INFILTRATION OF SUBBASE SAND INTO OPEN GRADED DRAINAGE COURSE (OGDC) BASES

MICHIGAN DEPARTMENT OF TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

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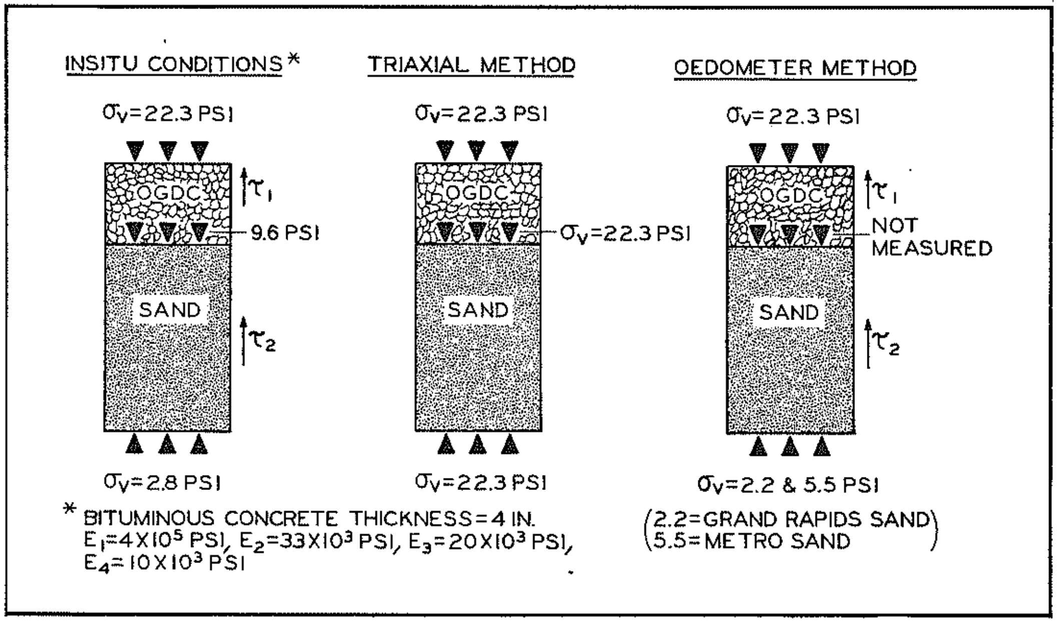


Figure 1. Vertical stress for in situ conditions compared with resulting vertical stress using the triaxial and oedometer test methods.

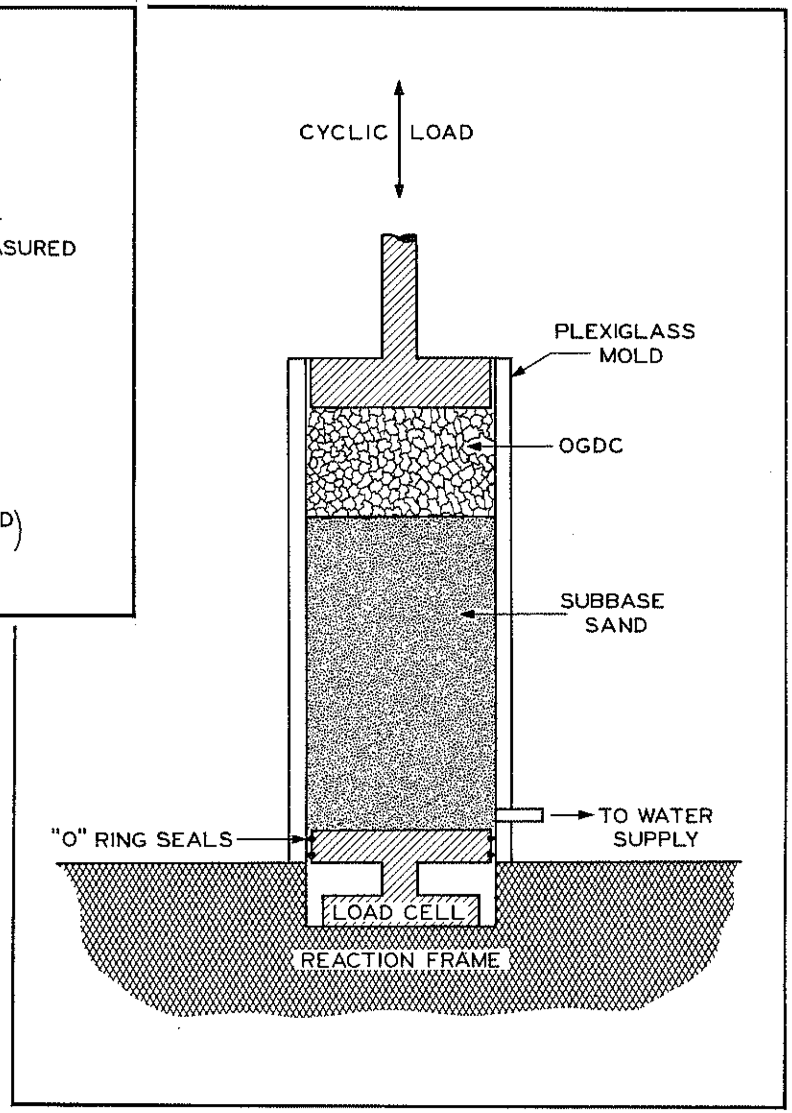
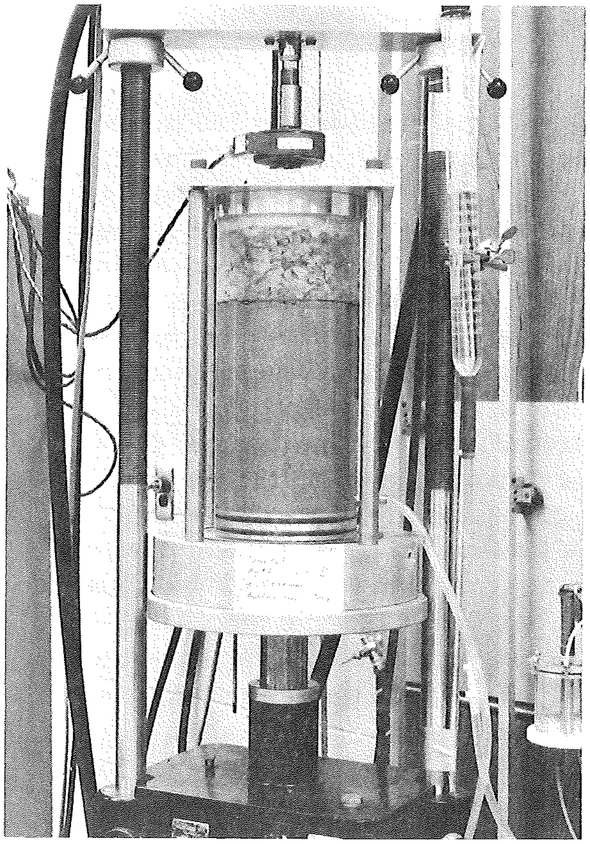
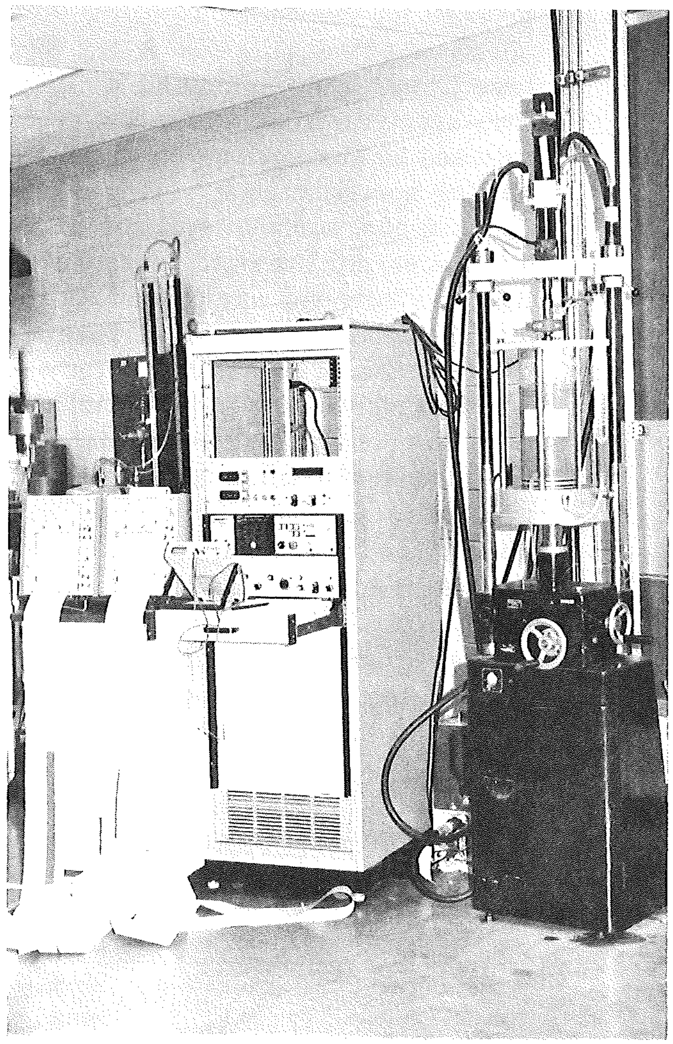


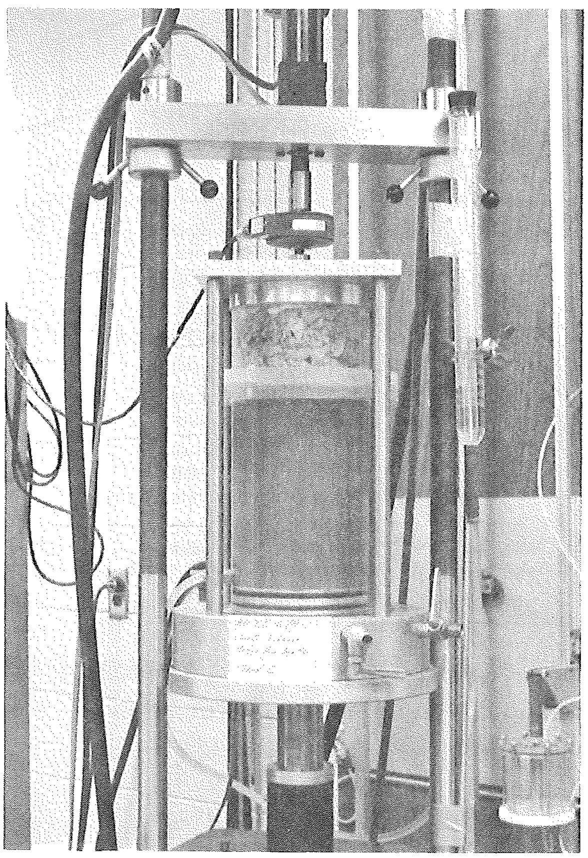
Figure 2. Cross-section of the oedometer test cell.



Test cell used when OGDC is placed directly on sand subbase.



Overall view of equipment test set-up used to study OGDC bases under cyclic load conditions.



Test cell used when filter fabric separates OGDC and subbase layers.

Figure 3. Testing equipment used to evaluate infiltration of OGDC voids by sand subbase materials.

Testing Program

Open graded drainage course base material used was a 100 percent crushed 6A limestone from the France Stone quarry. All test samples consisted of a 4-in. thick OGDC layer resting on a 10-in. thick sand subbase layer. For both flexible and rigid pavement conditions, the applied load spectrum simulated a 2S2 truck loading with 10 kips on the steering axle and 20 kips each on the dual wheel drive and rear tandem axles. This loading spectrum generated a maximum interface pressure at the base of the pavement surface layers of 22.3 psi for the flexible pavement condition and 4.4 psi for the rigid pavement condition. In order to study the effect a loss of structural integrity of the concrete slab might have on the OGDC subbase system, additional stress levels simulating slab cracking and joint deterioration of 8.8, 13.2, 17.6, and 22.0 psi were also applied. Two different subbase sands were included in the study, one a fine medium sand from the Metro area, the other a medium sand from Grand Rapids. The effectiveness of filter fabric placed between the OGDC and subbase layer was evaluated using Metro area sand subbase material with the same applied stresses as for flexible pavements. This should represent the worst possible field condition. Trevira 11/350 fabric, having an equivalent opening size of a sieve between No. 70+ to 100+ was used for this study. The testing program used is outlined in Table 1 with duplicate tests conducted for each test series listed.

TABLE 1
TESTING PROGRAM USED TO STUDY THE
INFILTRATION OF SUBBASE SAND INTO OGDC
AS A RESULT OF REPEATED LOADING CONDITIONS

Description	Test 1	Test 2	Test 3	Test 4	Test 5
Pavement Type	Flexible	Flexible	Flexible	Rigid	Rigid
Maximum Stress, psi	22.3	22.3	22.3	Initial 4.4 increased in 4.4 psi increments to a maximum of 22.0	
Subbase Material	Grand Rapids Sand	Metro Sand	Metro Sand	Grand Rapids Sand	Metro Sand
OGDC Material	6A Crushed Limestone	6A Crushed Limestone	6A Crushed Limestone	6A Crushed Limestone	6A Crushed Limestone
Subbase Compaction	95 Percent Standard Proctor Density	95 Percent Standard Proctor Density	95 Percent Standard Proctor Density	90 Percent Standard Proctor Density	90 Percent Standard Proctor Density
OGDC Compaction	95 Percent Michigan Cone Density	95 Percent Michigan Cone Density	95 Percent Michigan Cone Density	95 Percent Michigan Cone Density	95 Percent Michigan Cone Density
Filter Fabric	---	---	Trevira 11/350	---	---

For all samples tested, OGDC was compacted in one layer with a vibratory compactor until it reached a density of 100 lb/cu ft which is approximately 95 percent of Michigan cone density. The subbase was compacted in five layers using the same vibratory compactor with compaction effort applied until no further densification occurred. Resulting density was approximately 95 percent of Michigan cone density. For rigid pavement loading conditions, the OGDC layer was compacted in the same way as for the flexible pavement loading conditions. The subbase was compacted in five layers but with less compactive effort so that maximum density was roughly 90 percent of Michigan cone density. The lower density, it is thought, may indicate the effect of a loss of density due to one freeze-thaw cycle. Density data and the gradation of each base and subbase layer are summarized in Table 2. For all samples tested, the water table was maintained at the level of the visible OGDC-subbase interface.

TABLE 2
PROPERTIES OF THE MATERIALS STUDIED

Pavement Type	Source of Subbase Material	Number of Applied Load Repetitions	Subbase Density, lb/cu ft	Subbase Perme-ability, ft/day	OGDC Density, lb/cu ft	Gradation—In Percent Passing							
						OGDC				Subbase Sand			
						1 in.	1/2 in.	No. 4	No. 200	3/4 in.	No. 30	No. 100	No. 200
Flexible	Grand Rapids	272,100	108.7	89.5	100	100.0	48.7	5.8	1.3	100	94.7	1.7	0.4
Flexible	Metro Area	185,450	117.8	2.8	100	99.2	46.0	4.9	1.3	100	85.2	22.4	6.0
Flexible with Filter Fabric	Metro Area	221,500	119.9	1.4	100	100.0	45.4	5.8	1.4	100	84.2	24.6	6.8
Rigid	Grand Rapids	1,197,750	96.7	129.0	100	100.0	47.2	6.2	1.7	100	94.9	1.6	0.3
Rigid	Metro Area	928,600	108.9	6.3	100	100.0	46.0	4.7	1.1	100	84.2	24.6	6.8

Approximately 200,000 repeated 2S2 loadings were planned to be applied to each sample. In order to expedite testing, samples were allowed to cycle during weekends and overnight which, in some cases, resulted in the application of more than 200,000 load cycles.

Originally it was planned to use LVDT's to measure settlement of the OGDC surface. This arrangement was not satisfactory and was abandoned after two flexible pavement tests had been completed. For the remaining tests, settlement measurements were made with a machinist scale, which enabled reading settlement to the nearest 1/64th of an inch.

Test Results

Flexible Pavements — Test settlement test results for flexible pavement conditions are shown in Figure 4 for the Grand Rapids subbase sand, and in Figure 5 for the Metro subbase sand. These results indicate that settlement of the surface of the OGDC layer occurs primarily as a result

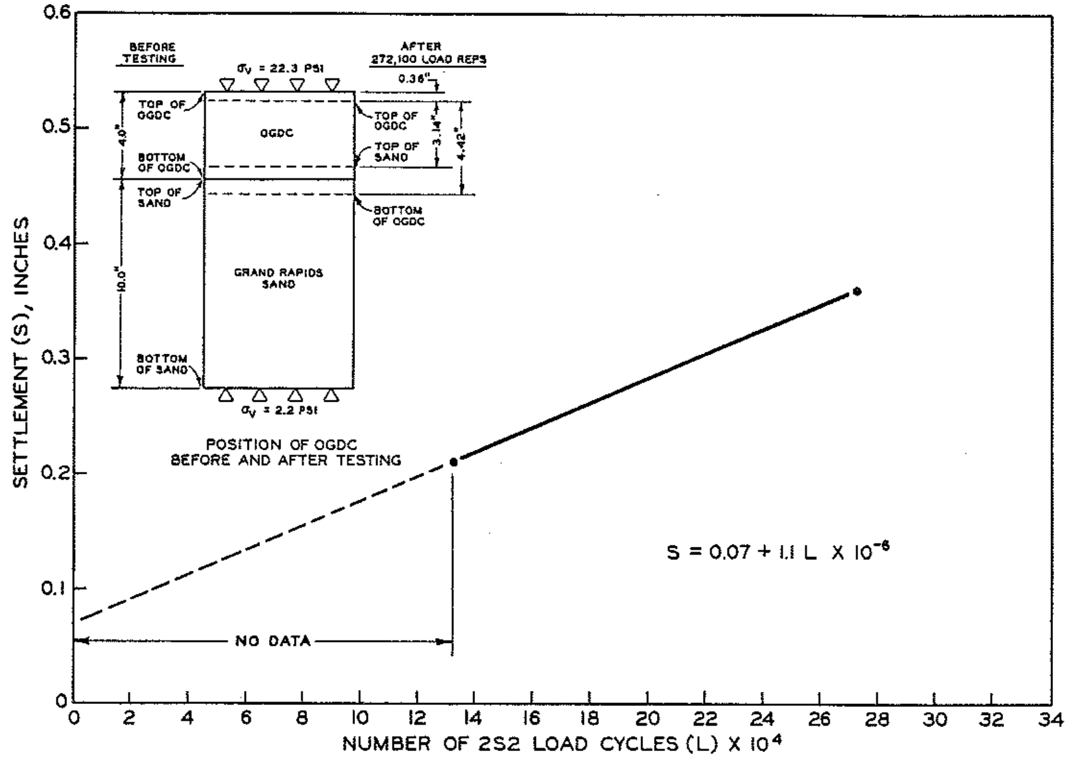


Figure 4. Settlement for Grand Rapids subbase sand and a flexible pavement stress condition.

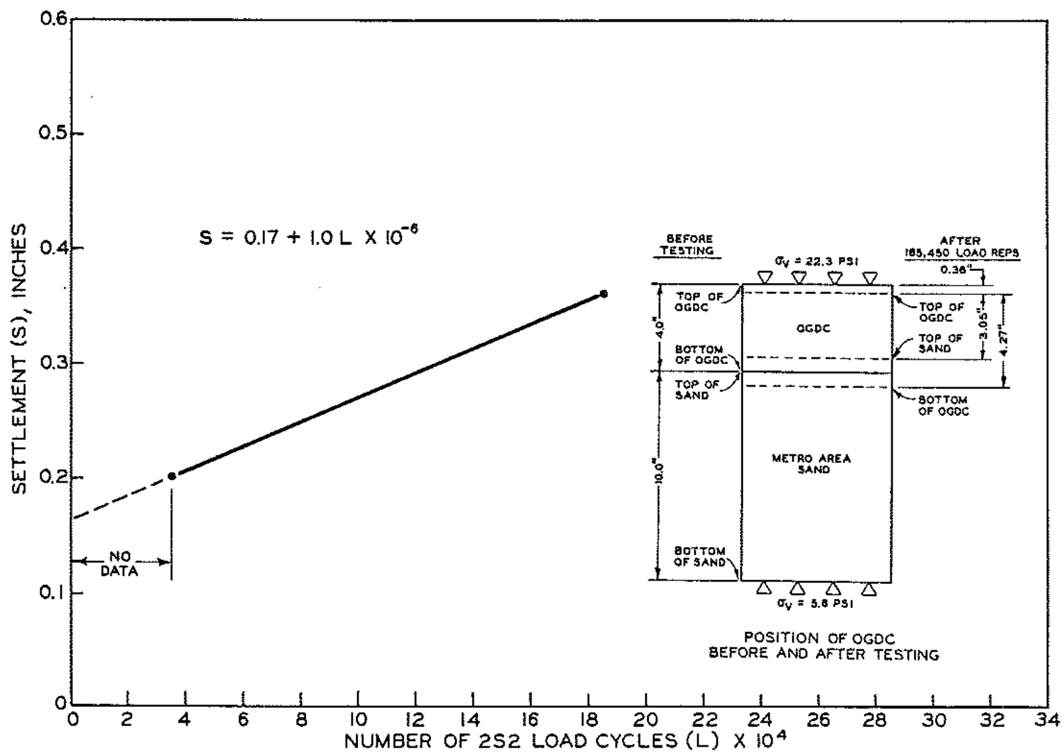


Figure 5. Settlement for Metro subbase sand and a flexible pavement stress condition.

of subbase sands occupying the voids of the OGDC layer. The rate of settlement is greatest at the start of testing, decreasing until reaching a lineal rate of settlement with each load application. The surface level of the sand subbase layer of each subbase type raised gradually during the entire test period. From Figures 4 and 5, the rate of settlement of a pavement surface may be estimated using the following equations:

Grand Rapids sand subbase:

$$S = 0.07 + 1.1L \times 10^{-6}$$

Metro sand subbase

$$S = 0.17 + 1.0L \times 10^{-6}$$

where: S = total settlement in inches,
L = number of 2S2 load cycles.

The effects on settlement values when placing a filter fabric between the OGDC base and sand subbase layers are presented in Figure 6. This

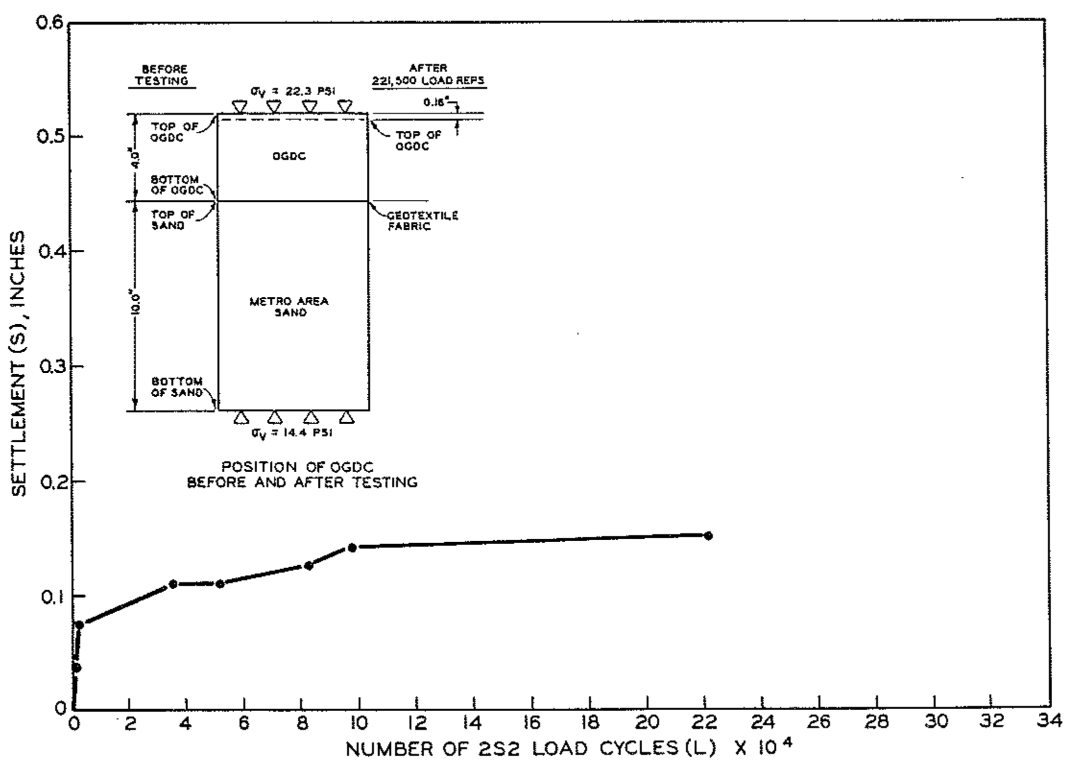


Figure 6. Settlement for Metro subbase sand which is separated from the OGDC by a filter fabric.

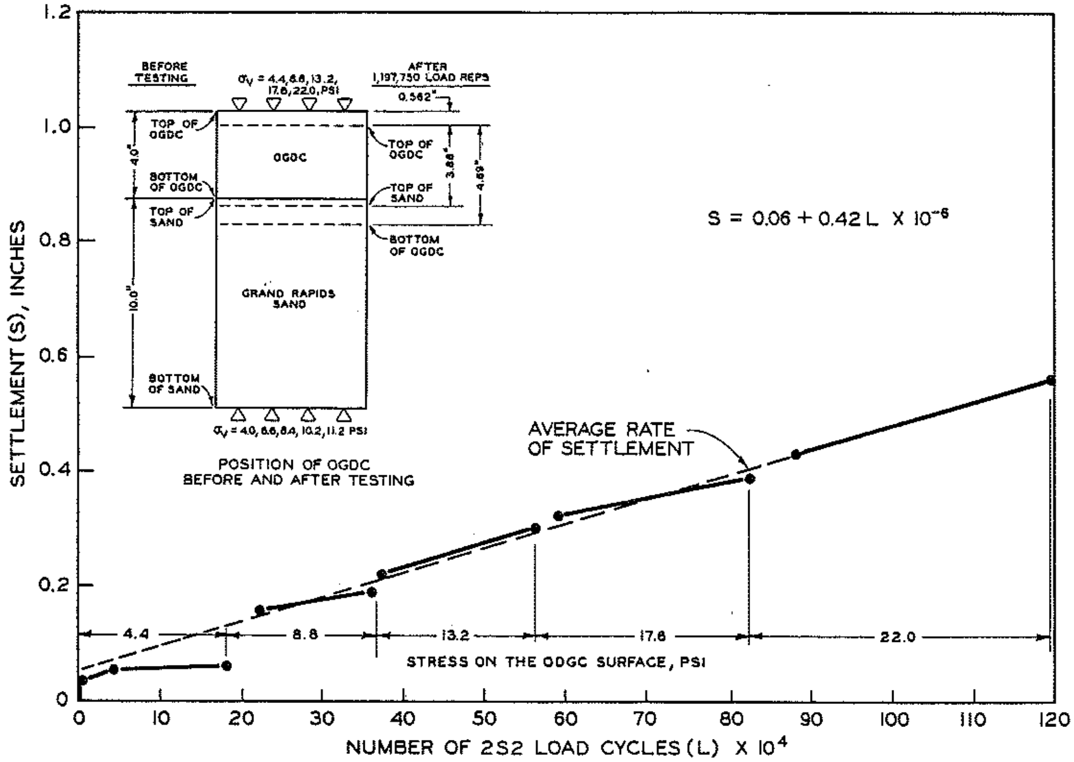


Figure 7. Settlement for Grand Rapids subbase sand and rigid pavement stress conditions for various levels of structural integrity of the portland cement concrete pavement surface.

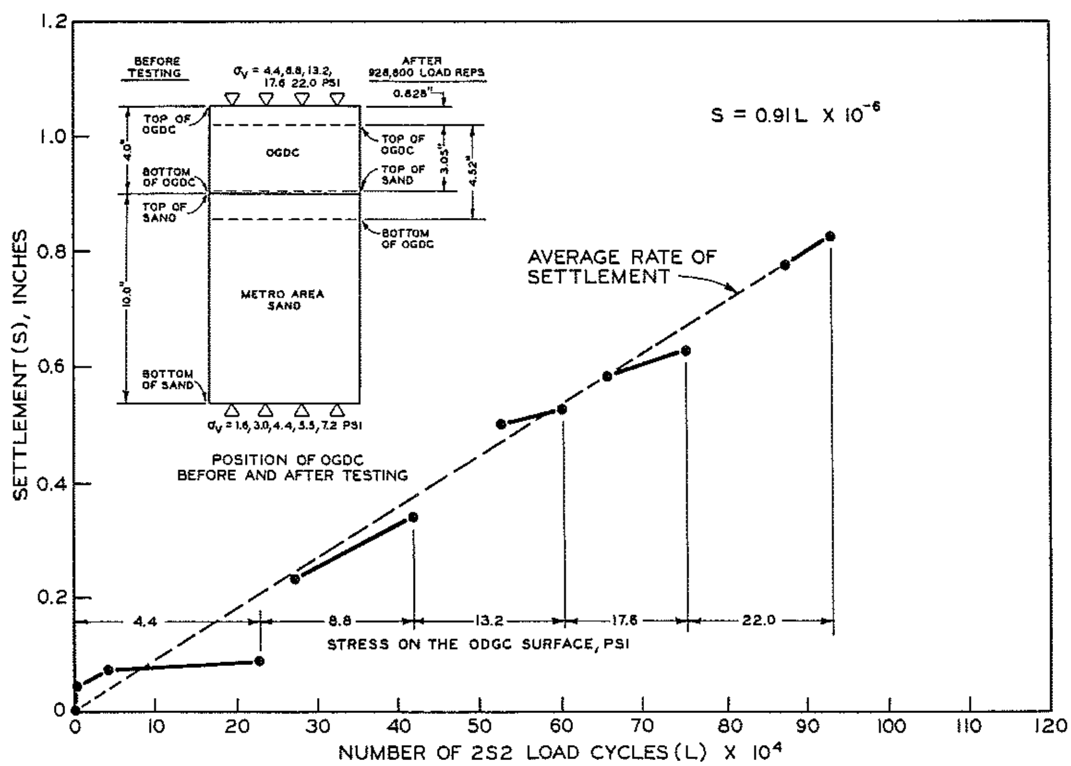


Figure 8. Settlement for Metro area subbase sand and rigid pavement stress conditions for various levels of structural integrity of the portland cement concrete pavement surface.

figure indicates that about one-third of the total settlement occurred within the first 2,000 2S2 load applications and almost no settlement occurred after 100,000 2S2 load applications. Therefore, the total settlement for this system should be about 0.15 in. with no significant settlement occurring after about 1,000 2S2 load applications, as Figure 6 shows.

Rigid Pavements — The settlement test results for rigid pavement conditions are summarized in Figures 7 and 8. These figures indicate that for Grand Rapids sand subbase, the surface level of the subbase settled downward rather than rising as it did for the flexible pavement condition. The Metro sand subbase surface remained at about its original position even though the OGDC surface settled over three-fourths of an inch. These figures also show that the OGDC particles became separated as they punched their way into the subbase sand thus increasing the apparent thickness of the OGDC layer. From Figures 7 and 8, the rate of settlement may be estimated from the following equations:

Grand Rapids sand subbase

$$S = 0.06 + 0.42L \times 10^{-6}$$

Metro sand subbase

$$S = 0.91L \times 10^{-6}$$

Discussion

The results of this study indicate that when the subbase is densely compacted, as it was for the flexible pavement conditions, the OGDC particles tended to punch their way into and displace the subbase sand. This action is characterized by an initial period in which the OGDC particles are being seated in the subbase sand. During the seating period, the rate of surface settlement gradually decreases until the OGDC particles are fully seated. At this time, the OGDC particle skeleton has reached a relatively constant cross-sectional contact area with the sand. Once the contact area is constant, the rate of settlement is constant. The performance of a flexible pavement having an OGDC base resting directly on a sand subbase should, as Figures 4 and 5 indicate, be characterized by a rising of the subbase surface, a decrease in the thickness of the OGDC layer above the subbase surface, and a separating of OGDC particles as they become immersed in subbase sand.

Under flexible pavement stress conditions, for which the subbase is densely compacted and a filter fabric separates OGDC and sand subbase layers, settlement should be limited to about 1/4 in. or less over the life of the pavement. This pavement condition should, as Figure 6 indicates, be characterized by a small initial settlement, that occurs as the OGDC becomes seated, followed by a minute increase in settlement with additional loading.

For rigid pavement conditions, the lower density of the subbase sand, as compared with that used for flexible pavement conditions, indicates what might occur if subbase density is reduced as a result of frost action. Figures 7 and 8 indicate that the subbase densifies as the OGDC particles punch their way into the sand. Densification of the subbase is indicated if during cyclic loading, the subbase surface remains near its original position or is lowered as the OGDC particles punch their way into the subbase sands. For both of the subbase sands tested, about 0.2 in. of settlement should have occurred over the normal life of a rigid pavement, provided the surface did not crack. Higher stress levels, caused by surface cracking, should increase the rate of surface settlement, thereby increasing the potential for differential movement and roughness of the pavement surface.

Using the results of this study, as shown in Figures 4 through 8, the total pavement surface settlement after application of a traffic load approximately equivalent to one million 18-kip equivalent axle load repetitions (EAL) and the sand subbase indicated would be as follows:

1. Flexible pavements

   a. Grand Rapids = 0.39 in.
   b. Metro = 0.46 in.

2. Rigid pavements

   a. Grand Rapids = 0.18 in.
   b. Metro = 0.27 in.

3. Filter fabric between OGDC base and subbase = 0.16 in.

The above settlement values are based on the 2S2 loading being equivalent to 3.4 18-kip EAL and a condition where there is no seasonal or repeated loss of density in the subbase layer due to frost action. On this basis, and for the data obtained in this study, the indication is that for rigid pavements there should be no problem with excessive pavement surface settlement nor from voids of the OGDC base filling with sand. For flexible pavements having a bituminous concrete thickness of 4 in. or more, the indicated rut depth is within AASHTO allowable limits for a pavement having a design life equivalent to one million 18 kip EAL. AASHTO's maximum allowable rut depth limit is 0.75 in. for a psi rating of 2.5. The use of a filter fabric between OGDC base and subbase layers should be superior to placing OGDC directly on the subbase because the fabric significantly reduces pavement surface settlement and prevents infiltration of sand into the OGDC base layer.

Although the test results indicate that OGDC may be placed directly on sand subbase, there are several limitations to this study, as well as consideration of field as opposed to laboratory conditions, which should be considered prior to reaching specific conclusions.

Limitations of this study include the small number of tests that were conducted, the use of only one load condition, and the effect that loss of subbase density, due to frost action, may have on performance. In this respect, two primary questions remain. The first is, will the loss of subbase density, resulting from frost action in the subbase layer, occur frequently enough to completely fill the voids of the OGDC layer in less than the pavement's design life? The second is, will frost action in the subbase layer result in excessive premature rutting of flexible pavement surfaces?

To, in part, answer these questions, the relationship between drainage time and thickness of the OGDC base was computed and is summarized in Figure 9. This figure indicates that the thickness of the OGDC base could be reduced significantly and still provide a high degree of drainage capacity. However, this study provides no information as to the quantitative effect subbase frost action may have on the rate of pavement settlement. The data indicate that when the subbase has a low initial density, repeated loading results in additional subbase compaction. It also shows that the rate of settlement for low initial density subbases is less than for a more densely compacted subbase as can be seen by comparing Figures 4 and 5 to Figures 7 and 8, respectively. These figures also indicate that low subbase density reduced the tendency for the OGDC voids to fill with subbase sand.

A hypothesis for these results is that under loose subbase conditions repeated load causes formation of a compaction plane in which the bottom OGDC particles and subbase sand interlock to form the equivalent of a rigid plate. Under this condition, the OGDC particles and compacted sand act as a homogeneous unit that minimizes stress concentrations. In this way, the stress concentrations that created the punching of OGDC particles in dense subbase conditions are replaced by a compaction plane in which stresses are more uniformly distributed from sand grain to sand grain at

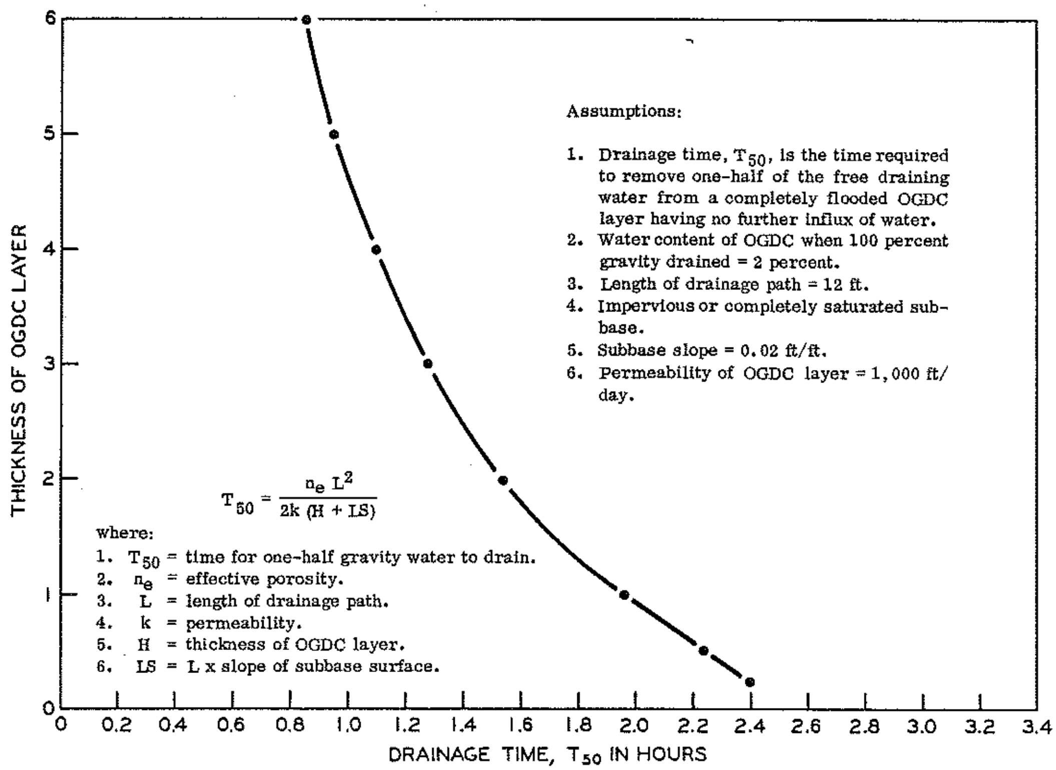


Figure 9. Relationship between drainage time and thickness of OGDC layer.

a lower stress level. Another possible explanation is that the higher rate of punching of OGDC particles into dense sand, compared to loose sand, is the result of the difference in shape of the applied loading spectrum used for the flexible and rigid pavement test conditions.

The above results could be interpreted as a clear indication that, for rigid pavements, OGDC may be placed directly on subbase sand regardless of whether the subbase is or is not subject to loss of density as a result of frost action. It is believed, however, that this study provides too little data to arrive at such a conclusion. It is also believed that frost effects could destroy the compaction plane thus altering the punching characteristics observed in this study. Therefore, it is cautioned that proper evaluation of conditions when OGDC is placed directly on subbase layers subject to frost action should require additional field and laboratory study. Additional study should be important since all 'daylighted' subbases are considered to be subject to frost action. The reason for this situation is that the drainage capacity of nearly all subbase layers is too slow (considering the quantity of water to be drained, the length of the drainage path, the hydraulic head, and the permeability of the material) to avoid freezing of the subbase while it is 100 percent water saturated.

Because of the mechanism by which frost action in the subbase layer is responsible for rutting of flexible pavement surfaces, the use of OGDC under flexible pavements is of primary concern. Because loss of subbase density, caused by frost action, results in recompaction and lateral displacement of the subbase in the wheelpaths, rutting of flexible pavement should occur whether or not filter fabric is used to separate the OGDC and subbase layers. Therefore, it is cautioned that OGDC base layers may perform satisfactorily only when the subbase will not lose density as a result of frost action. All sand grades having a water table 5 ft or more below plan grade should be free of frost action.

Non-uniform infiltration of OGDC voids and localized subbase frost susceptibility could affect the performance of flexible pavements but should have little affect on rigid pavements. Rigidity of rigid pavements should provide bridging action over small areas of greater frost or infiltration potential. As for larger areas of potential movement, the relatively small indicated total residual movement of less than 1 in. should be easily accommodated by rigid pavements. For flexible pavements, small areas of greater potential for frost or infiltration could create pavement surface distortions which could significantly reduce pavement serviceability. Such localized areas could occur at longitudinal pavement shoulder joints, and wherever bituminous cracking may occur.

In summary, it should be possible to use OGDC base layers for both flexible and rigid pavements wherever the subgrade or subbase meets the subbase gradation requirements and plan grade is at least 5 ft above the high groundwater level. However, additional study should be necessary before OGDC is routinely placed directly on a daylighted sand subbase. In this respect, greatest risk of unsatisfactory performance exists for flexible pavements. The use of filter fabric between base and subbase layers should be beneficial for rigid pavements under any subbase condition. However, for flexible pavements filter fabrics may have little or no influence in attenuating rutting caused by frost action in the subbase layer.

Conclusions

This abbreviated study was conducted to determine if OGDC bases could be expected to perform satisfactorily when placed directly on sand subbase and to evaluate the effectiveness of filter fabric for improving performance when placed between OGDC base and subbase layers. However, much of the information obtained is not specific enough to offer definite conclusions at this time. Also, the effect that subbase frost action might have on settlement of the pavement surface could not be established.

The results of this study show that unless a filter fabric separates base and subbase layers, sand will infiltrate into the voids of OGDC bases. The degree to which sand infiltration takes place will govern the performance of OGDC bases and ultimately influence pavement surface performance. Based on results of this study and presumed environmental effects, the following conclusions regarding the performance of OGDC bases appear to be warranted:

1. Rigid pavements —

a. The use of a layer of filter fabric between OGDC and subbase layers should ensure good performance of OGDC bases under any subbase condition.

b. OGDC bases having a gradation no coarser than that used for this study should perform satisfactorily when placed directly on a sand subbase when the subgrade permeability is approximately equal to or greater than that of the subbase, generally true of any area where the subgrade meets porous material class II grading requirements.

c. OGDC bases may or may not perform satisfactorily when placed directly on a sand subbase layer that is subject to a loss of density as a result of frost heave. Generally, this conclusion applies to all daylighted subbase layers.

2. Flexible pavements where the bituminous concrete layer is four or more inches thick —

a. OGDC bases having a gradation no coarser than that used for this study should perform satisfactorily when placed directly on a sand subbase when the subgrade permeability is approximately equal to or greater than that of the subbase layer.

b. OGDC bases placed directly on a daylighted sand subbase should be subject to pavement surface rutting. The magnitude of this rutting should be dependent on the following factors:

1) thickness of the bituminous concrete layers,
2) pavement design life,
3) susceptibility of the subbase to frost action.

c. A filter fabric layer placed between OGDC base and subbase layers should minimize rutting of flexible pavements. However, if the subbase is daylighted, it is not known if the presence of a filter fabric layer would be sufficient to avoid excessive premature rutting.

3. Additional study should be necessary before OGDC is routinely placed directly on a sand subbase that is daylighted or supported by a relatively impervious subgrade.

4. Laboratory study of the performance of OGDC bases can satisfactorily duplicate frost-free field conditions when the oedometer test method is used.