FLEXIBLE TYPE BITUMINOUS ROADS
SUMMARY

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Upon perusing the excellent papers that have been presented, one comes to the inevitable question After all, when is a low-cost road a low-cost road? We have seen that in California, Kansas and Minnesota there is an endeavor to utilize the soil, the gravel, mine tailings, and the like, but in Pennsylvania the low-cost road takes the form of a modified macadam And if you will talk to your neighbor you will find that his idea of the subject is at variance with your own In other words we have no definite status for this road This really is as it should be, for, in spite of our mad desire to standardize everything in the United States and its possessions, Nature steps in and says, "I purposely scrambled things, what are you going to do about it?"

Since the time of Adam we have been doing nothing about it But now the Highway Research Board has wisely recommended that we study the subject from all angles, with special emphasis on the scientific phase Much has been published as to methods of construction, but little if any attempt has been made to try to find out the WHY of the successes and the failures The papers presented here are, it is thought, the first to be gathered together as a subgrade on which to build for a successful future

If you will delve into the Victorian era you will discover that about 1840 an Englishman, whose name unfortunately I have forgotten, invented and patented a tar bound macadam, which was, in many respects, similar to the low-cost roads described by Mr Ulman It is more than interesting, rather it is imperative to note that the inventor, nearly a century ago, wrote into his patent the statement that on hillsides large size stone chips should be rolled into the tarred roadcrust to provide against the skidding of horses and vehicles He advocated the sand-paper finish 95 years ago He stated the consistency of the binder to be used (judged by jaw action in chewing a sample) in order to do away with the possibility of the pavement getting out of shape The statement was included, that over a period of years this type would be found to be inexpensive Here was the first instance on record of a "low-cost road with a flexible type road surface "

It seems strange to the Youth of today that such an important invention as that just described should have come to naught, that it should have been allowed to slumber away in the British Patent Office for nearly three quarters of a century before being put to use But today's young engineer forgets that traffic was not ready for this type of improvement until the advent of the motor vehicle We must go to Nice about the year 1902 to find Gugliominnetti tarring the streets of Monte Carlo and the nearby towns, thus opening the era of dustless roads

Shortly thereafter Philip P Sharples visited France and Monaco to study Gugliominnetti's methods, and he returned to America fired with enthusiasm to surface-treat all suitable roads The first job attempted was at Jacksonville, Tennessee, where the main street of the town was given a surface treatment of light tar The South Side Park Board of Chicago next experimented with the new idea and surface treating of highways was launched I wish here to pay tribute to Mr Sharples for his unbounded energy, enthusiasm, and vision in this work, and to call attention to the fact that it was he who first gave the name to the type of road we are discussing Among his writings an article will be found, published about 1907, entitled "The Field of the Low Cost Road" This had wide distribution and made the name prominent He is a chemical engineer whose training was such that when he was manager of the highway division of a large bituminous industry, he instructed his field men to try always to discover the exact cause of the failure of any treatment The information thus gathered went far toward placing bituminous treatments on a scientific basis Yet, for years his was a voice crying in the wilderness Millions of gallons of tars and asphalts were sold and applied without thought or care as to their subsequent success or failure Today we are just emerging from the muck of misapplied bitumens

The Bureau of Public Roads and the Highway Research Board have accomplished much in bringing to our attention the study of soils, most excellently presented in Mr Hogentogler's various reports Isn't it strange that the entire civilized world has studied soils last, instead of first? The wonder is that our highway endeavors have been as successful as they have been! Luck and horse sense probably account for it

But now we have made a start Mr Hogentogler's "Soil Science Relating to Flexible Type Road Surfaces" presented at this meeting tells us definitely that certain types of soil will support loads and may be used as foundations for the cheaper road surfaces, that other types are excellent as subgrades if base courses are added, and that still other types are not suitable without special treatment Mr Lang goes on to show us how this information may be put to use

All of the investigators seem agreed that "if a sufficiently firm road bed can be obtained, any thin surface that will not shatter under traffic, and will withstand abrasive wear, is sufficient" This has lead to the study of stability, where our investigators apparently do not agree Allen & Gibson state that "the results of the swell test on mixtures containing *no* 200 mesh material indicate that a high void content in a bituminous mix tends to produce a large volume change" But Stanton & Hveem say that "fine mixtures having a high surface area may be expected to show greater swell than the same aggregate in coarse grading" This contradiction needs attention

Probably it is the duty of him who makes a summary of a symposium to search out those particular pet theories of the authors, and expose them to the light of day If they are sound, well and good If they are unsound . so much the better

Allen & Gibson state that 5 to 7 per cent of oil will product the most satisfactory results Here I must inject one of my own pet theories From 1912 to 1915 I experimented at considerable length on this question of the stability of various bituminous mixes, and I came to the conclusion that Allen & Gibson have expressed The result of these earlier investigations was the mastic cushion for brick and wood block pavements (1919) in which a maximum of seven per cent of bituminous material is used, for it was found that such a proportion gave the greatest stability Further tests in 1931 to 1933 substantiated this conclusion However, I believe that the statement as made is too broad, since neither Allen & Gibson nor I made tests on all sorts and conditions of aggregates and bitumens Here the study of Stanton & Hveem is important, for it suggests formulas for the amount of binder, based on the surface area of the aggregate and California oil Again, I believe that such formulas, good as they may be for the materials under examination, may be subject to considerable modification with other bitumens, and, possibly, with other aggregates My experience in the laboratory with California oils leads me to think that their behavior in some instances is more like that of water gas tar than like some of the oils the Easterner is likely to handle, hence, some degree of caution is advisable in taking either the flat statement of seven percent of oil, or the use of a formula suited to certain unique conditions. The New Mexico formula, and several others that have been suggested and tried in specific localities must be scrutinized carefully and tried both in laboratory and field before any definite statement of their worth may be made

But this, you will say, takes time Certainly it does However, since we have been several million years getting to this point we need not be too much in a hurry not to take enough time to indicate which way we should go The Stanton & Hveem paper indicates conclusively that the laboratory can predict very closely just how given materials will behave, even in the California climate My own observations on the predictability of field performance from previous laboratory investigations convince me that the laboratory man now has a new future opened to him, and that he is the answer to the success or the failure of the low-cost road

"Stability is unpredictably affected, if at all, by changes in grading" says Stanton, yet later on he says that too many fines make for failure unless the percentage of oil is just right The two statements do not hitch well, nor do they seem to fit in with his further statement that an aggregate should have a high natural inherent stability to assure the stability of the mixture It would seem from the two latter statements that there is some predictable variation in stability induced by changes in grading Furthermore, all of these are somewhat contradictory to Allen who says in his summary that to obtain the best results, from 5 to 15 per cent of the aggregate must pass a 200 mesh sieve

Lang's investigations proceed along a different course He is undertaking to build a low-cost road by seeing to it that the subgrade is right, and he says little about the top, other than that he is not trying to obtain slab strength, which is correct, but that he is constructing a thin, rich, waterproof wearing surface which will serve traffic needs as well as protect the subgrade itself The subgrade study derives from the soils investigations of Hogentogler, and seem to me to be very much in order The failure of the subgrade means the ultimate failure of the entire project, and hence this subject is of first importance No matter how well we design and construct our upper crust, whether it be of Society or of the Highway, it is doomed to disintegration if the foundation is rotten We all know it, yet how few put the information to use!

When we examine the Ulman paper we find different conditions in the field from those confronting the other men For Mr Ulman comes from a state where, for the most part, unlimited quantities of good road making materials are ubiquitous The type of low-cost road that he is building is vastly different from that of the region west of the Alleghenies to the Rockies In fact, his "low-cost road" would be a first class highway in many of the states of our land Furthermore, he uses bitumens of different characteristics from those noted in the other men's papers Hence, it is rather difficult to examine all of these texts and include them in a single summary Yet, such differences are precisely what we need, so that we may point out to each investigator what he may have missed, and what he should be looking for There is much meat in the Ulman paper in the matter of the bitumens used, their preparation, their tests, and the reasons why such changes from the customary specifications have been made Those of you who have taken bituminous materials for granted will do well to study the carefully outlined reasoning in the Ulman report

One of the most important points in any of the papers is that which Stanton & Hveem make, that any mineral aggregate, fine or coarse, which is more readily wetted by water than by asphaltic oil, will give trouble in the presence of water The study of preferential adsorption is relatively new, and we should be on the lookout for more information Victor Nicholson's work is highly interesting, and it throws a flood of light on those road failures for which there formerly was no answer

Probably every one of the older men here has been told at one time or another by a foreman, or by a resident engineer, that the particular bitumen being furnished on the job today isn't a sticky as the one sent yesterday I have repeatedly taken samples of such apparently non-adhesive material to the laboratory, only to find that in every respect they were identical with the so-called sticky ones I have taken those samples because I myself could see a difference in the way they adhered to the aggregate Preferential adsorption, or affinity of the aggregate for water rather than the bitumen was the answer The aggregate had become moist during the preceeding night and refused to let the bitumen adhere to it

With this auspicious beginning what should we expect in the near future? It would be well if all of the states, municipalities, and others engaged in constructing low-cost roads would send their findings to the Highway Research Board, or to a committee of the Board, at frequent intervals The information so gathered could be readily made available through the News Letter The items that will be most serviceable at first will be those relating to action of soils under varying climatic and weather conditions, the correlation of laboratory tests to field observations, new methods of testing materials and finished products, descriptions and specifications for new materials, or for old materials used in new ways, and comment on the behavior of those roads already built

Our investigators should make sure that the materials they tell us about are positively identified It is very confusing to the local man to be told in general terms about a material he never has worked with Thus, when a man from the Hudson River valley mentions limestone, he has in mind a stone that is about as hard as trap rock, but the man from Indiana visualizes a soft stone, almost like chalk Neither can understand the other, but there would be no difficulty if a thorough explanation were appended, or if the tests that were run on the stone were given

In the bituminous lines we should be careful to state exactly what the materials are Sometimes the specifications that the bitumen passed do not show up the special qualities that the specimen possesses Here it would be well to add explanatory notes to indicate the difference between the sample under consideration and others that will pass the same specification but which are different in their action I believe that knowledge of the source of supply would be helpful

Climate plays such an important part in the life of the road that the reports should state not only the locality, but also the cold, hard facts Many readers are upset by the bally-hoo of the real estate advertizing agents and really never know how severe the weather may be in some of our best advertized sections A short statement covering the items of rainfall, snowfall, humidity, and ranges of temperature would be sufficient

And may I suggest that photographs aid wonderfully in explaining things that otherwise are murky? Lantern slides at these meetings are of enormous advantage and the half tones reproduced in the Proceedings are of great value. May we have more of them!

Our investigations reported here have included the study of soils, aggregates, and bituminous materials. There are other materials to be observed and tried. Water, as a binder, has its uses, and the Proctor tests indicate a line of attack. Many other materials may have a place in the soil, and we welcome information concerning these. This is the first time that a series of papers discussing the scientific side of investigation of the low-cost road has been assembled at one meeting. The excellent work that has been done recently, as these papers so well attest, augurs well for the future, and we may hope for a wealth of material in the next year or so that will take us out of the hazy atmosphere of the present and place us in the clear light of research.

DISCUSSION ON SOIL SCIENCE RELATING TO FLEXIBLE TYPE ROAD SURFACES

MR. W. S. HOUSEL, *Michigan State Highway Department:* The trend in highway construction toward the low cost flexible type surfaces has focused the attention of highway engineers on the importance of providing such surfaces with an adequate foundation. In a great many cases a sufficiently stable subgrade may be available, requiring only a properly correlated design to fully develop its possibilities. In other cases where deficient subgrades are encountered it often appears that greater economies are possible by stabilization of the existing foundation than by building a roadway slab sufficiently rigid to distribute concentrated loads over the comparatively large areas required. Several of the papers presented in the symposium on flexible type surfaces place emphasis on the importance of soil mechanics in problems of this nature and Mr. Hogentogler's dissertation in particular brings out a number of fascinating possibilities in addition to indicating in a general way the present status of this comparatively new science.

The problem of a definite design of stabilized sub-bases or utilization of existing subgrades is little different from any design problem which involves the strength of a material and may be divided into two major steps. In the first place such a problem requires a determination of the manner in which the particular material develops resistance to deformation under load and an accurate description of the behavior of the material under a given set of conditions. Such a group of conceptions describing the results of observation and measurement may be framed into what is conveniently referred to as a Theory of Stability. In the writer's opinion "Soil Mechanics" has progressed to a point at the present time where it is possible to describe the behavior of this rather complex material, soil, even more fully than indicated by Mr Hogentogler, and it is the purpose of this discussion to attempt to amplify the original article in this respect

In the second place, it is necessary in any correlated design to determine the stresses to which a material is subjected under given load conditions and match these conditions with the ability of the material to develop resistance This latter aspect of the problem has been rather widely investigated in connection with the distribution of concentrated static loads, but much remains to be done in a determination of the dynamic effect of moving loads There also appears to be some failure to appreciate the relation between surface loads and the behavior of soil mixtures under stress

ELEMENTS OF STABILITY

Cohesive Mixtures In Mr Hogentogler's Figure 1 are illustrated several aspects of the manner in which soil may be displaced under a surface load There appears to have been sufficient observation of this phenomenon at least in the case of cohesive soils to afford a rather complete description In Figure 1 of this discussion are shown several diagrams intended to illustrate the manner in which soil is displaced, embodying several features which have been quite definitely determined

For the sake of simplicity the bearing area is assumed to be of indefinite length and unit width, thus treating the stress conditions in two rather than three dimensions As a first step only a uniform vertical pressure is considered in the applied load although in general the distribution may be non-uniform due to boundary effects which will be considered later Work done by Michell[1] in the field of the mathematical theory of elasticity has shown that under such load conditions the surface of maximum shearing stress is cylindrical, shown as a semi-circle in cross-section with a diameter equal to the width of the bearing area

Treating the elementary cube of unit dimensions shown in Part A of Figure 1 in the conventional manner of describing stress conditions in elastic materials, the horizontal surface of the bearing area is a principal plane of maximum normal stress n Consequently the vertical planes are also principal planes and the lateral pressure P_h is the least principal stress The two planes of maximum shearing stress are at an angle of 45 degrees with the principal planes and it may be shown by the application of the fundamental laws of statistics that equilibrium can only be maintained when the difference between the greatest and least principal stress is equal to or less than twice the shearing resistance ($n - P_h = 2m^1$) When the tangential stress applied on the planes of maximum shear exceeds the shearing resistance of the soil it has been observed frequently that a penetrating wedge of material sometimes highly compacted is forced downward by the bearing area,

[1] Proceedings, London Mathematical Society Vol 31, 32, 34

splitting the bottom portion of the cube and forcing the side quarters of the cube in a lateral direction Whether the sliding planes are the 45 degree planes of maximum shear as pictured by the penetrating wedge or a more complex curved surface does not detract from the practical value of the simpler conception As soon as stress reactions other than the simple compression or developed pressure n are introduced, both the mathematical result and the simple stress condition pictured by the cubical element are changed, including the location of the principal planes as shown It is, however, accurate as well as convenient to

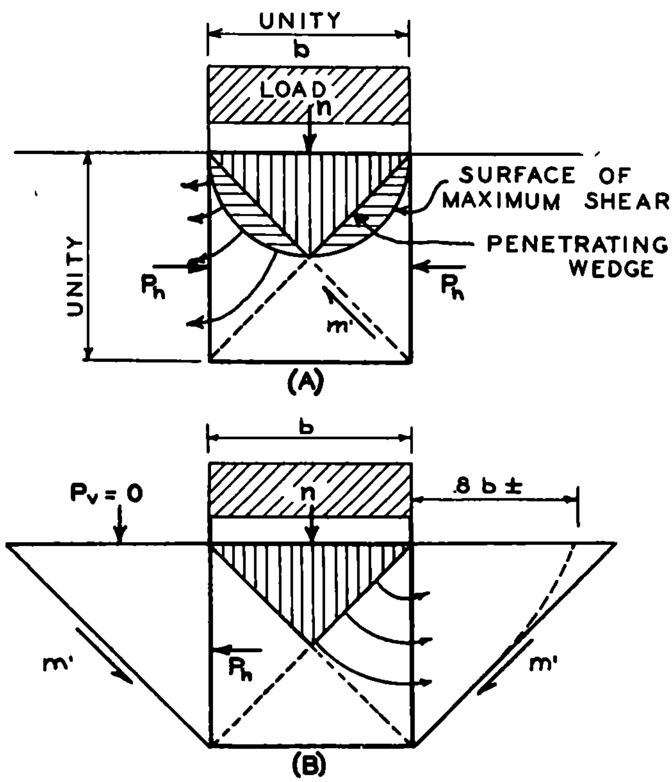


Figure 1

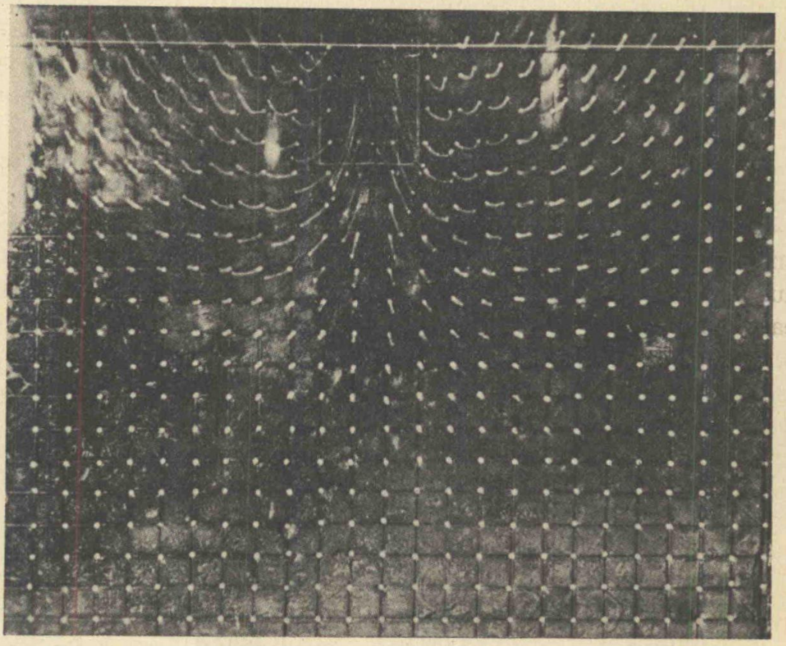
treat the different stress reactions separately and make use of the principle of superposition to obtain the complete picture

In Part B of Figure 1 is shown the next step in describing lateral displacement of soil The lateral pressure which is furnished by cubical elements on either side of the first element may be considered as a pressure P_h acting upon each adjacent cube Applying the same fundamental stress relations as before and considering the fact that the vertical pressure P_v is zero it may be shown that the ultimate value of the lateral pressure is equal to twice the shearing resistance of the material ($P_b = 2m^1$). The developed pressure n under the load conditions shown is then equal to four times the shearing resistance ($n = 4m^1$) This relation between the cohesive strength of the soil or the shearing resistance and the developed pressure has been verified within the limits of experimental error by series of tests in which the shearing resistance of the soil and the pressure developed under surface loads have been measured independently

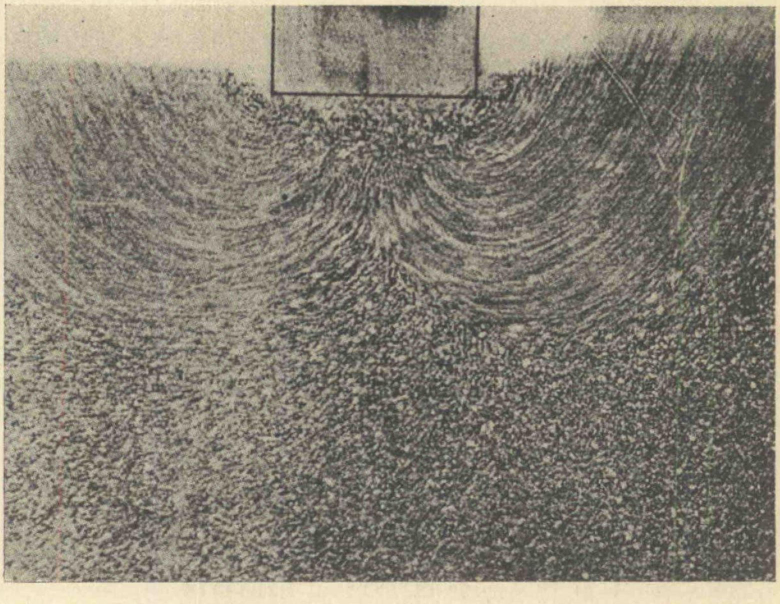
Aside from the quantitative relations indicated, the manner in which the lateral displacement takes place is of considerable interest The failure surface or sliding plane along which upward movement of the soil takes place is shown as having an inclination of 45 degrees There is also indicated a curved surface which appears from observation to be a surface of least resistance In a large number of tests on granular materials this failure surface appears to emerge on the top horizontal surface at a distance approaching the width of the bearing area The actual observations show a variation between the limits of 0 5b and b, the average of a number of observations being approximately 0 8b

In Figure 2 are shown two photographs of lateral displacement of soil illustrating this phenomenon for both clay and granular material It appears from these photographs that there is little if any difference in the lateral displacement for either type of material Particularly in the case of the granular particles it is possible to identify the portions of the body which are represented by the various wedges used for illustration in Figure 1 and at the same time it is shown that actual slip surfaces are curved rather than plane In Figure 3 are shown two photographs taken before and after a bearing capacity test on dry sand The test was conducted with standard Ottawa sand without binder but thoroughly compacted by vibration The failure which took place was typical and the slip surface emerged at a distance slightly less than the width of the bearing area, beyond which point the original surface was undisturbed

The quantitative relation between shearing resistance and developed pressure for cohesive soils as indicated in connection with Figure 1 raises a very fundamental question in mechanics of material having to do with internal resistance Mr Hogentogler in his Table I lists the influence of internal friction and cohesion upon supporting value The cohesion c is given in pounds per square foot and corresponds with the shearing resistance m^1 used by the writer The supporting value given in Table I corresponds to the developed pressure n used in the present discussion It will be noted that if the assumed angle of internal friction is zero the developed pressure is four times the shearing resistance, while increasing values of the angle of internal friction result in increased supporting value The results here shown may be duplicated by the application of well-known theories of earth pressure embodying a combi-



A. Displacement in Clay

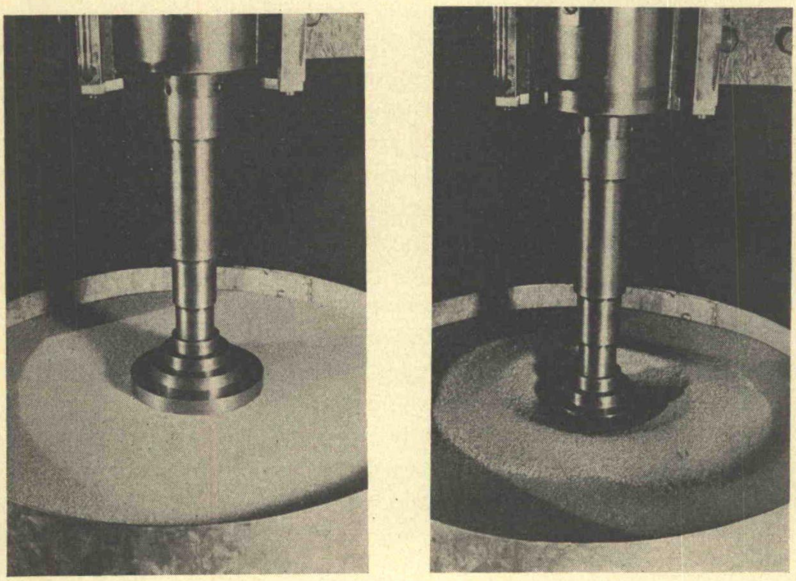


B. Displacement in Sand

Figure 2

nation of cohesion and internal friction as formulated by both Résal and Bell.

There are several important considerations in connection with these relations which cannot be passed over lightly. In the first place, supporting value must include more than the stress reaction which has been referred to as developed pressure. Particularly in small bearing areas such as are commonly encountered on highway surfaces one must consider an entirely independent stress reaction which is developed at the boundary of the bearing area. It is quite deceiving to give supporting value in terms of a uniform pressure or for a particular size of bearing area when it is quite definitely known that supporting value may vary



A. Before **B. After**

Figure 3. Loading Failure in Sand

with a change in the size of bearing area. Results of tests by a number of investigators have been interpreted as showing that supporting value of cohesive soils at any given amount of settlement varies inversely as the lateral dimension or diameter of the loaded area.[2] If this principle were universally true it may be shown that supporting value would be due entirely to a boundary stress reaction or perimeter shear and the developed pressure would be negligible.[3] On the other hand, tests conducted in a number of investigations indicate that perimeter shear is the source of a considerable portion of the supporting value of small

[2] The Science of Foundations—Terzaghi, Trans. Am. Soc. C. E. Vol. 93, p. 304.
[3] Loc. Cited—Discussion, page 322.

areas but neither stress reaction can be used alone to present a complete picture of bearing capacity

Granular Mixtures The rejection of internal friction theories in application to cohesive materials has been quite generally accepted, but the view that they may be inapplicable even in the case of granular materials has been little more than suggested There is, however, increasing justification for dissatisfaction with the use of internal friction to represent stability of such materials Terzaghi has demonstrated that failure or displacement of granular particles along some surface within a confined mass involves a stage of volume expansion in order to provide space for the particles to roll over one another The fact that this expansion must take place in opposition to components of pressure normal to the slip surface gives such a mass of granular material semi-elastic properties [4] Record of direct measurements of internal resistance of granular materials with special reference to the stress components developed on internal surfaces are few and far between in the literature on the subject

Some tests which might be indicative of internal stability are open to question because the measurements frequently involve or fail to eliminate other factors which should not be confused with ability to resist displacement An example of measurements which are not strictly representative of stability but are frequently used for that purpose is given by a number of testing devices which measure the lateral pressure transmitted by a sample of soil or similar mixture subjected to an applied vertical pressure In some cases the test specimen is confined in a rigid container which does not allow lateral deformation necessary to develop its inherent resistance In other cases the sample is surrounded by a comparatively incompressible liquid and the pressure transmitted to the liquid as lateral pressure is taken as an indication of the stability In the case of either type of test it is apparent that a perfectly elastic solid would suffer lateral deformation in proportion to a specific value of Poisson's ratio, and the lateral pressure necessary to prevent that deformation would not necessarily be a measure of the ability of that material to develop resistance

A proper determination of the ability of the material to develop a difference between the greatest and least principal stress without slipping or permanent shearing deformation would be a direct measure of one factor in stability In the case of granular materials shearing resistance is in some degree a function of normal components and it seems that a direct measure of tangential and normal components might be made with a comparatively simple testing apparatus Bell in his investigation of shearing resistance of clay also made some tests on sand, but it does not appear that he made provision for maintaining a constant normal com-

[4] Old Earth Pressure Theories and New Test Results—Terzaghi Eng N R, Vol 85, p 632.

ponent during the stage of volume expansion which has been noted by Terzaghi

In Figure 4 are shown some results of tests to determine the relation between normal and tangential components of stress in granular materials The tests have been conducted in the State Highway Laboratory at the University of Michigan with apparatus that is similar to that used by Bell [5] These tests indicate that the tangential components in all of the materials tested were greater than the normal components It is interesting to note that the smallest value of the angle ϕ, which has previously been used to represent the angle of internal friction, is 45 degrees and was obtained for chilled lead shot In this case it appears that any mechanical advantage due to interlocking would be eliminated For Ottawa sand compacted by vibration, the mechanical advantage due to interlocking has increased the angle to approximately 51 degrees, and for graded concrete sand of local origin, the angle is approximately 64 degrees These data, of course, must be extended and amplified by additional tests with greater variations in particle shape and grading before more definite conclusions can be drawn

If in all cases the mechanical advantage referred to is sufficient to develop tangential stress as great, or greater than the normal components, the stability of a compact granular mass must be treated in more nearly the same manner used for elastic or cohesive materials The evidence being accumulated appears to justify more than a suspicion that all is not well with internal friction theories when applied to problems of stability There is yet insufficient experimental evidence to go far in formulating a comprehensive theory describing the behavior of granular materials in this respect There are, however, parcels of such evidence that are beginning to match up, and perhaps these furnish a vague idea of what the complete picture will be

The analysis of data from investigations of the supporting value of various soils and mixtures which are being made both abroad and in this country show some salient features which point the way for future research In the first place all such investigations show that supporting value varies with the size and shape of the area for both granular and cohesive mixtures This variation has been quite definitely connected with boundary conditions as a stress reaction distinct from the pressure differential which a material is capable of sustaining This boundary stress reaction may be positive or negative depending upon whether the boundary is a source of additional resistance as in cohesive materials or a source of weakness as in granular materials In some ranges of size the stress reaction at the boundary appears to be unaffected by the width of the bearing area so that bearing capacity can be expressed by a linear equation when the settlement is held constant At certain critical

[5] The Lateral Pressure and Resistance of Clay —Bell, Minutes and Proc , Westminster Inst C E , Vol 199, Part I

sizes a radical change in this relation takes place and it may be said that a secondary dimensional effect causes the bearing capacity to depart from the linear relation

The nature of the phenomenon is not entirely clear but may soon be subject to analysis which will make possible a consistent treatment of bearing capacity or stability for the entire range of size and for both granular and cohesive materials At present bearing capacity tests must avoid these critical dimensional effects or else accept distinct limitations as to the range of application of test data Unfortunately the size of bearing areas which are ordinarily encountered in connection with high-

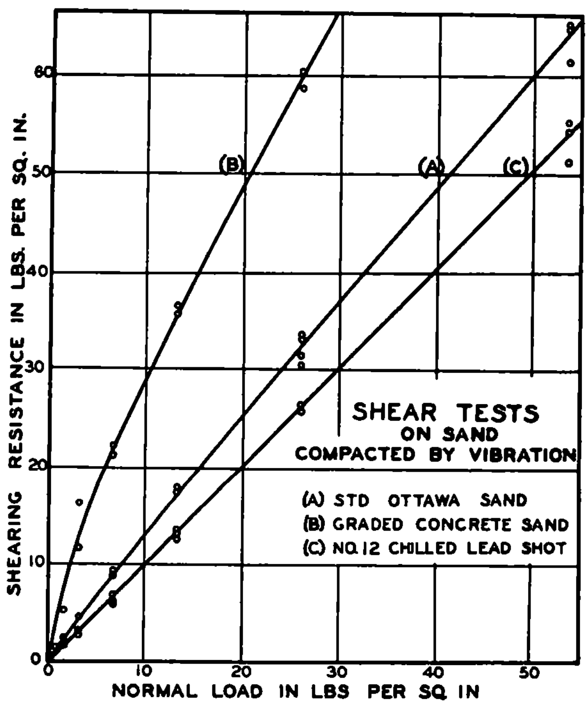


Figure 4

way surfaces include this critical range, and few positive results can be expected until additional research exposes what appears to be a rather complex dimensional phenomenon. This situation should be no more than a temporary one and present research in this field is exposing and clarifying the fundamental elements of stability which must be understood before sound practical applications can be made

PROF F H. ENO, *Ohio State University* I met with a peculiar incident in putting in some subgrade treatment in Ohio in which I was using kerosene to see what effect it would have

The road had been open to traffic before treatment was put on and a heavy dust had formed There had been a heavy rain and the mud was three inches thick and very plastic The application of the kerosene surprised me Mr Hogentogler's statement evidently solved a problem —upon the application of the kerosene I could walk across that road as on a paved street I don't know how long that lasted although it continued during that day I suppose it was due to some of these special actions that Mr Hogentogler mentioned

DISCUSSION ON SUMMARY

Mr Stanton Certainly Professor Crandell is to be commended for the thoroughness in which he has covered the large number of papers and the mass of material, but naturally in attempting to cover this particular field it is not always possible for the individual to go back and attempt to reconcile apparently contradictory papers, that is, by way of explanation, if Dr Crandell had time we could go over this material, explain the use of words, eliminate the apparent contradictions on several points mentioned in my paper He apparently reached the conclusion that we use and approve the use of formulas against surface area methods of determination of oil content, whereas I want to point out the difficulties of using all formulas which are based on only a few cases and that we actually use complete surface areas besides or a large number of sieve sizes That is, the difficulty involved in the formula is explained by the fact that in the original studies of the oil mix road we had what is called the McKesson-Frickstad formula which was later found to be improper when based on later tests in other localities, and so we developed a formula and we have the New Mexico formula Neither the Frickstad nor the New Mexico formula will apply to all conditions in all States, they were developed for particular problems and particular types of materials that they appear to fit We offer as a substitute in all cases complete surface area determinations