ENVIRONMENTALLY SENSITIVE ARTICULATED CONCRETE PAVEMENT

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SYNOPSIS

This paper describes the development and laboratory testing of a new form of articulated concrete pavement comprising precast concrete slabs linked at their corners by plastic connectors. This form of paving is designed to be laid over sand subgrades with minimal base preparation and to carry a full range of vehicular traffic up to and including light aircraft. The pavement is intended for use where vehicular access must be provided to delicate, environmentally-sensitive sand terrain or where construction must be carried out in remote or inaccessible areas using unskilled labour, simple plant and minimal importation of materials

The paper begins by briefly describing the paving system. Its application in exploratory field trials on Fraser Island, Australia, is described. The paper then reports detailed laboratory evaluations of the paving under laboratory conditions. In these tests the paving slabs were subjected to dynamic repeated loading whilst installed on fully instrumented sand subgrades. Factors studied included the contributions of the plastic connectors to structural performance, the position and magnitude of the applied loads and the effects of load repetition. Measurements included surface deformations and deflections and the distribution of subgrade stresses. The experimental data backed by field experience confirmed that this form of paving is viable for loads and numbers of repetitions similar to those likely to be applied by both trucks and medium size aircraft.

INTRODUCTION

In Australia, as in many other parts of the world, there are large area of sand terrain. Often this terrain is remote from large population or manufacturing centres and, accordingly, poses logistical problems whenever pavements must be constructed. A further complication arises because, in Australia, these areas often form part of the national park system and comprise delicate, environmentally sensitive terrain. A need therefore exists for paving systems capable of being layed in remote areas without normal construction plant and requiring only minimal importation of materials. This paper describes the evaluation of a new environmentally friendly concrete paving system developed in Australia to address these needs. The system is known as Enviropave

Enviropave is designed to facilitate rapid, non-invasive and easy construction of roads and runways over sand terrain. The system eliminates the need for excavation and the use of imported road base. Rather it uses precast concrete slabs locked together at their corners by plastic connectors to form a continuous but articulated concrete pavement. This articulated mat then uses the in-situ sand subgrade as the base. The potential benefits conferred by this system are:

a) The use of small slabs reduces the tensile stresses induced by traffic loading and, thereby, permits the use of relatively thin, light and easily transported slabs.
b) The paving does not require the use of a base or sub-base and therefore minimise environmental impact and cost.
c) The paving can be installed by unskilled labour without the need for large or heavy construction equipment.
d) The paving is as easy to lift and remove as to install and therefore is suited to temporary as well as permanent works.
e) Because the paving can be covered with sand it is suited to areas where the natural appearance of sand terrain must be preserved.

The system can be easily hand laid over a graded surface using unskilled labour. It requires no edge restraints. Once laid, sand is swept over the surface to fill in gaps, giving additional stability. Where appropriate, additional sand can be swept over the pavers to provide and maintain the illusion of a untreated natural sand surface.

The new system was first trialed in 1995 at Williams Retreat Tourist Complex on one of Australia's most unique wilderness environments, Fraser Island. As well as providing cost-effective and environmentally sensitive access to wilderness and other areas, the new system has proved to be a highly practical solution for allowing tourist bus and heavy equipment access to sensitive areas. The versatility of the system makes it ideal for construction of permanent or temporary access roads for requirements such as carrying defence forces heavy equipment. Other applications include parking areas, boat ramps, sand stabilisation, causeways, embankments, country saleyards, dairy walk-ups and feed lots. However, the principal engineering challenge is to provide all-weather runways for aircraft access to remote outback areas. To investigate the feasibility of such applications laboratory trials were initiated at the University of New South Wales in 1996. Preliminary results from these trials are described below.

PRINCIPLES OF THE ENVIROPAVE SYSTEM

Enviropave consists of concrete slabs which are 390 mm by 290 mm in plan and just 90 mm thick. They can easily be made using normal concrete precasting plant. The slabs are provided with tapered vertical holes in each corner. These enable the pavers to hook onto plastic connectors placed at the slab corners. These connectors consist of mats made from recycled plastic which are 290 mm by 290 mm in plan and which support 4 vertical spigots as shown in Figure 1. The concrete slabs are then placed over these spigots and plastic wedging cones are forced or screwed into the spigots. By this simple means the slabs are locked together to eliminate horizontal creep.

The sequence of construction operations is illustrated in Figures 1 to 3. First, the sand subgrade is screeded to level and the plastic connectors are dropped into position. Next the slabs are placed over the connectors and the wedging cones are used to lock the slabs in place. Finally, the pavement is compacted. Typically compaction is by a small vibrating plate compactor. This is the only construction equipment needed other than the small hand clamps used to lift the slab into position. The total weight of paving materials is approximately 188 kg m^{-2}. It may be seen that the system fulfils the requirements for a simple and easily transported form of paving. The arrangement of the slabs in plan is shown in Figure 4.

TESTS

Subgrade Material

All of the trials were conducted using subgrades composed of sand having the grading shown in Figure 5. This material is a typical windblown dune sand. The sand was tested in an air-dry condition (moisture content = 1.8 %). Tests of similar sand in-situ suggest that, when compacted, it achieves a Modulus of Subgrade Reaction, k, between about 60 and 100 kPa/mm.

Test Apparatus

Trial pavements were built in a specially constructed loading rig. A schematic diagram of the equipment is given as Figure 6. This consisted of a sand tank approximately 1.6 x 2.4 m in cross-section and 1 m deep. The sand subgrades were placed in this tank by pluvial compaction allowing the sand to flow freely under gravity through a constant height of approximately 1 m. This gave a dry density of 1.28 tonnes/cu m. Eight pressure cells were installed at the depths and locations shown in Figure 6. The pavements were laid directly on top of the loose sand layer. Load was repetitively applied to the pavements via a computer controlled pneumatic jack having a maximum load capacity of 14 tonnes. The vertical deformations and deflections of the slab surfaces were measured using both displacement transducers (LSCTs) and dial gauges placed at a variety of locations to measure both vertical displacements and rotations.

Test Procedure

Each test involved repetitively loading the pavements. Initially the load was set at 18.6 kN applied at a contact (tyre) pressure of 1.4 MPa. This loading condition was chosen to represent a greater contact pressure and a more concentrated load than that likely to be applied by any aircraft likely to use an Enviropave runway. In later tests, the load was increased progressively up to 55.7 kN The frequency of loading was 0.2 Hz. The tests were designed to explore the following factors:

1. The effect of load positioning and magnitude.
2. The role of compaction.
3. The contribution of the plastic connectors to the pavement performance.
4. Cost-effective methods (such as the use of reinforcing geomesh) for improving pavement performance.

Effect of Load Position and Magnitude

As shown in Figure 4, the pavements were tested with the load applied at the centre of a slab (interior loading), at the junction between four slabs (ie centred over the plastic connector) or at entirely within the corner of one slab. As shown in Figures 7 and 8 both the permanent deformations and resilient deflections were higher for interior loading than for corner loading when the slabs were layed without compaction. For these uncompacted pavements, the deformations and deflections were much higher than would normally be tolerated in trafficked pavements. For slabs layed on compacted subgrades the placement of the load had only a very small effect, As shown in Figure 9, the permanent deformations were slightly higher when the load was placed entirely within the corner of a single slab than when the load was placed at either the interior of a slab or over the junction between four slabs.

For pavements layed on compacted subgrades the effects of increasing the applied load were studied. In general, the tests were terminated once the deformations exceeded 20 mm because this represented the level at which the pavements would be regarded as becoming unserviceable. As shown in Figure 9, for loads of 37 and 57 kN, the effects of load placement were more critical than for the 19 kN load and the accumulation of deformation was more rapid. At a load of 37 kN, the pavement could withstand approximately 10 000 repetitions of load before reaching the limit of serviceability. For the 57 kN load this dropped to just 200 load repetitions.

The initial trial pavements were installed without compaction because this would represent the simplest form of construction. As laid, the pavements had joints approximately 10 mm wide separating the slabs. These joints were filled with sand. Under repeated loading it was observed that the sand rapidly settled from the joints and the slabs tended to rotate together until they touched along their upper edges. For these reasons two methods having the potential to improve performance were investigated. These comprised compaction and the use of a reinforcing geofabric mesh.

Effect of Subgrade Compaction

The effects of the support provided by the sand subgrade were investigated, for corner loading, by comparing the performance of pavements layed both loose and compacted. Compaction was achieved by applying a light vibratory plate compactor (Wacker) to the surface of the slabs after they were layed. No attempt was made to compact the loose sand before slab installation. This was done to make construction of the pavements as simple as possible. The effects of up to 10 passes of the plate compactor were studied. Most compaction occurred during the first 3 passes of the compactor with the sand exhibiting vertical deformations between 25 and 40 mm. However, as shown in Figure 10, further compaction continued with subsequent passes of the compactor, albeit at a much lower rate. Overall, the application of plate compaction produced total vertical compressions of between 50 and 60 mm despite the small size and weight of the compactor.

As shown in Figure 11, compaction had a pronounced effect of the response of the pavements to repeated loading. For the uncompacted pavement, the vertical deformation attained 90 mm at 10 000 load repetitions. By contrast, the compacted pavement exhibited permanent deformations of only about 8 mm at 20 000 repetitions.

In the case of the resilient (elastic) deflections the effects of compaction were to reduce the deflections from between 2 and 4 mm to approximately 0.3 mm. This is shown in Figure 8. It was also observed that, in the compacted pavements, the sand tended to be retained in the joints when the slabs were subjected to repeated loading.

Overall, the results demonstrated that the effects of compaction, even with a light compactor, were highly beneficial to pavement performance under repeated load. However, from Figure 10, it may be seen that 10 passes of the compactor did not produce a shakedown condition. This indicates that the use of more passes, a heavier compactor or pre-compaction of the subgrade might be expected to produce further improvements in performance. Such improvements are likely to be small because, as shown in Figures 9 and 10, the use of just 10 passes of the plate compactor was already sufficient to yield good levels of performance.

Effects of Mesh Reinforcement

The use of a geofabric mesh was studied as an alternative or supplement to compaction. The mesh had an aperture size of 6 mm and was laid directly on top of the loose sand subgrade beneath the plastic connectors and slabs. As shown in Figure 10, the presence of the mesh reduced the vertical deformations induced by the plate compactor by about 50%.

For uncompacted pavements the use of the mesh reduced the load-induced permanent deformations by about 25% and also slightly reduced the resilient deflections. This is shown in Figures 8 and 11. From these figures it may be seen that the use of the mesh combined with compaction produced only a small reduction in deformation and deflection in uncompacted pavements. For the compacted pavements the deformations and deflections were slightly higher in the pavements incorporating the mesh. This suggested that the mesh may have impeded compaction of the subgrade.

From these test data it was concluded that, although the use of a geofabric mesh was beneficial to both the permanent deformation and resilient response of uncompacted pavements, it did not provide a viable alternative to the use of compaction nor did it yield sufficient performance improvement to warrant its use to supplement compaction.

Effects of the Connectors

In previous paving systems based on the use of small slabs, connection between the units has usually been by means of steel bolts or dowells (eg 1). These systems have attempted to achieve load transference from one slab to the next. By contrast, the plastic connectors used in the Enviropave system have relatively low rigidity and might be expected not to provide much load transference from slab to slab. Furthermore, as noted above, for uncompacted pavements, there were significant deformations and deflections under load in the trial sections. These movements were accompanied by rotations of the slabs and the contribution of the plastic connectors to the structural performance of the pavements was not clear. For this reason, a pavement was installed without connectors and was subjected to loading distibruted over the corners of four adjacent slabs. This pavement failed during the first load application with the deformation exceeding 50 mm. This demonstrated that the connectors did, in fact, significantly contribute to structural performance under load ie their role was not just to locate the slabs relative to one another. In this respect, it is important to note that, as shown in Figure 4, the connectors had a base 290 mm square bearing directly on the subgrade. This means that corner loads on the slabs were more widely distributed than if the slabs had been placed directly on the subgrade. Moreover, for the load levels used in the tests, there was no significant faulting or stepping between adjacent slabs. This indicated that load transference was adequate for the proposed traffic load levels.

Load Distribution

Typical distributions of vertical stress are shown in Figure 12 for interior and corner loading respectively. It may be seen that there was little difference in the stresses induced by edge and corner loading. However, where the plastic connectors were omitted from the pavement, the stresses induced at depths above 300 mm were much greater than those for the systems installed with connectors. This provided further evidence of the important structural role of the connectors.

The effects of load repetition on the distributions of stress were not clearly defined. The stresses measured immediately below the slabs tended to increase with load repetition for both interior and corner loading. At depths of 150 mm or more below the slabs the stresses tended to increase slightly with load repetition for interior loading and to marginally decrease for corner loading. In the early stages of load repetition the greatest stress was usually measured at a depth of 150 mm rather than immediately below the slabs (Figure 12).

Overall, there was no evidence of the uncompacted pavements either stiffening or weakening due to load repetition. However, where the pavements were compacted the stresses measured immediately below the slabs consistently decreased with load repetition. This is shown in Figure 13. Initially, as may seen from Figures 12 and 13, the stresses in the compacted pavements immediately below the slabs were higher than for the uncompacted pavements. Thereafter, there was progressive stiffening of the compacted pavements under simulated service loadings ie the slab mat gradually accepted more of the applied load with stress repetition.

If the sand subgrade is modelled as an elastic half space it is possible to use the well known analyses by Steinbrenner (2), Fadum (3) and others to predict the theoretical distribution of stress. For example, in Figure 14, the predictions of Fadum's theory are shown superimposed on the measured stress distributions at 1 and 20 000 load cycles for a compacted pavement. It may be seen that Fadum theory underestimated the stresses beneath the slabs especially at shallow depths during the initial stages of loading but slightly overestimated the stresses at all depths once the pavements had stiffened under repetitive loading. Custom analyses for Enviropave are yet to be developed. However, as shown in Figure 14, the use of Fadum charts etc for designing and analysing Enviropave pavements is likely to prove acceptably conservative in the interim.

CONCLUSIONS

The principal conclusions of the study were:

1. Enviropave sections exhibited much greater resilient deflections than would normally tolerated in either conventional rigid or flexible pavements. For uncompacted pavements, deflections of up to about 8 mm were recorded although, for compacted sections, the deflections were generally less than 0.3 mm. It is important to note, however, that these large deflections had no adverse impact on in-service performance because of the articulated nature of the paving. Rather, the performance of the Enviropave sections could be defined solely in terms of the permanent deformations caused by traffic.

2. For loads up to 18.5 kN applied at contact pressures of 1.4 MPa, it was possible to achieve good levels of performance where the slabs were loaded up to 20 000 times in the one position using corner loading. The deformations were then less than 8 mm and the deflections were below 5 mm. Doubling the applied load to 37 kN produced deformations of 20 mm by about 10 000 load repetitions. However, further increase in load to 57 kN led to the rapid accumulation of deformation with the limits of serviceability being reached by about 200 load repetitions. Overall, these levels of performance can be regarded as being more than satisfactory for the proposed applications where the traffic loads will be widely distributed over the pavement surface and will typically be less than 20 kN in magnitude.

3. The plastic connectors were an integral and indispensable part of the EnviroPave system. Much of the structural integrity of the system derived from the mats despite their low structural rigidity.

4. At the load levels studied, satisfactory performance of the trial pavements under repeated loading could not be achieved where the slabs were laid directly on loose sand without compaction.

5. Placing a 6mm geofabric mesh on top of a loose sand subgrade improved the performance of the uncompacted trial sections in terms of both permanent deformations and resilient deflections. However, the use of the mesh was not an adequate substitute for compaction as the deformations remained higher than would be desirable in service.

6. Placing the slabs on loose sand and then compacting the pavements with a plate compactor significantly reduced the deformations induced by repetitive loading. Only 10 passes of the compactor were studied but the data suggested that more compaction would have improved performance, albeit slightly.

7. The data from the pressure cells showed that the stress conditions under the Enviropave mats could be approximated using existing, simple widely available analysis methods such as Fadum Charts. This should assist the development of design procedures.

Overall, this new system of articulated concrete slabs provides a viable technique for paving over unprepared dry sand subgrades carrying loads up to and including those typical of medium size planes widely used to service remote regions of Australia.. Further work is being conducted to assess the effects of moisture in the subgrade.

FIGURE CAPTIONS

Figure 1. The plastic connector mat.

Figure 2. Installing the slabs on the plastic connectors

Figure 3. The cones use to lock the slabs onto the plastic connectors

Figure 4. Schematic plan view of the paving system.

Figure 5. Grading of the sand subgrade.

Figure 6. Schematic diagram of the test rig.

Figure 7. Deformation of pavements laid on uncompacted subgrades

Figure 8. Resilient deflection of pavements laid on uncompacted subgrades.

Figure 9. Effects of load position and magnitude.

Figure 10. Effects of compaction.

Figure 11. Effects of geomesh on pavement performance.

Figure 12. Distribution of stress with depth below the slabs

Figure 13. Variation of the stress just below the slabs with load repetition.

Figure 14. Comparison of measured and theoretical stress distributions.

Figure 1. The plastic connector mat.

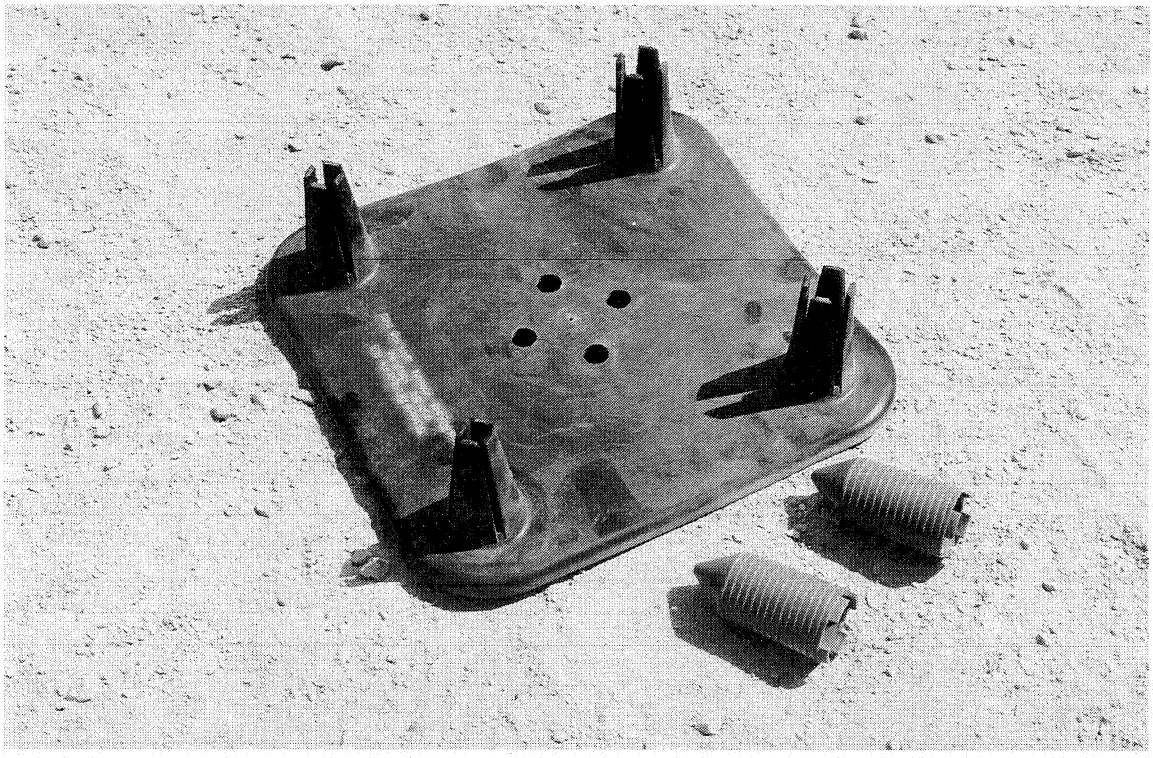


Figure 2. Installing the slabs on the plastic connectors

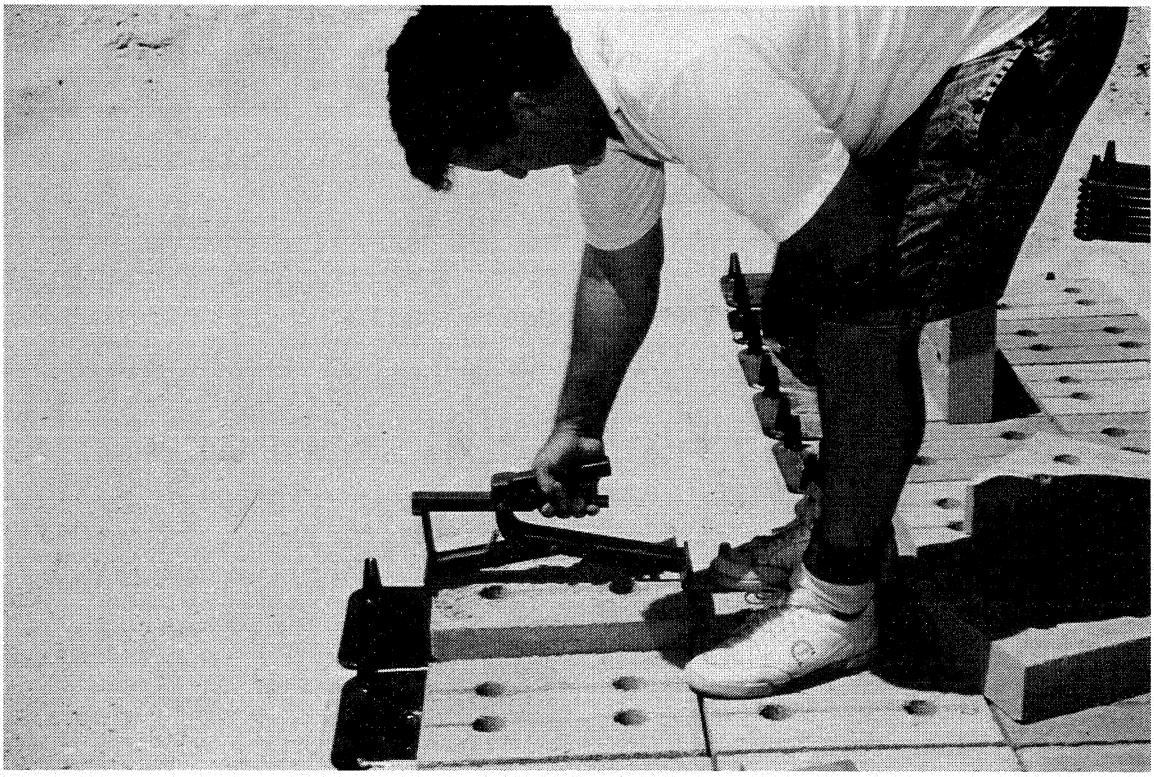


Figure 3. The cones use to lock the slabs onto the plastic connectors

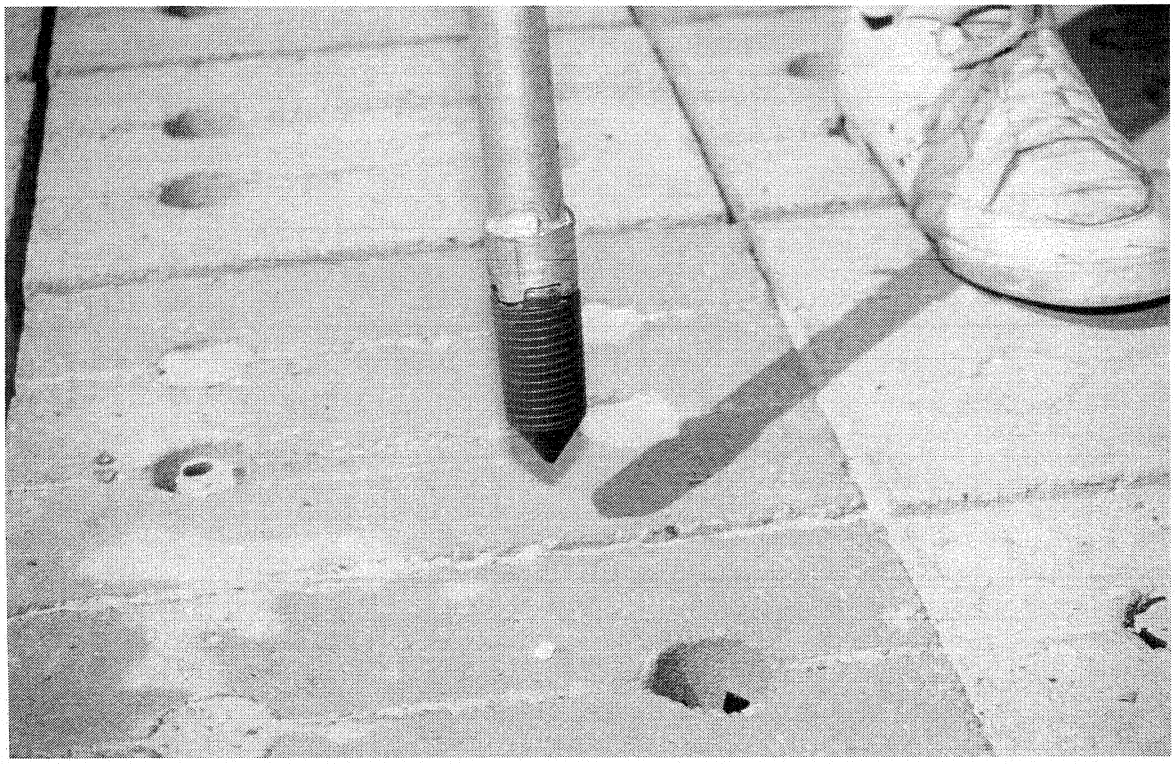


Figure 4. Schematic plan view of the paving system.

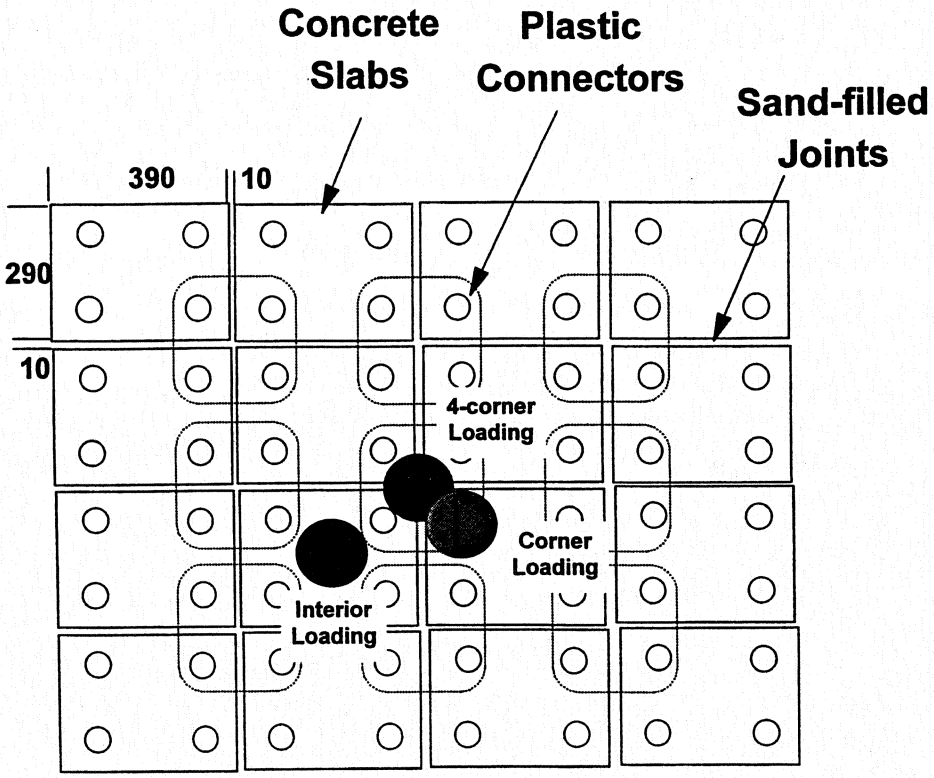


Figure 5. Grading of the sand subgrade.

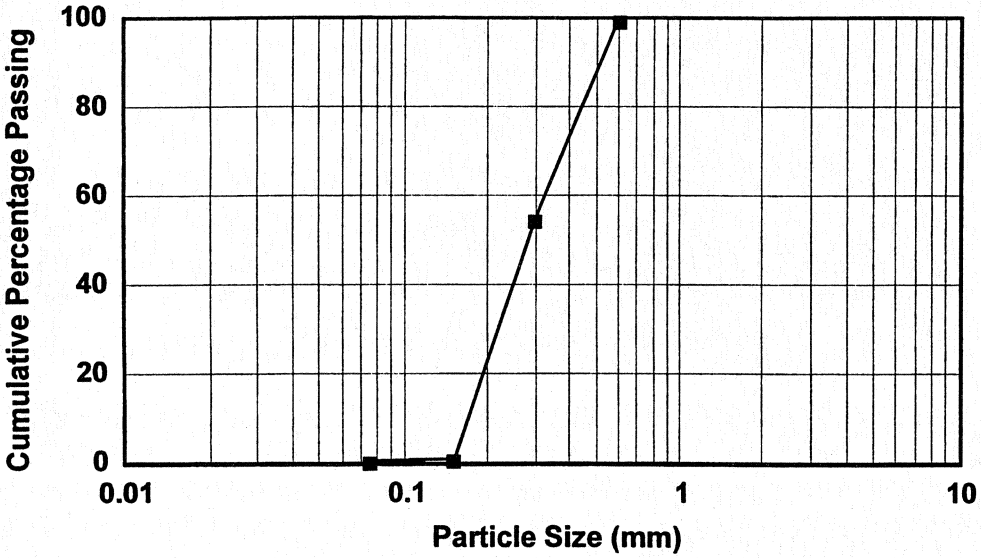


Figure 6. Schematic diagram of the test rig.

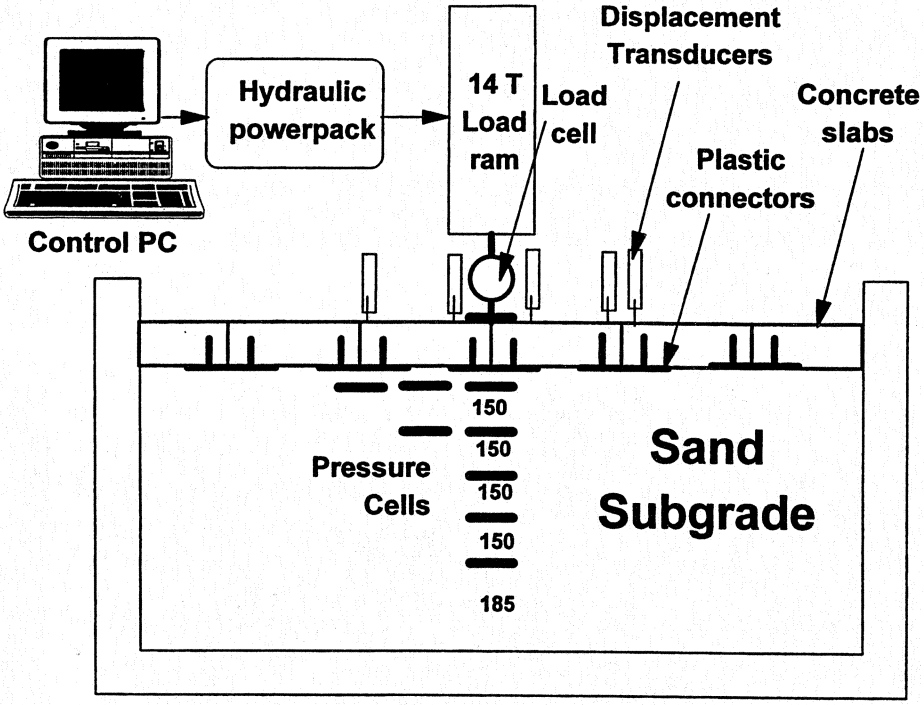


Figure 7. Deformation of pavements laid on uncompacted subgrades

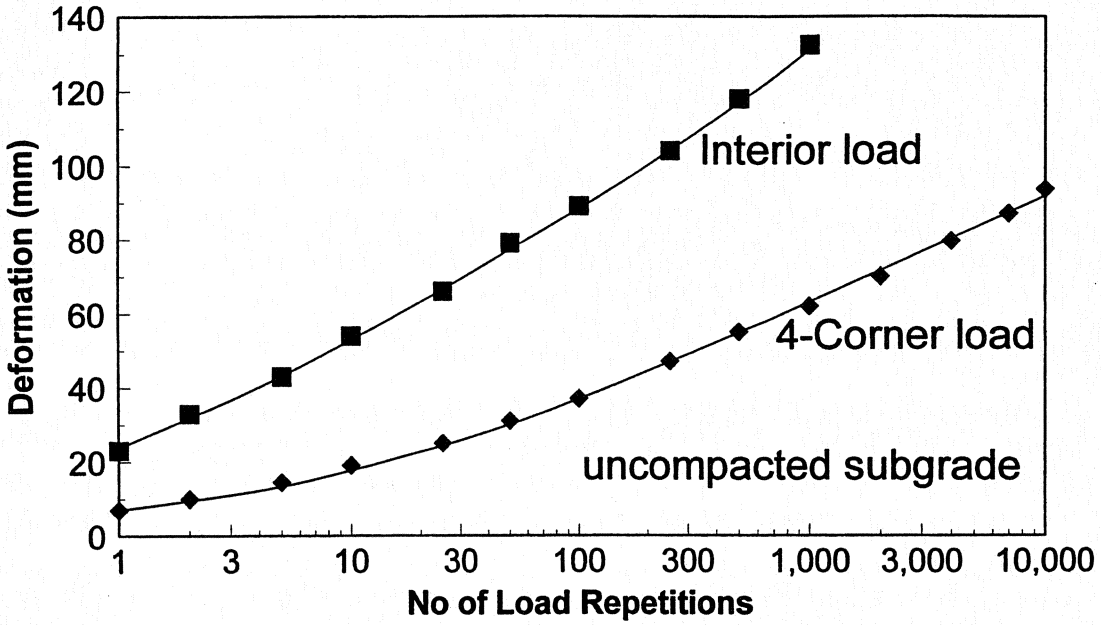


Figure 8. Resilient deflection of pavements laid on uncompacted subgrades.

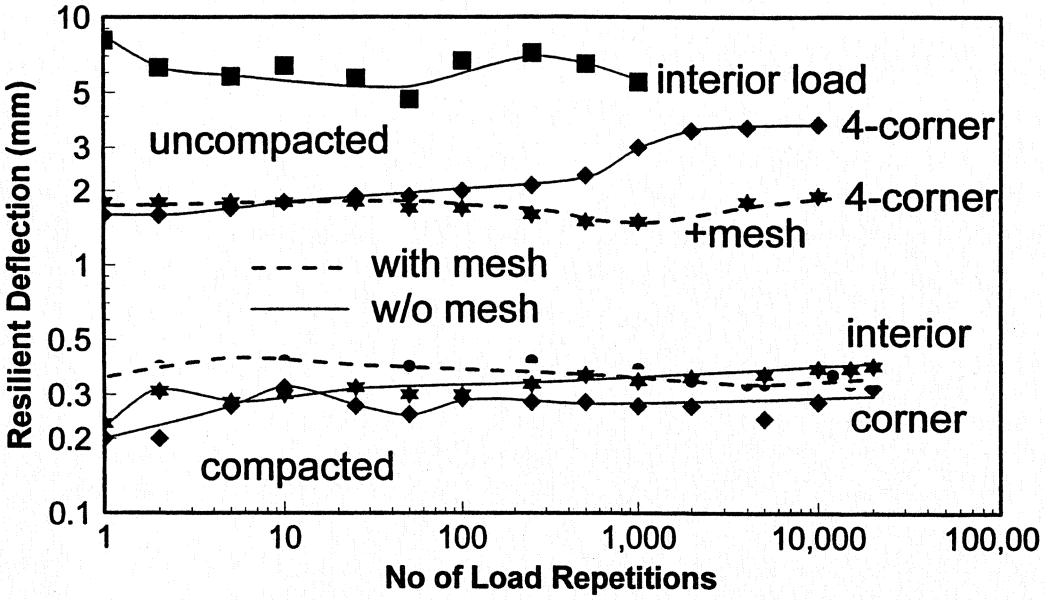


Figure 9. Effects of load position and magnitude.

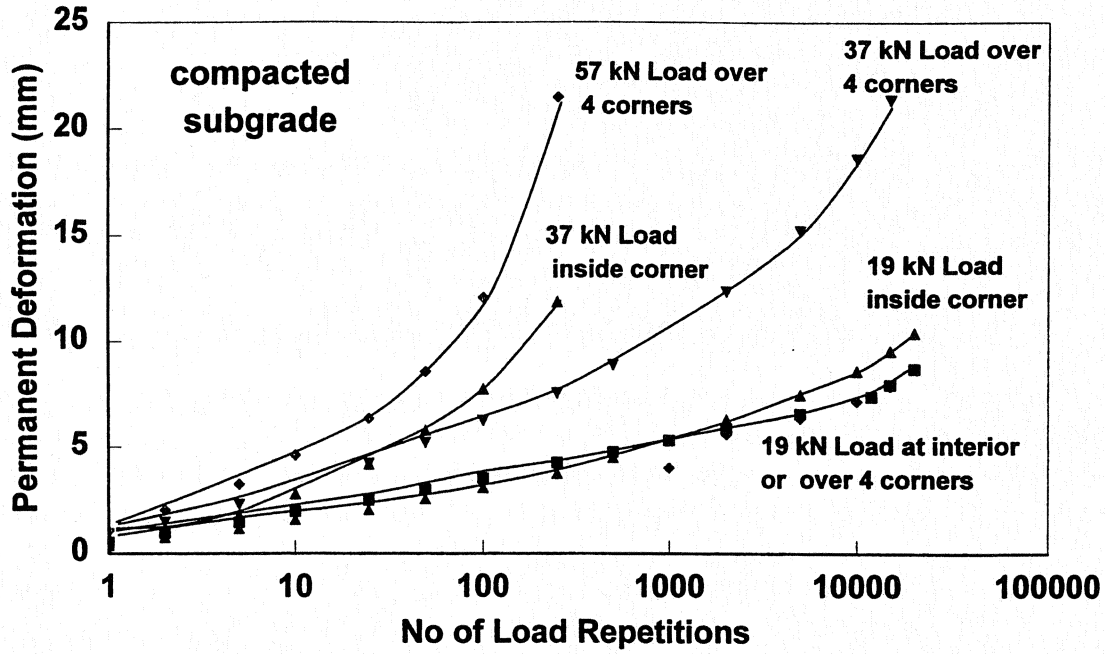


Figure 10. Effects of compaction.

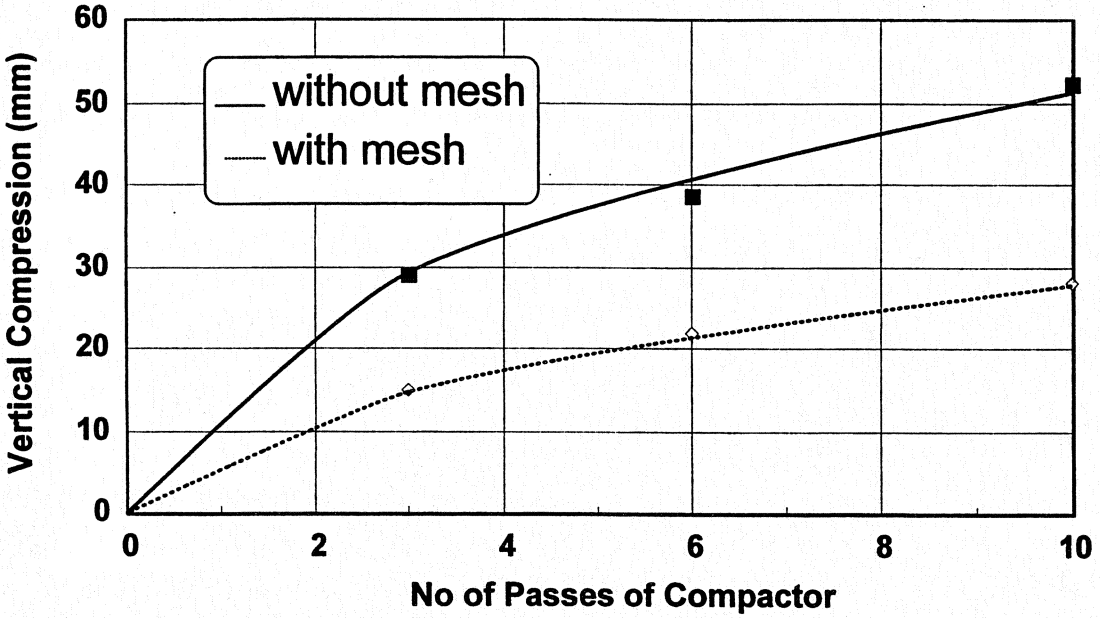


Figure 11. Effects of geomesh on pavement performance.

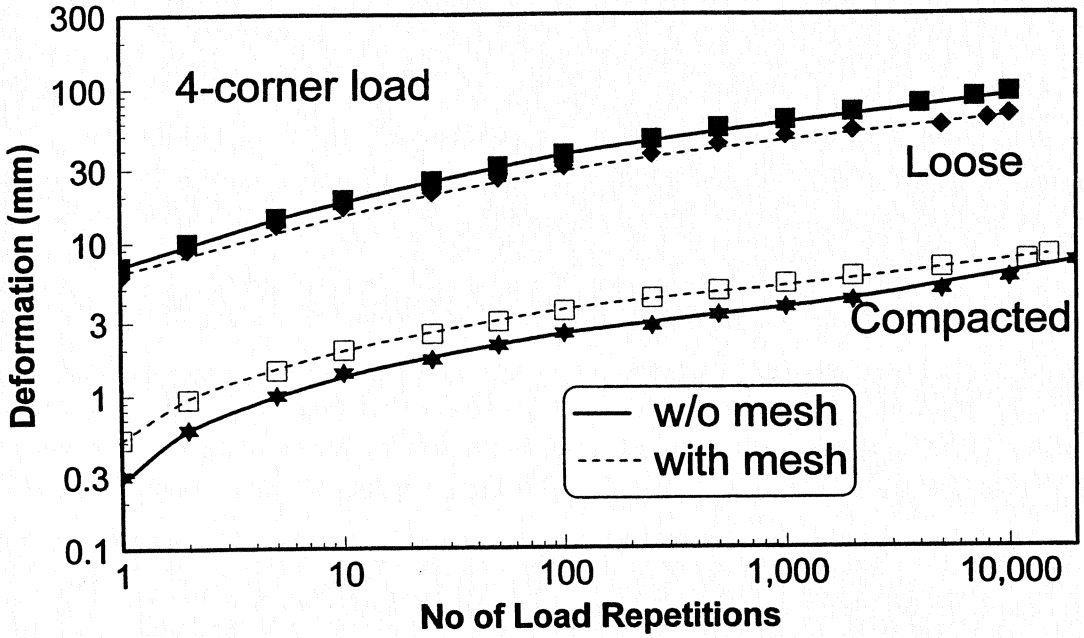


Figure 12. Distribution of stress with depth below the slabs

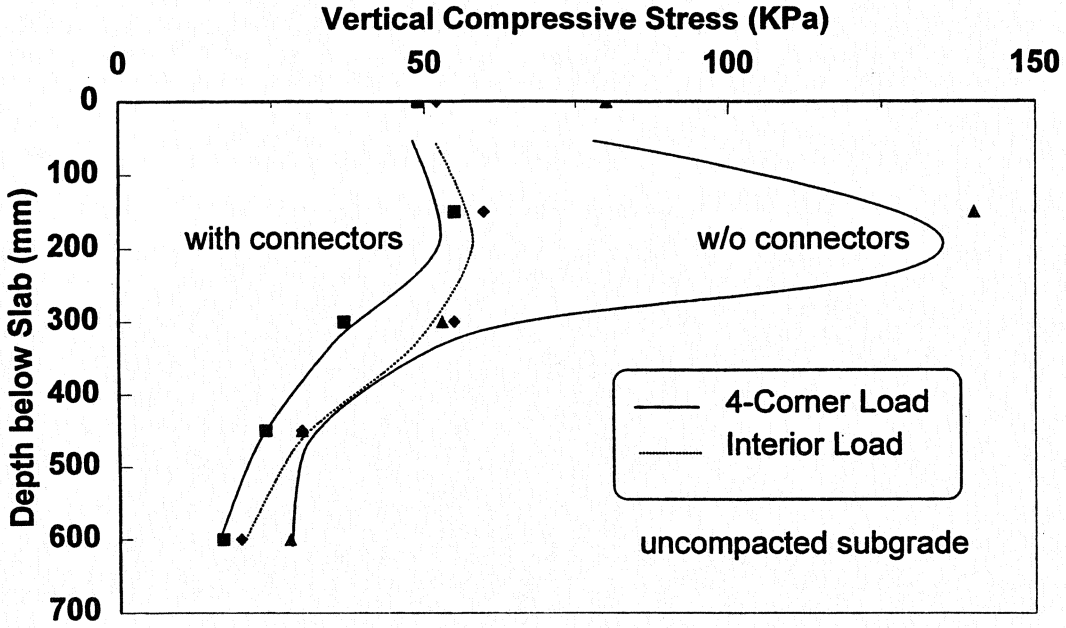


Figure 13. Variation of the stress just below the slabs with load repetition.

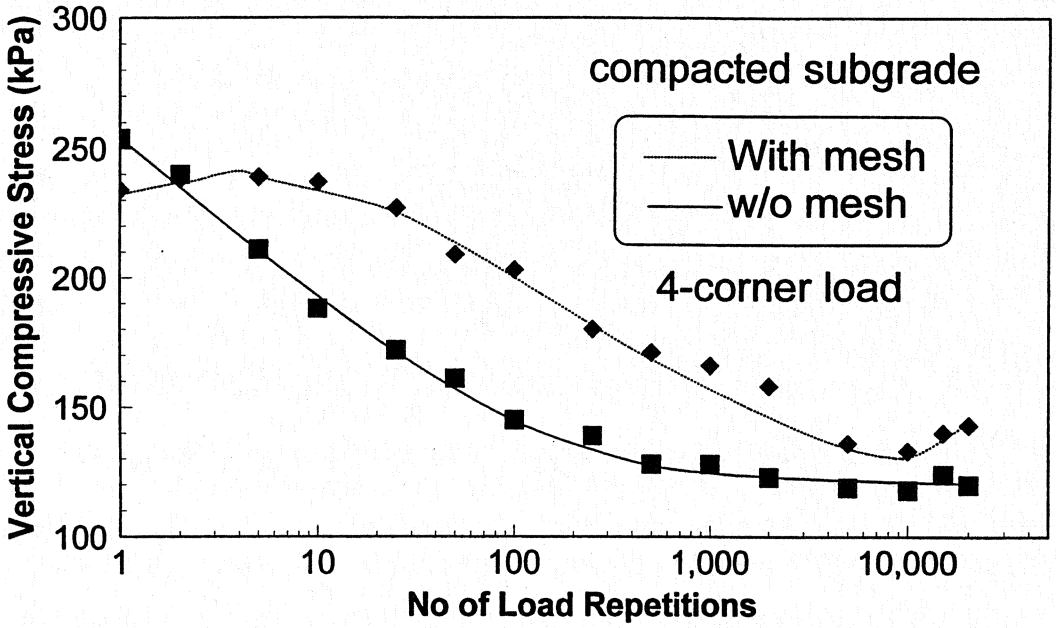
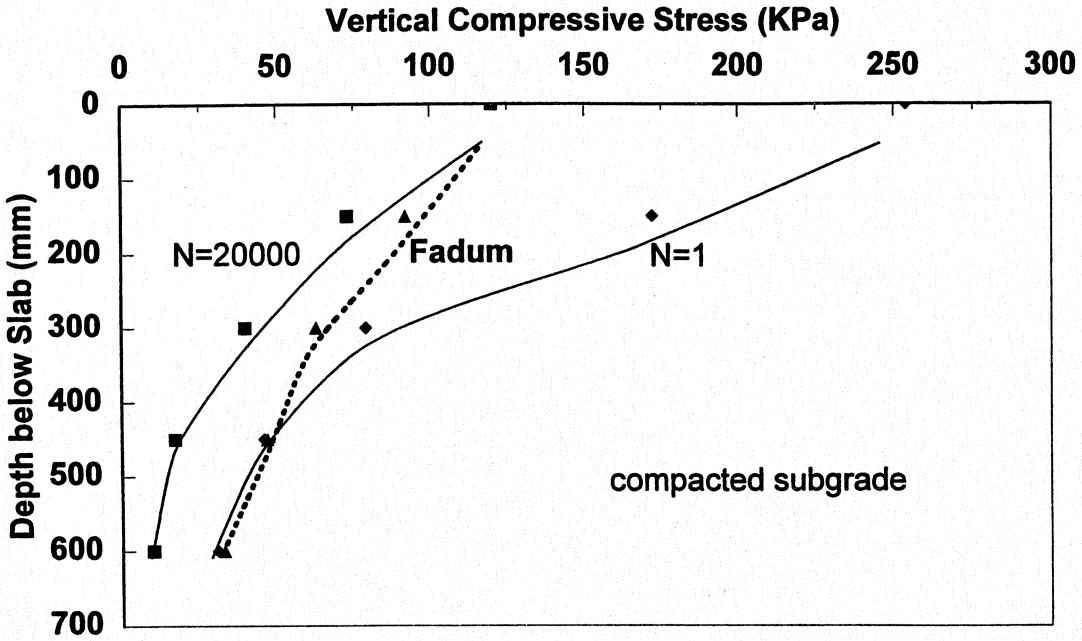


Figure 14. Comparison of measured and theoretical stress distributions.



REFERENCES

1. Central Road Research Institute, India (1984) The development of special purpose paving blocks in India, *Proc 2nd Int Conf. On Concrete Block Paving,* Delft .pp 387-344.

2. Steinbrenner (1934). *Tafeln zur Setzunsberechung*. Schriftenreihe Strasse 1, S121

3. Fadum. (1948) Influence values for estimating stresses in elastic foundations. *Proc 2nd Int. Conf on soil Mechanics and Foundation Engg,* Rotterdam, Vol 3,pp77.

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