezing and thawing conditions.

The winter of 1947–48 was severe in the plateau region of northern Arizona, insofar as damage to bituminous highway surfaces was concerned. The weather alternated between periods of sub-zero temperatures and warm periods during which extensive thawing occurred. Frost depth reportedly reached two feet on northern exposures while unshaded areas that sloped to the south apparently did not freeze to significant depths.

Most of the subgrade soils within this area consist principally of clays and fall within the A-7 group. The total base thickness is usually heavy because of the soil type, logging traffic and unfavorable climatic conditions. Combined thickness of sub-base, base and surface course is often 24 in.

The type of frost trouble commonly encountered in this area is that associated with supersaturation and softening of the base and (or) sub-base, during a thawing period. It is not the spectacular type associated with heaving, and due to the thickness of stabilizing materials, the subgrade soils are not usually involved. The loss of stability is generally most pronounced in the top 3 to 4 in. of base course where thawing first occurs. The softening of the base is accompanied by the usual "alligator" cracking of the bituminous surface, water pumping up through the cracks, rutting and occasional corrugating. This condition variously affected more than a hundred miles of several hundred in the area during the winter of 1947–1948. Figures 1 to 4 illustrate the type of damage involved.

The bases affected are classified as usually satisfactory for the purpose. This emphasized the fact that the usual criterions of grading and soil characteristics were often inadequate for complete evaluation of base materials for use under these conditions. With a few exceptions the bases on the projects involved were of low plasticity and most of them were nonplastic. The percentage of material passing the No. 200 sieve was generally under 20 and averaged 15 on those bases affected by frost. Comparative field examination of the projects located at higher altitudes which were affected and unaffected by frost troubles showed no significant differences in drainage, exposure, etc. However, it was noted that drainage and exposure, particularly the latter, did appear to affect the degree of frost damage in bases where the climate was milder at lower altitudes.

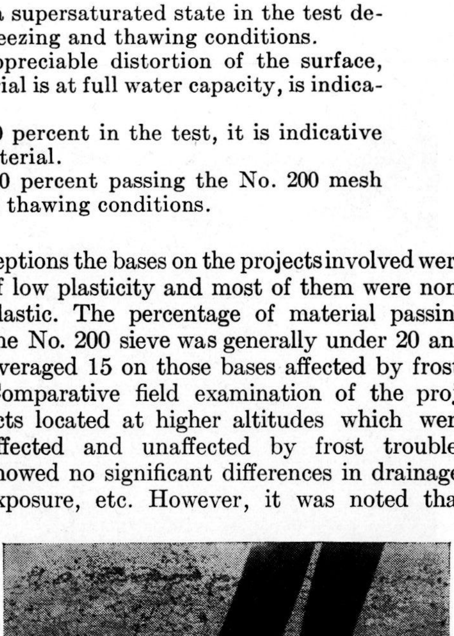

Figure 1. Surface Detail Showing Typical Frost Pattern Cracking of Moderate Severity in a Bituminous Surface—Water oozing thru cracks from the supersaturated base shows up as dark spots.

These studies and observations led to the question of what were the fundamental differences in these materials. To answer this it is necessary to reason deductively from the accepted principles of excessive water accumulation in materials through frost action. The cardinal principle here involved is that the capillary pores must be small enough to hold free water against the force of gravity and the expulsive action of traffic. Under normal drainage conditions it is obvious that softening by excessive pore pressure, developed under wheel load, cannot occur unless the

Figure 2. Area of Typical Damage to a Bituminous Surface Resulting from Severe Frost Action in the Base Course

Figure 3. View of Distorted Bituminous Surface Caused by Supersaturation of the Base by Frost Action—The basic distortion is in the base course but the overlying 2-in. S.C. 2 roadmix is also soft and saturated with water

above condition exists. It should be emphasized at this point that the materials under discussion are normal base materials sufficiently low in fines, plasticity or both so that lubricating effects are not involved in their stability except those provided by excessive pore pressure which prevents effective point contact of the mineral particles.

Since capillary pore size is a major controlling factor, any attack on the problem must consider the factors involved in the determination of pore size. These factors are grading, particle shape, and degree of compaction. Factors contributing to the effectiveness of the pore size are the surface affinity of the particles for water, texture of particle surface and absorption.

Any test designed to indicate the effect of frost on base material as it exists in the roadway, must take into account all of these factors in their complete and complementary effect. The conventional tests which measure capillary phenomena, directly or indirectly, such as capillary rise, permeability, centrifuge moisture equivalent, liquid limit, etc. do not give good correlation with field experience on granular materials because one or more of the above factors (for example density), as they occur in the field, are missing in the test.

It had been noted that many of the bases which later developed frost trouble showed a tendency toward excessive pore pressure during construction, evidenced as a supersaturated condition. They refused to compact properly under the rollers when the moisture content appreciably exceeded the optimum. In other words, the material was spongy and shoved around under the rollers in the manner of a rubbery, semi-liquid material. The general effect was the same as that encountered on a thawing, frost damaged base and the weight of the roller was in effect, being borne by hydrostatic pressure. This effect was not observed on bases which did not later develop frost trouble, even though water was present in such excess that it was free draining from the windrow during the laydown. A significant point here is the fact that some bases of comparable grading showed this difference in their ability to develop excessive pore pressure, indicating the importance of the previously mentioned factors other than grading.

It was but a step to recall that similar pore pressure phenomena had been observed in the reaction of granular materials in the Proctor mold when making the AASHO standard density test T 99. This suggested the possibility of adapting T 99 procedure, with certain modifications, as a means of identifying base materials that possessed the capillary characteristics essential to lowered stability after freezing. It was anticipated that these materials, when compacted at high moisture contents, would retain excess water against the force of gravity and the expulsive action of the rammer, resulting in excessive pore pressure signified by "mushiness" and shoving of the material under the rammer. In order to simulate field conditions which involve the several factors, it was necessary to modify Method T-99 by providing free drainage at the base of the cylinder and by using the complete grading range of the base material.

Theoretically, it appeared that this test would fulfill the requirements for water holding capacity of the material in place as related to the pore size and effectiveness factors previously mentioned. Naturally, the roadway conditions would not be duplicated exactly but it was believed that the similarities would be close enough. A brief discussion of probable similarities and dissimilarities follows:

Grading: The specifications for the base courses involved require 100 percent passing the 1-in. sieve. The proposed compaction tests were to be run on material passing the 1-in. sieve. Minor fractions that happened to be retained on the 1-in. sieve were proportioned in by slight additions of material retained on the No. 4 and passing the ¾-in. sieve.

Particle shape: Same as on the road.

Degree of compaction: The greatest variable is probably in this factor although the degree of compaction attained in this test, at optimum moisture, is probably close to the average of that obtained by normal construction practice in this State. The question arises here as to the effect on the density at the high moisture contents where supersaturation occurs. The tests show that in these granular materials, density drop at high moisture contents seldom exceeds 4 percent below maximum.

Surface affinity of the particles for water, *surface texture* and *absorption* are, of course, unchanged. The action of the rammer in the test is intended to approximate the water expulsive force of traffic on the road.

Although all of these factors are important in themselves, it is the combined effect, resulting from the inter-relationship of all factors, that must be similar to that under field conditions.

Regardless of the reasonableness of the theory of a test, it is of little practical value unless it can be correlated with actual field performance. Mr. H. H. Brown, Engineer of Materials, for the Arizona Highway Department, offered the laboratory facilities and full cooperation of his staff to undertake the necessary research work of attempting to establish such correlation.

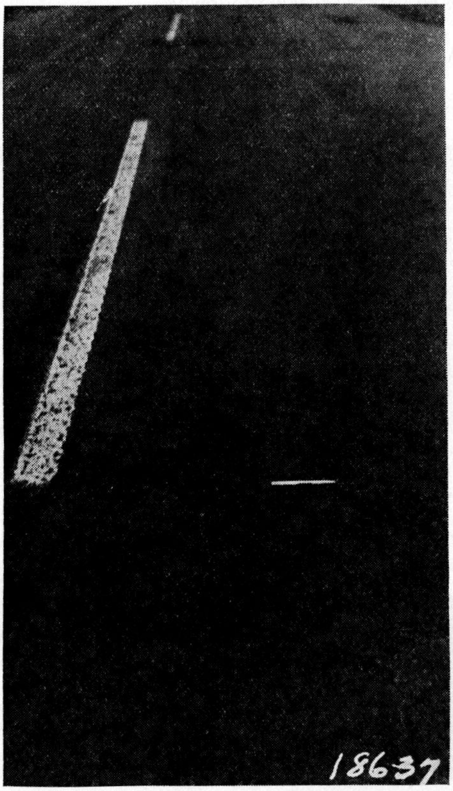

Figure 4. Typical Frost Pattern in Cracking of Mild Degree in a Bituminous Surface—This condition prevails thruout the project but has not resulted in any cost for repairs to date

Samples of base were taken from eight projects that had a history of frost distress, one project which had suffered no appreciable damage but on which there is evidence of borderline susceptibility to frost damage, six projects which were unquestionably free of frost troubles and several projects under construction. Since the latter group is only applicable to future correlation studies, the data on them are not presented in this report.

In order to include several possibilities of developing significant data and possible correlation, the research work was not confined to the single operation of compacting a sample at the saturation point. The program used on each sample was as follows:

1. Density curve was run according to AASHO T-99 except as follows:

(a) Material passing 1-in. sieve was used and new material was used for each moisture

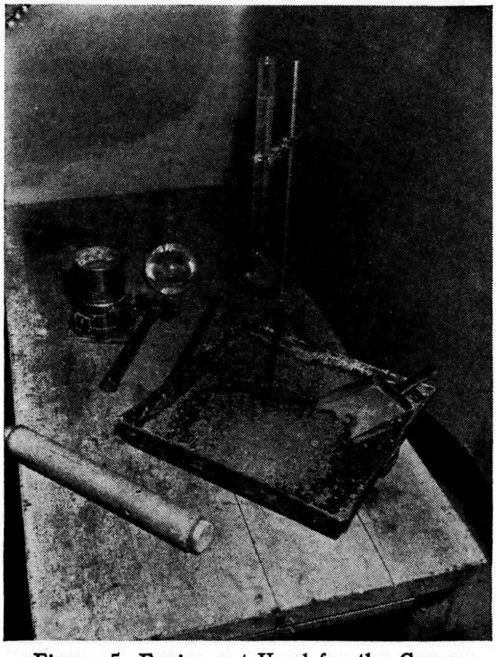

Figure 5. Equipment Used for the Compaction Type Portion of the Frost Susceptibility Test.

point to eliminate the possibility of progressive degradation of the material. All material was separated into component sieve sizes and recombined proportionally by weight for each test to insure consistent grading.

(b) The grooved base of the mold was turned over to present a flat surface to the bottom of the cylinder and a wire screen was placed between the base and the cylinder to provide drainage. Figure 5, showing the familiar compaction equipment, also shows the position of this screen between the base and cylinder of the mold.

(c) The first test of a series was at the approximate consistency of rather dry but workable concrete and the moisture contents of succeeding tests were reduced until approximate optimum moisture content was reached. The consistency of the material in the first trial is typically illustrated in Figure 6.

2. The penetration resistance was determined with a Proctor needle at each moisture content, using a needle area of 1 sq. in. In nearly all cases no appreciable penetration was obtained at the 110 psi. maximum capacity of the device. It was not deemed advisable to use a smaller needle because the maximum size of the material being penetrated was 1 in.

3. The penetration resistance was taken on a standard testing machine at each moisture content using a needle having a bearing area of 1 sq. in. Values for ½-in. penetration, at a rate of 0.1 in. per min., were recorded. On the wettest sample of each series, penetration was continued to a depth of 1 in. after permitting the sample to drain in the moist cabinet for 30 min. This was to get an approximation of the stabilizing effect of drainage after this period of time. Figure 7 shows the arrangement of equipment for running these penetration tests.

4. Observations were made of the reaction of the material under the rammer and the reaction under the last five blows on the final layer was recorded. The recorded observations are defined as follows:

Firm: The material yields little, if any, under the impact of the rammer, which strikes with a loud, resounding blow. There may be a slight rebound. The right hand specimen in Figure 8 shows the appearance of the surface of the material where this condition is encountered. Note free water at base of mold.

Semi-Firm: There is a slight yielding of the material under the impact of the rammer causing a cushioning effect. The sound of the blow is a dull thud and there is no rebound.

Soft: The material yields readily and suffers excessive deformation under the impact of the rammer. The sound of the blow is that produced by striking a semi-liquid material and it is obvious that the force of impact is being borne by hydraulic pore pressure. This effect must not be confused with the accumulation of a thin layer (¼ to ½ in.) of slurry on the surface when the material is essentially firm or semi-firm below. The soft condition is illustrated by the left hand specimen in Figure 8.

5. The distortion of the surface of the material after the last rammer blow on the wettest sample of each series was recorded. This was done at Mr. Brown's suggestion as a possible method of determining the reaction under the rammer by a physical measurement. The effect of the surface slurry should not be confused with true distortion of the mass in taking this measurement. An example of surface distortion is illustrated by the schematic drawing in Figure 9.

6. Visual observations were made on the degree of saturation of the final compacted sample and were recorded as unsaturated, saturated and supersaturated. The distinction between the terms saturated and supersaturated is important. In either case there may be considerable drainage of free water from the bottom of the mold but the supersaturated condition applies only where the material is "mushy" and soft from excessive pore pressure. Stated in other words, the capillarity is sufficiently high to hold enough water in the material to reduce the stability substantially. Here again the effect of surface slurry should not be confused with true supersaturation of the mass.

7. Visual observations were made on the water draining from the base of the mold and recorded as none, slight, or large. The principal value of this observation is to make certain that the material contains more than enough water to reach supersaturation if the material is capable of reaching that state. This water may be noted at the base of the molds in Figures 7 and 8.

8. The following tests were run on the original material: sieve analysis, hydrometer analysis, liquid limit, plastic limit, plasticity index and centrifuge moisture equivalent.

9. All materials are being checked in a special freeze cabinet designed to simulate freezing conditions as they exist in the field. It is believed that the State will report on this work upon its completion.

10. Significant data were tabulated and checked against known field performance for correlation. The tabulation and correlation is shown in Table 1.

It will be noted in Table 1 that sample No. 6451 did not give good correlation between its

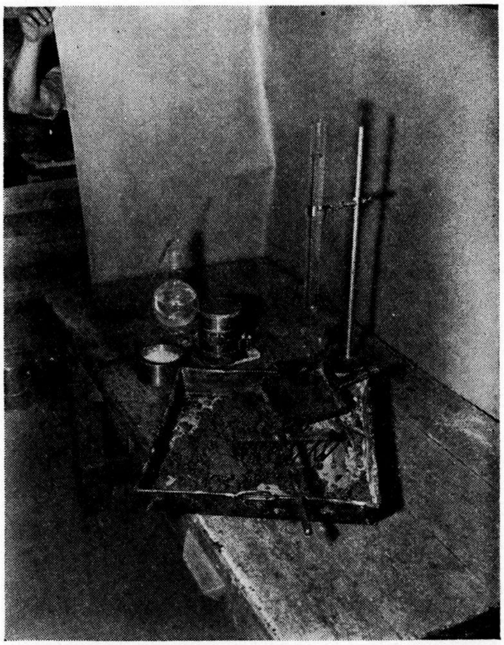

Figure 6. Shows Consistency of the Material Used in the Wettest Phase of a Test

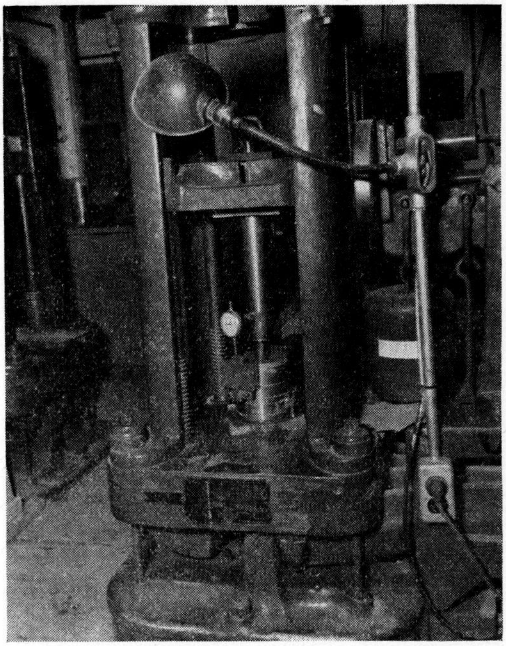

Figure 7. Equipment Used in Making the Penetration Resistance Measurements

history and the reactions under compaction at full water capacity or penetration values. It is pertinent to point out here that the project from which this sample was taken is located in an area of relatively low precipitation, at an elevation of around 6000 ft. Most of our frost troubles occur in areas of greater precipitation, around 7000 ft. in elevation, so it is not improbable that the history of this material might have been different had it

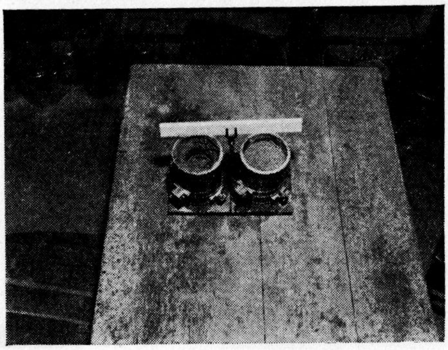

Figure 8. Left specimen shows an extreme example of supersaturation, soft reaction under rammer with accompanying distortion. Right specimen is saturated but not supersaturated, showed firm reaction under rammer with no significant distortion. Note free water draining from base of both molds

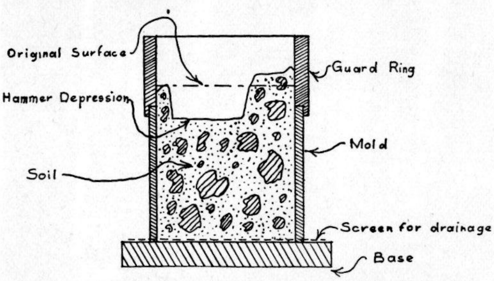

Figure 9. Schematic Drawing of Soil Deformation in Frost Susceptibility Test.

been used under more severe climatic conditions.

The tabulated results of this study indicate several items of significant value, as well as some of little value, in evaluating susceptibility to frost damage of base materials. A brief point by point discussion of the significance of the elements involved follows:

Grading: The more open graded materials generally had the best frost history but No. 2464 is a significant exception and brings up the factor of particle shape. This material is densely graded by sieve sizes but is actually open textured because of the extreme angularity of the individual particles. This is one example, of other known similar ones, which serves to emphasize the importance of factors other than grading alone. The one consistent correlating feature of the grading in this study is that all of the materials with a good history do not carry more than 10 percent passing the No. 200 sieve. The .02-mm. size does not appear to be as significant in this case.

Liquid Limit: No correlation was found.

Plasticity Index: No correlation was found although it should be noted that few plastic materials are represented.

Centrifuge Moisture Equivalent: No correlation was found.

Percentage Change in Penetration Resistance from the Maximum Unsaturated Value (approx. optimum) to the Minimum Saturated or Supersaturated Value: This percentage change is the figure obtained by dividing the difference between the maximum penetration resistance and the minimum resistance (pounds per square inch for ½-in. penetration) by the maximum penetration resistance. It is a measure of the relative difference in stability between material at its approximate optimum moisture and the same material at its full water holding capacity. Correlation is generally good with the dividing line between the frost susceptible and non-frost susceptible materials appearing to be at about 50 percent. It was found that it was important in this test to run the penetration without delay after striking off and weighing the cylinder. The reason is that these materials tend to gain stability rapidly through drainage as can be observed after the 30-min. draining period recorded in the adjoining column. It might be asked why this does not occur in the field with similar promptness and the probable answer is that the still frozen material beneath a thawing surface prevents free drainage.

Percentage Increase in Penetration Resistance from Saturated or Supersaturated Value to that Obtained after a Thirty-Minute Draining Period: This percentage increase is obtained by dividing the difference between the penetration resistance after a 30-min. draining period and the original penetration resistance on the wettest sample by the original penetration resistance. It is a measure of the gain in stability accomplished by drainage and apparently bears little correlation to performance in the field. Note that some of the frost susceptible materials showed the greatest percentage recoveries.

Reaction Under Rammer at Full Water Capacity. This observation showed generally good correlation with field performance as far as the "poor" and "good" classifications are concerned. Apparently it is not possible to draw a sufficiently fine distinction with this observation to segregate the borderline materials.

Distortion of Surface after Last Rammer

TABLE 1

Laboratory Number (1948 Series) and Project Number	Type of Material Used as Base (All Cinders are Volcanic)	Particle Size Distribution Percent Passing						Liquid Limit	Plastic Index	Centrifuge Moisture Equivalent	Percentage Change in Penetration Resistance from Maximum Unsaturated Value to Minimum Saturated or Super Saturated Value	Percentage increase in penetration Resistance from Saturated or Super Saturated Value to that Obtained after 30 Minute Draining Period	Reaction Under Rammer at Full Water Capacity	Distortion of Surface After Last Rammer Blow	Degree of Saturation at Full Water Capacity	Frost History of Portion of Project Involved
		¾ in	No 4	No 10	No 40	No 200	02 mm									
2464 FH17B(7)	Cinder	95	63	48	28	10	4		N P	30	−14	89	Firm	None	Sat	Good
2466 FH3H	Nodular Basalt	92	46	29	14	9	5	29	8	32	−26		Semi-[a] Firm	None	Sat	Good
3465 FH3I	Cinder Sand	95	64	39	18	5	3	22	N P.	33	−17	61	Semi-Firm	¾[a]	Sat	Good
3473 F62A(2)	Cinder	85	59	37	13	3	2	24	N P	33	−15	143	Firm	None	Sat.	Good
3475 F89G	Cinder	91	51	36	20	7	2	28	N P	32	−18	38	Firm	None	Sat	Good
6450 S104(3)	Cinder	85	48	35	19	6	3		N P.	35	+34	13	Firm	None	Sat.	Good
6451 S104(3)	Sand & Gravel	86	50	43	28	9	7	22	3	29	−98	1004	Soft	1	Super Sat	Good
2465 FH30A(3)	Nodular Basalt	96	58	35	16	9	6		N P.	30	−26	80	Semi-Firm	½	Sat	Border Line
3467 FH2D(5)	Cinder & Sand	98	59	32	17	11	6	22	N P	34	−79	146	Soft	¼	Super Sat	Poor
2468 S7(4)	Cinder Sand	95	79	69	50	16	6		N P	48	−73	154	Soft	¾	Super Sat	Poor
2469 S24(2)	Sand & Gravel	93	80	59	32	14	8		N.P	24	−68	171	Soft	1	Super Sat	Poor
3466 FH3I	Cinder Sand	96	72	52	34	11	4	25	N P	37	−85	338	Soft	2¼	Super Sat	Poor
3467A FH2D(5)	Cinder & Sand	99	80	66	30	18			N P		−100	225	Soft	1	Super Sat	Poor
3474 F80H	Sand Gravel	87	56	39	22	11	5	20	3	22	−72	63	Soft	¼	Super Sat	Poor
3476 F95G	Sand Gravel	86	63	61	56	23	7	20	N P	21	−100	149	Soft	1	Super Sat	Poor
6729 F105C	Cinder & Silt	90	54	40	25	11	8		N P.	43	−25	166	Soft	¼	Super Sat	Poor
6729A F105C	Cinder & Silt	94	74	55	34	15			N P	43	−85	235	Soft	¼	Super Sat	Poor

[a] ¼ in of slurry on top but semi-firm below.

Blow: This measurement is particularly useful in discriminating between the supersaturated and saturated states and gives good correlation with field performance Laboratory report No 3465 is a questionable case involving a semi-slurried condition of the surface.

Degree of Saturation at Full Water Capacity: This observation gave good correlation with field performance except that borderline materials may not be defined clearly. More data are needed before reliable evaluation of these materials may be attempted.

A legitimate objection will undoubtedly be raised that the personal equation will enter into the observations on the rammer reaction and degree of saturation observations. It is true that the person making these observations must be familiar with the basic principles involved in order to render an intelligent interpretation of the results. There are no inflexible mathematical figures on which to put one's finger but this objection may be answered by the following question. When wading a stream is it necessary to have figures to tell whether the bottom is quicksand or firm material? The principle of excessive pore pressure involved is the same.

A big advantage of this observation type of test for water retention capacity is that it can be done quickly, in either the field or laboratory, with a minimum of equipment If numerical values and additional verification are desired, the penetration ratio phase can be performed in the laboratory

It is recognized that there are many refinements that could have been applied to this research procedure For instance, the matter of using a bearing area of one sq. in on material passing the one-in. sieve and compacted in a four-in diameter mold, obviously violates recognized principles for such work. A large mold and larger bearing area would have been in order. The reason for adopting this method of test was to see whether a correlative test could be devised around simple equipment in universal use and refinements could be developed later if they are found to be warranted

CONCLUSIONS

Categorical conclusions are, of course, unwarranted on the basis of the limited data developed in this work. It is believed that the correlations obtained do strongly indicate the validity of the concept and it is hoped that others may be induced to attempt to correlate the test with field experience outside of Arizona. The Arizona experience warrants the following tentative conclusions.

1. A material that is capable of attaining a supersaturated state in the test described is apt to suffer instability under freezing and thawing conditions.
2 A "soft" reaction, accompanied by appreciable distortion of the surface, under blows of the rammer, when the material is at full water capacity, is indicative of a supersaturated state
3. The relative loss in stability, as measured by penetration resistance, from the optimum moisture content to the state of full water capacity is indicative of material susceptible to frost damage when the stability loss exceeds approximately 50 percent.
4. Base materials containing in excess of 10 percent passing the No. 200 mesh sieve may lose stability under freezing and thawing conditions

DISCUSSION

W. H. Campen, *Omaha Testing Laboratories*—Mr. McDonald has made a rather extensive study of some of the factors which might be responsible for the distress shown on about 100 miles of flexible highway pavements in the Spring of 1948 Whether one agrees with his conclusion or not, he should be complimented for conducting a systematic investigation for the purpose of determining the causes of failure.

Briefly he attempts to correlate the susceptibility to frost action damage with the behavior of the mixtures in the moisture-density test. More specifically he observes the effect of moisture contents higher than optimum and carries to the general conclusion that base mixtures which lose bearing value rapidly on the wet side of the moisture-density curve are susceptible to frost action This conclusion comes as a big surprise for the reason that most satisfactory base mixtures do lose bearing value very rapidly as the water content is raised above the optimum The writer does not agree with Mr McDonald's conclusion

However the type of failure reported in this paper is worthy of notice since it indicates one of two things, either that mechanically stabilized bases in general are not suitable for highways or that the particular bases mentioned in the paper were not properly designed or placed. As to the suitability of stabilized bases, enough satisfactory flexible type pavements have been constructed to prove their worth. On the other hand the data in Table 1 do show some poorly graded mixtures. Furthermore very little attention is given in the paper to field densities, either at the time of construction or after the failures. It is quite possible that a study of the density, optimum moisture and air void content (at optimum moisture) at the time of construction as well as in the Spring of 1948 would have shown why some areas stood up while others failed

Mr McDonald uses the expression "supersaturation". By the usual definition a saturated soil mass is one whose voids are completely filled with water and since a soil mass can not hold more water than is required to fill the voids, it can not be supersaturated. It appears therefore that there is no such thing as "supersaturation "

C H. McDonald, *Closure*—Mr Campen comments, "This conclusion comes as a big surprise for the reason that most satisfactory base mixtures do lose bearing value very rapidly as the water content is raised above the optimum " I think that this statement is too broad in scope, except as it may apply to certain localities. Certainly this is not true in the case of Arizona, as the investigation data demonstrates this fact I would agree that many otherwise satisfactory base mixtures do lose bearing value very rapidly as the water content is raised above the optimum

The economic significance of the conclusions reached in the report has driven us to seek other possible explanations but continued experience since the paper was written, only serves to verify the original conclusions. The only observation which might be added is that we have observed no indications of loss of stability from frost action in a base material that was indicated to be non-frost susceptible in the test.

I do not agree with Mr. Campen that the type of failure reported in this paper indicates that "either mechanically stabilized bases are not suitable or that the particular bases mentioned were not properly designed or placed " A cursory glance at Table 1 will show that the bases with a good frost history are stabilized bases by definition As evidence it is submitted that they comply, with a few immaterial exceptions, with the AASHO specification for stabilized base course M 56, type B, Grading B-1. It is important to note, however, that the percentage passing the No 200 sieve is on the low side of the AASHO grading limitation range.

This brings us to the question of placing and the related one of density. All of the bases on the projects listed were placed in layers of 3 to 5 in. and satisfactorily compacted by watering and rolling, in accordance with the specifications

Mr. Campen implies that inadequate field densities may well have contributed to the poor performance of some of these bases. An example which indicates that this could hardly be true is shown by compaction measurements made on one of the bases listed that later lost stability from frost action. The average relative density was 99 percent of standard density as determined by the 2000 psi. static loading method Another project investigated since the paper was written, was built without any compaction other than that afforded by construction traffic and normal light traffic. The base material consisted of disintegrated granite but it was taken from two different sources The section built with material from one source suffered frost damage and the material showed an unfavorable reaction in the frost susceptibility test The section built from the other source did not suffer frost damage even though no special compaction was employed. This material gave a favorable reaction in the frost susceptibility test

Two different sections on another project are represented by samples designated by laboratory numbers 3465 and 3466 in Table 1. The placement and compaction of these two sections were handled in accordance with specifications, by the same contractor, under the same contract The only difference is that the material for the good section came from a coarser portion of the same pit.

Space does not permit the listing of other examples but the above do indicate that high density is no panacea for base materials that are subject to frost damage This is reasonable because it is axiomatic that if a material is subject to damage by frost action, some volume change and therefore loss of density, is inevitable, even though it may be temporary. For example: the previously mentioned base with 99 percent relative compaction contained 8 percent moisture, approximate optimum, in the fall when the measurements were taken The following spring the moisture content was approximately 17 percent and the base was quite unstable. It is self evident that the original degree of compaction held little significance during the spring thaw.

Mr Campen also comments that some of the base mixtures are "poorly graded." It is part of the theme of this paper that bases which are poorly graded in the sense that the grading affects capillarity, are subject to frost damage.

The use of the term "supersaturation" has been questioned. Webster's dictionary defines "supersaturate" as "to add to beyond saturation". This definition describes what takes place in reaching a state of supersaturation. The distinction between the conditions "saturated" and "supersaturated" have been further carefully described in the text in order to avoid confusion in the use of the terms. If a better and more descriptive word for the condition here termed "supersaturated" is available, the suggestion would be appreciated.

PRINCIPLES AND TECHNIQUES OF SOIL IDENTIFICATION

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SYNOPSIS

The accurate complete identification of soils is the first and most fundamental step in all soil investigations for engineering works. Identification not only refers to the physical techniques of identifying soils, but also as an integral part refers to the careful, systematic and precise written and spoken identifications of soils, which can be made to convey definite and significant information on soil character An appraisal of the classification and identification approaches in soil investigations is made to show the fundamental importance and possibilities of the identification approach Identication places the emphasis on recognizing and establishing the identity and individuality of soils, and on identifying accurately and completely the inherent characteristis of each soil. The significant characteristics of the soil material, which determine behavior, and by which soils may be identified, are composition and inherent character with regard to the proportions and gradations of the granular gravel, sand and silt components, and the proportion, plasticity and clay qualities of the clay component The identification approach recognizes the inherently variable and complex character of soils and of natural situations, of which the soil is an essential part The behavior of soils must be considered in relation to the specific conditions that control in a situation Accurate complete identifications of soils, the rating of soils with regard to potential behavior characteristics, and the appraisal of natural situations with regard to the controlling conditions that determine the actual behavior of soils are fundamental and most important analyses in soil investigations. The principles of soil identification and a significant naming and identification of soils are discussed for granular soils and clay-soils. Interpretative ratings of soils are given with regard to fundamental behavior characteristics in order to give point to the principles and techniques of soil identification. The techniques of soil identification by visual and manual methods are presented in tables of identification techniques for three basic soil types: (a) Composite granular soils with less than five percent silt; (b) composite granular soils with more than five percent silt, and (c) composite clay-soils The techniques of iden-