THE PERFORMANCE OF CONCRETE BLOCK SURFACING ON A CEMENT-BOUND BASE IN AIRFIELD PAVEMENTS

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SUMMARY

As part of an ongoing development programme on the use of Concrete Blocks on airfield pavements, research was carried out into the structural contribution of Concrete Block Surfacing on a cement-bound base. An experimental pavement was constructed and trafficked by 10 000 load repetitions of a 10 tonne wheel load. The structural contribution of the Concrete Block Surfacing has been assessed from measurements of vertical subgrade strain.

Other aspects of the construction and performance of Concrete Block Surfacing were examined, including the development of rutting, two methods of placing the sand laying course, the upsurge of sand laying course into the joints during construction and its effect on performance, the effect of using a vibrating roller as the last stage of the construction, and the applicability of deflection measurements in determining the pavement strength.

It was found that the Concrete Block Surfacing contributed little to the structural strength of the pavement. During the trafficking the Concrete Block Surfacing developed 6 to 8 mm ruts with a small amount of heave. The different methods of placing the sand laying course and the amount of upsurge in the joints had no significant effect on the structural performance. Partial pre-compaction of the sand laying course during placing improved the upsurge. The vibrating roller had some effect on the amount of rutting that occurred during early trafficking, although the final rut depth was not significantly affected by the rolling. Falling Weight Deflectometer and Benkelman Beam measurements were affected by the sand laying course, even after trafficking.

INTRODUCTION

Concrete Block Surfacing (CBS) is an increasingly popular form of pavement surfacing that has some potential advantages in airfield pavement applications. In particular it can provide many properties of a concrete surface, giving a relatively thin rehabilitation layer for concrete pavements or allowing the use of flexible pavements in situations where the standard practice would be to use a rigid (concrete) pavement.

An investigation was carried out to assess the structural performance of CBS as part of the standard PSA Airfields Branch new construction both with regard to its contribution to the bearing capacity of a pavement and its ability to withstand long-term trafficking. At the same time the opportunity has been taken to examine the effect of certain construction techniques on the performance and to appraise the suitability of common methods for testing pavement strength when used on CBS.

The use of CBS for airfield pavements involves some significant changes in comparison with the conditions under which the CBS has been tested in most research to date. These include:

i) the use in flexible pavements comprising CBS on relatively weak cement-bound bases,

ii) higher loads and tyre pressures,

In 1984 PSA Airfields Branch undertook an investigation for Luton Borough Council into the structural performance of CBS overlaying a concrete pavement at Luton Airport (1). Plate Bearing tests were carried out on an asphalt surface on the concrete, on the concrete after removal of the asphalt and on

the finished CBS. This work was the origin of the provisional equivalency of CBS to 100 mm bituminous surfacing suggested by a number of sources (1), (2) .

The equivalency was regarded as provisional as there was no evidence to show that it applied to all forms of pavement construction. For new pavements the most obvious form of construction for CBS is a flexible pavement with a cement-bound base. The PSA Airfields Branch philosophy for design of this type of pavement is to use a relatively weak material - Dry lean Concrete (DLC) - which cracks rapidly under loading, transferring more of the load to the subgrade and eventually acting as a flexible pavement. Additional evidence was required on the structural contribution of CBS to this type of pavement.

The tyre pressures on airfield pavements can be as high as 325 psi. Given the reports of rutting occurring due to failures in the sand laying course of CBS evidence of the ability of CBS to withstand tyre pressures greater than those found on road vehicles was also necessary.

PSA Airfields Branch experience had also suggested that two other areas of CBS required some investigation:

i) The upsurge of sand from the sand laying course into the gaps between blocks.

i) The effect of the sand laying course on deflection measurements.

The following aspects of the performance of CBS have been examined in accelerated testing under controlled conditions:

i) The structural contribution of a CBS laid on DLC. However, when new the elastic stiffness of DLC is of the same order as that of concrete and a cracked state takes some time to develop. It was therefore decided to use an existing DLC pavement that had reached a substantially cracked condition, to examine the CBS under the conditions in which it would be working some time into the pavement life.

ii) The long-term performance of the CBS, in terms of the rutting developed under concentrated trafficking by a moderately high wheel load and tyre pressure (the maximum within the test facility).

iii) The effect of the method of placing the sand laying course on the performance of the CBS. The British Standard usually adopted for the laying of CBS in the UK (3) allows the sand laying course to be placed as a single uncompacted layer, with all compaction taking place after laying the blocks, or by pre-compacting the first two-thirds of the finished layer thickness and then spreading the final third uncompacted before laying the blocks and compacting. The first method has generally been used by PSA Airfields Branch because it has been felt that the uncompacted sand would be easier to force in the joints between blocks improving interlock. However, it has also been felt that the uncompacted sand may not behave as well under trafficking so the specification calls for final compaction with a 6 tonne vibrating roller to try to increase the density of the sand to an acceptable level. It is possible that the pre-compaction may improve the performance of the sand laying course under trafficking.

iv) The effect of the 6 tonne vibrating roller on the properties of the CBS.

v) The applicability of deflection measurements by Falling Weight Deflectometer (FWD) and Benkelman Beam on a CBS to the evaluation of the pavement strength.

THE INVESTIGATION

A CBS was constructed and tested in the Pavement Test Facility (PTF) at the Transport and Road Research Laboratory (TRRL). The work was supervised by members of the Pavement Engineering Division of TRRL.

The existing pavement on which the CBS was to be laid consisted of a 200 mm nominal thickness DLC base overlaying 2.8 m of heavy clay subgrade of CBR 8 to 11%. The subgrade was instrumented with gauges to measure the vertical component of subgrade strain. Six gauges were installed along the trafficked line of the pavement with their centres 200 mm below the surface of the clay.

FWD testing indicated that a substantial reduction in modulus of the DLC had occurred as a result of previous testing, in which 23 000 repetitions of a canalised 100 kN wheel had been applied.

The CBS using 80 mm thick rectangular paving blocks complying with BS 6717: Part 1: 1986 (4), was applied to the 10 m long by 2.4 m wide pavement. It was laid in accordance with a current PSA Airfields Branch specification but with modifications to allow different laying course sand thickness and compaction techniques. It was tested by applying 10 000 repetitions of the PTF machines 100 kN rolling test wheel. The central 7 m section of the constructed pavement was tested at 20 kph.

To prevent movement of the block surfacing under the action of the test wheel, restraints were provided around the periphery of the existing pavement. Side restraints consisting of 100 mm angle irons were anchored in place using metal staves, and timber restraints were rawl-bolted into the DLC at each end of the pavement. The end restraints reduced the actual length of the CBS to 9 m.

To investigate the effect of different construction techniques, a 5.5 m length of the block surfacing was laid on uncompacted laying course sand, the remainder being laid on sand of which the lower two thirds had been pre-compacted .

Initial compaction of the blocks and part pre-compaction of the laying course sand was achieved using a pedestrian operated, front loaded vibrating plate compactor. Sufficient applications of the compactor were made until no further compaction occurred and a smooth surface profile was obtained.

After compaction, joint filler sand was brushed over the surface of the block pavement, the ingress of sand into the joints between the blocks being encouraged by a further application of the compactor. The pavement was then sprayed with water to further accelerate this ingress. After allowing the surface of the blocks to dry, a further application of joint filler sand and final application of the compactor was made. Finally the pavement was subjected to eight passes of a 6 tonne deadweight single-drum vibrating roller J

Before constructing the block surfacing, measurements were made on the existing pavement to establish a control datum. Measurements included pavement deflection using both the FWD[1] [2] and Benkelman beam, surface profile derived from optical levels and surface rut measured under a 2 m straight edge. In addition, 500 bi-directional repetitions of the 100 kN wheel were applied to the pavement. Measurements of transient subgrade strain were recorded.

During construction the measurements were repeated, except the rolling wheel test. Surface evenness under a 3 m straightedge was also measured. Measurements were made both before, and again after, the application of the roller. In addition, the upsurge of laying course sand and ingress of joint filler sand occurring between the blocks was measured, again before and after applying the roller, by carefully removing blocks over a 500 mm square area

[1] Bomag, Type BW172AR (Hydrostatic), 6 tonne working weight, self propelled, single drum vibrating rubber tyred roller

[2] Dynatest 8081 Heavy Weight Deflectometer

in both constructions at each end of the pavement. Contrary to expectations, no upsurge had occurred in the section constructed on uncompacted sand. In view of this the work was extended to include the reconstruction and testing of the block surfacing.

However, before reconstruction 10 000 repetitions of the machines canalised 100 kN wheel were applied to the existing block surfacing. The pavement was maintained at a temperature of 15°C for the duration of the test. Measurements of transient strain were recorded, regularly during the initial phase when the measured parameter was changing rapidly, but less frequently as the number of load repetitions increased and the rate of change reduced. Rut development in the wheelpath, measured under a 2 m straightedge was recorded after the completion of each 500 load repetitions.

On completion of the test, measurements including FWD, Benkelman beam, pavement profile and rut measured under the 2 m straight edge were again recorded.

Finally the block surfacing was removed from the test bay. This operation allowed a detailed study of laying course sand upsurge to be made.

Before reconstructing the block surfacing, trial compactions were undertaken on the drylean base to investigate the effect on sand upsurge of different numbers of applications of the pedestrian operated vibrating plate compactor.

The construction and measurements procedures previously detailed were adhered to during the reconstruction with the exception that the single drum vibrating roller was not applied following initial compaction using the vibrating plate compactor. The concrete blocks were reused, except those in the original wheelpath, which were discarded. Fresh laying course and joint filler sands were supplied.

The upsurge of laying course sand and ingress of joint filler sand was again assessed using the method previously described.

The reconstructed pavement was tested by applying a further 10 000 repetitions of the machines canalised 100 kN wheel. The measurements previously detailed were repeated.

On completion of the test, measurements were made on the block surfacing and again on the exposed DLC base after removal of the blocks. As before, these included FWD, Benkelman beam, pavement profile and rut depth measured under the 2 m straightedge.

Finally, after removal of the block surfacing a further 7 000 repetitions of the canalised 100 kN wheel were applied directly on the exposed surface of the DLC base. Infrequent measurements of transient strain and deflection were recorded together with regular inspection of the condition of the DLC material.

RESULTS

Structural Equivalency Factor

The results of the vertical subgrade strain measurements are summarised in Figure 1. In general there is no indication of any significant improvement in the strain-load repetition curves that might indicate the occurrence of lock-up.

The structural contribution of the CBS to the performance of the pavement has been assessed from the measurements of vertical subgrade strain. The principle that the strain is related to the stiffness of the overlying pavement has been used. This should be represented in the difference between the strains immediately before and after the laying of the CBS. In addition if the CBS does have a structural contribution and increases the strength of the pavement overall, the rate of increase in strain with load repetitions should also decrease.

The calculations have been carried out in the following stages:

i) determine the percentage reduction in the vertical subgrade strain after laying the CBS,

ii) estimate the stiffness of the DLC base and subgrade from the FWD measurements before laying the CBS,

iii) calculate the percentage decrease in the vertical subgrade strain if the thickness of the unsurfaced DLC is increased, and plot the decrease against the thickness,

iv) from the results of Stage i and the plot of percentage decrease in strain against DLC thickness determine the equivalent thickness of DLC,

v) find the structural contribution of the CBS by subtracting the actual DLC thickness from the equivalent thickness.

The result is an equivalency of CBS to DLC with the stiffness found in Stage ii, which can then be converted to an equivalency to bituminous surfacing. In this final stage the Odemark method of equivalency has been adopted (5), i.e.:

$$h_{2e} = h_1 \times \sqrt[3]{\frac{E_2\ (1 - \mu_1^2)}{E_1\ (1 - \mu_2^2)}} \qquad (1)$$

where

h_1 = Thickness of Material 1

h_{2e} = Equivalent Thickness of Material 1 in terms of Material 2

E_1, E_2 = Elastic Stiffness

μ_1, μ_2 = Poisson's Ratio

A lower bound value for the stiffness of bituminous surfacing of 3000 N/mm^2 was used.

The elastic stiffnesses of the DLC base and subgrade before the construction of the CBS have been calculated by back-analysis of the FWD deflection basins. The pavement structure adopted is shown in Figure 8. A linear elastic subgrade model has been used. The calculations were undertaken with the Shell Multi-layer Elastic Analysis program BISAR (6).

The effect on the vertical subgrade strains of increasing DLC thickness was also calculated using BISAR.

Strains under the unsurfaced DLC were compared with those under the CBS on DLC, at the beginning and end of each trial, for the uncompacted and pre-compacted sand sections. The results are variable, with no clear cut difference between the two sections or the two trials, and are not easy to interpret because of the recovery in subgrade strains that occurs whenever trafficking is halted for a relatively long period. However, it is clear that the decrease in strains is less than 10%, and more generally in the range 2 to 5%, although for the pre-compacted sand section of Trial 1 there is no apparent decrease. The performance at the end of Trial 1 does appear to be slightly better than at the beginning. After Trial 2 trafficking was continued on the unsurfaced DLC which began to fail dramatically, with wide cracks opening up on the pavement surface either side of the wheel and acting as hinges in the structure. It was not possible to determine the actual condition of the DLC under the CBS after Trial 2 and therefore it is not possible to be certain if the CBS was actually contributing greatly to the pavement performance or if it was coincidental that serious failure of the DLC occurred soon after the end of Trial 2.

It proved possible to back-analyse the FWD deflection basins for the tests on DLC at the beginning of Trial 1 and for the test on the DEC under the uncompacted section at the end of Trial 1. The results indicated an elastic stiffness of DLC of about 6000 N/mm^2 at the beginning of the testing, decreasing to about 2500 N/mm^2 at the end of Trial 1. In the other cases it was apparent that multi-layer elastic theory assuming semi-infinite homogenous and isotropic layers was no longer able to model with any degree of accuracy what had actually become a semi-particulate material.

Based on the calculated elastic stiffnesses for the DLC the measured decreases in subgrade strain represent an effective increase in DLC thickness of less than 10 mm, and generally between 4 to 6 mm. The equivalent thickness of bituminous material would be 8 to 10 mm.

As a check the vertical subgrade strain against load repetition curves for Trials 1 and 2, and for the last 10 000 load repetitions of the previous testing on the DLC, have been plotted inFigure 1, for the uncompacted and pre-compacted sections. The rate of increase of the vertical subgrade strain with load repetitions can be seen to be very similar at the end of the DLC testing and at the beginning of Trial 1, confirming that the CBS has little effect. The performance in Trial 2 is better especially when considering that the DLC had deteriorated substantially.

The results of Trial 2, together with the sharp deterioration of the DLC during trafficking after the removal of the CBS at the end of Trial 2, suggests that the performance of the CBS may improve as the condition of the DLC deteriorates.

Long-term Trafficking

The long term performance is demonstrated in Figure 2 which shows typical variations of levels, and Figure 3 which shows the development of rutting. The rut depths have been adjusted to allow for the deformation of the original DLC surface. The level results were similar for both sections in both trials.

The results show that although some permanent deformation has occurred in the DLC the majority of the rutting has taken place in the sand layer, accompanied by a small amount of heave. The width of the rut is similar to the width of the tyre. The rutting after 10 000 load repetitions lies in the range 6 mm to 8 mm. In both Trials the rut in the pre-compacted sand was greater than that in the uncompacted sand, but the difference is not statistically significant. The rutting initially developed at a high rate before levelling out, and then continuing to develop roughly linearly with load repetitions. The high rate continued for longer in Trial 2 than in Trial 1, but the final values were very similar.

The high rate of rutting early in the pavement life shows that the compactive effort applied during construction is less than that applied by the wheel load. Compaction therefore continues during trafficking until the density of the sand is adequate for the load. The difference in the period for which a high rate of rutting occurs, suggests that the roller has had some effect in stabilizing the CBS.

The presence of heave indicates that the final rut is at least partially caused by displacement as well as compaction of the sand laying course. The shear strength of the sand laying course may therefore present a practical limitation on the maximum tyre pressure.

Rolling

As shown in Figure 2 there was little change in levels after rolling, and no appreciable difference between the behaviour of the uncompacted and pre-compacted sand was observed during rolling. The roller appears to have little effect on the compaction of the sand laying course, and no effect on the upsurge as shown in Table 1.

The Benkelman Beam and FWD tests show an increase in the deflections after rolling and it was suspected that the roller may have caused some damage to the DLC. This was possibly due to the dynamic effects of vibration on the

already cracked material as the effective static compactive effort of the roller, even with vibration, was lower than the wheel loading.

The rate at which rutting developed in Trials 1 and 2 suggests that even if the roller has had little effect on the relative density in the sand, it does stabilize the sand laying course to some degree, restricting that rate at which rutting develops. However, the final rut depth appears to be related to the compactive effort of the live load, independent of the rolling.

Sand Upsurge

The depths of upsurge from the sand laying course into the joints are shown in Table 1 . It can be seen that the upsurge is greater in the pre-compacted sand than in the uncompacted sand, and that the upsurge from the uncompacted sand is very low. In both Trials a small area of blocks was laid and compacted with the plate vibrator to assess the surcharge of sand laying course required to achieve the final levels. In both cases upsurge of 10 mm and more was seen. During the construction of Trial 2 the upsurge was monitored at various stages by removing randomly selected blocks. After initial compaction heights of up to 10 mm were found. The values of upsurge for the uncompacted sand in Trial 2 measured after all construction operations are lower than those observed during construction.

Trial	**Uncompacted Sand Section**	**Pre-compacted Sand Section**
1 Before Rolling After Rolling	0 mm 0 mm	5 to 10 mm 5 to 10 mm
2	1 to 5 mm	3 to 5 mm

Table 1. Upsurge of Laying Course Sand.

There is obviously a serious discrepancy between the result observed during construction and those measured after completion of construction. An ad hoc experiment with placing blocks on sand and compacting them suggested that small sideways shuffling movements to the blocks tends to push up sand in the joint. It is therefore possible that if the CBS is compacted behind a free working face small horizontal movements can cause the 10 mm plus upsurge. However, if the blocks are fully restrained horizontally before compaction the only mechanism for creating upsurge is vertical movement. In this case the upsurge from the pre-compacted sand is greater than from the uncompacted, possibly because the pre-compacted layer gives a firmer foundation on which to compact the blocks, helping to force sand into the joints. It also appeared that after the initial upsurge has occurred further compactive effort tended to reduce the amount.

Deflection Measurements

Typical deflection basins measured by the FWD are shown in Figure 4, the remaining deflection basins were all very similar. The changes in deflections measured by the FWD and Benkelman Beam after the various stages in the construction and testing, as a percentage of the deflection on the DLC before testing, are shown in Figure 5 to Figure 7. The results show a general increase in deflection when carried out on the surface of the blocks, even after the completion of 10 000 load repetitions. The FWD results also show a steepening of the gradient close to the plate (within 300 mm). The deflection results are obviously being affected by the sand layer and in the case of the FWD by some lack of interlock between blocks. The depth of upsurge from the sand laying course has no influence on the results.

CONCLUSIONS

The CBS had little effect on the structural performance of the pavement in Trial 1. At best it is equivalent to about 10 mm of bituminous surfacing, but in some cases it appeared to have no effect at all. As the DLC deteriorated the performance appeared to improve.

On a well constructed CBS over a cement-bound base 10 000 load repetitions by a 100 kN wheel load with a tyre pressure of 1.25 MPa (180 psi), produced a 6 to 8 mm rut within the sand laying course. The rate of rut formation was initially high, but it then reduced and became roughly linear with load repetitions. The amount of rutting occurring early in the pavement life was reduced by the use of the vibrating roller, but the final depth was not significantly influenced by the rolling. The rut depth at the end of trafficking was greatest in the pre-compacted sand section but the differences were not significant. Some heave occurred showing that the rut was caused partially by sand displacement as well as compaction and suggesting that the shear strength of the sand laying course may impose a limitation on the maximum tyre pressure.

The different methods of placing the sand laying course and the amount of upsurge in the joints had no significant effect on the structural performance. Partial pre-compaction of the sand laying course during placing improved the upsurge, which may be important in situations were the surfacing is subject to high horizontal loads. However, the amount of upsurge is very variable and it is obviously influenced by factors other than compactive effort.

The use of a vibrating roller had little effect on the levels of the CBS and it did not appear to carry out much compaction of the sand laying course. Neither did it have any effect on the upsurge of sand laying course. However, it had some effect on the amount of rutting that occurred early in the pavement life, although the final rut depth was not significantly influenced by the rolling.

Deflection measurements by Falling Weight Deflectometer and Benkelman Beam were affected by the sand laying course, even after trafficking.

ACKNOWLEDGMENTS

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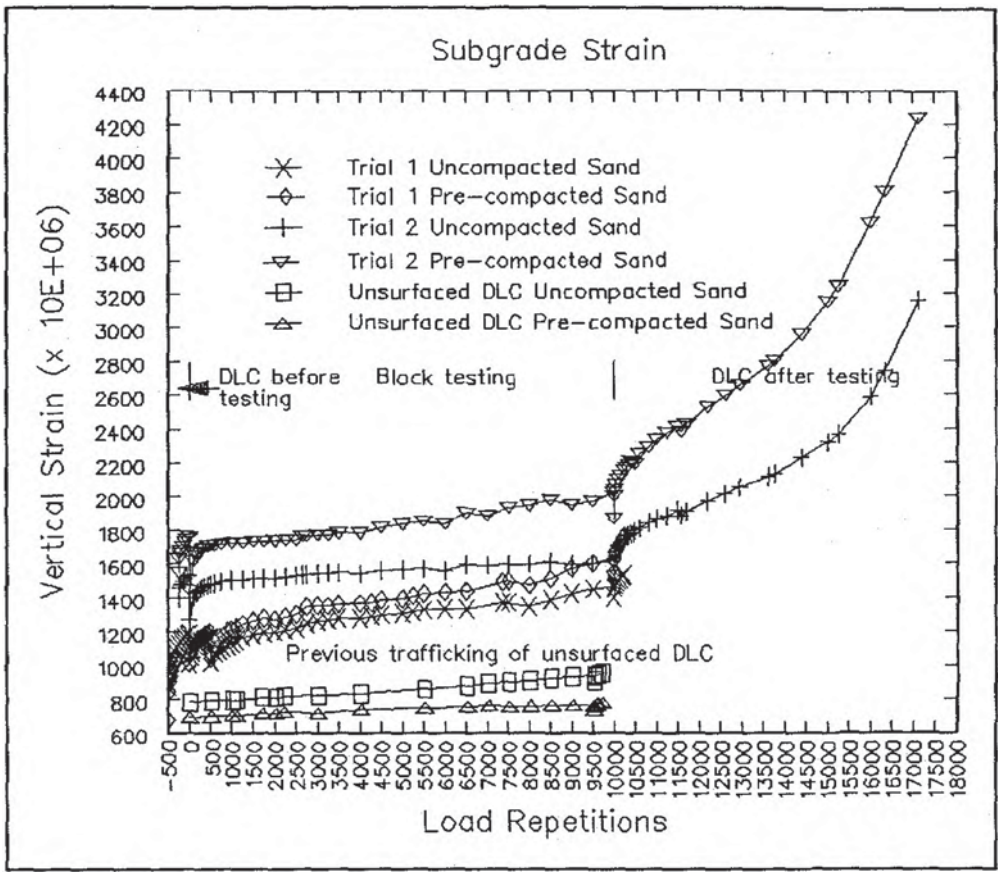


Figure 1. Variation In Vertical Subgrade Strain.

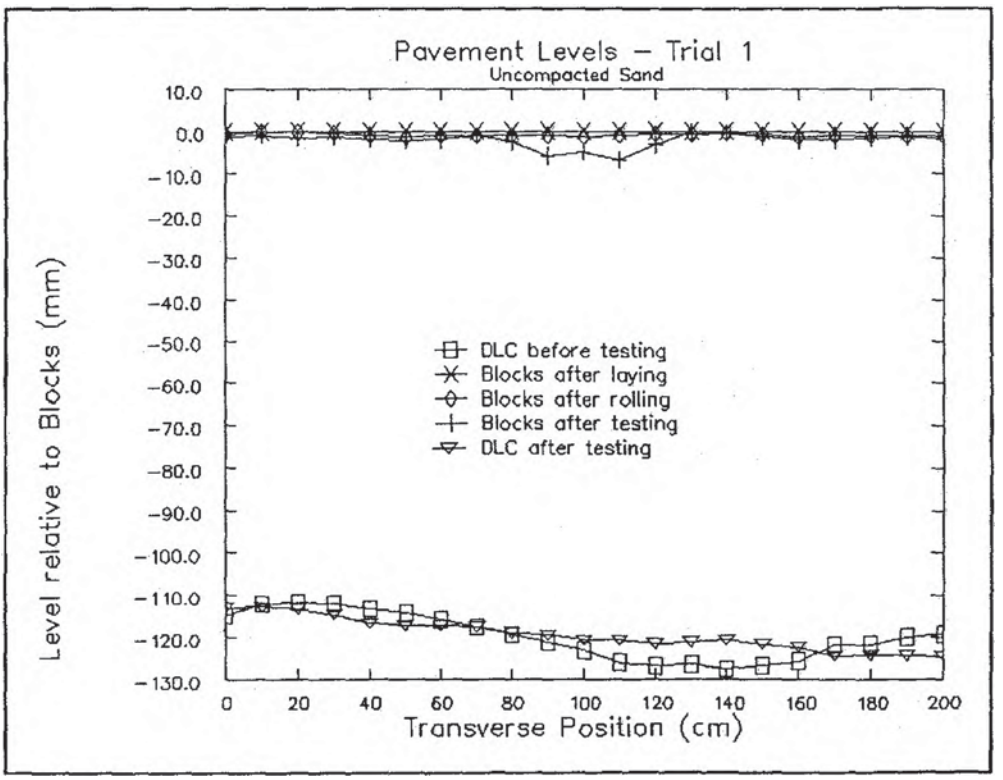


Figure 2. Variation in Levels. Trial 1, Uncompacted Sand.

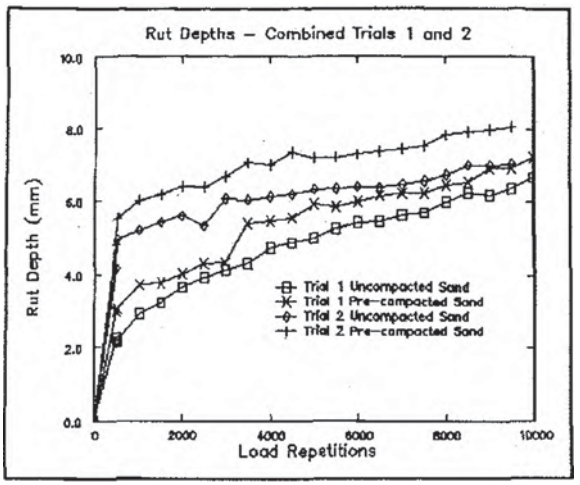


Figure 3. Development of Rutting.

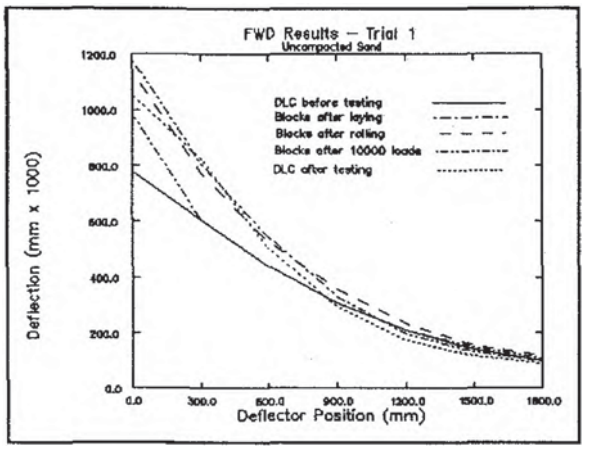


Figure 4. Summary of FWD Measurements. Trial 1, Uncompacted Sand.

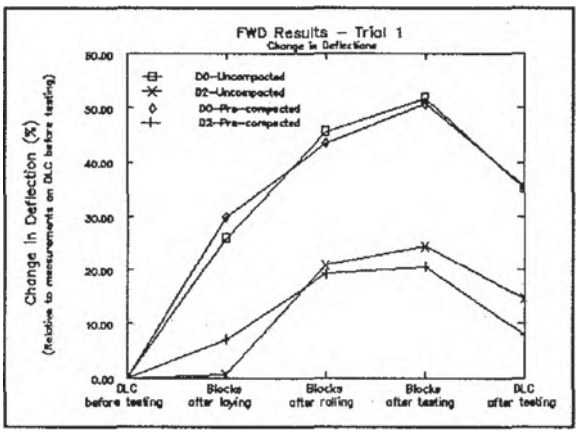


Figure 5. Changes in FWD Measurements relative to the DLC before testing. Trial 1.

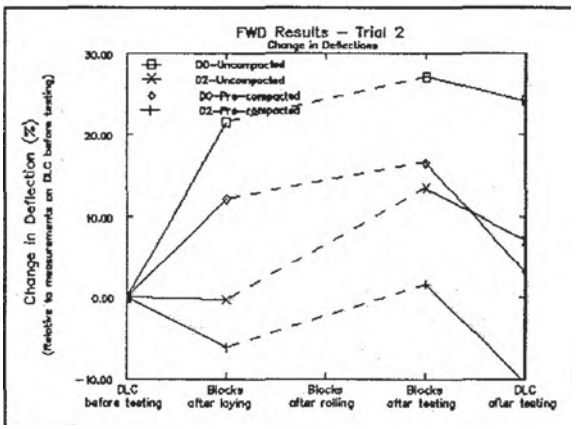


Figure 6. Changes in FWD Measurements relative to the DLC before testing. Trial 2.

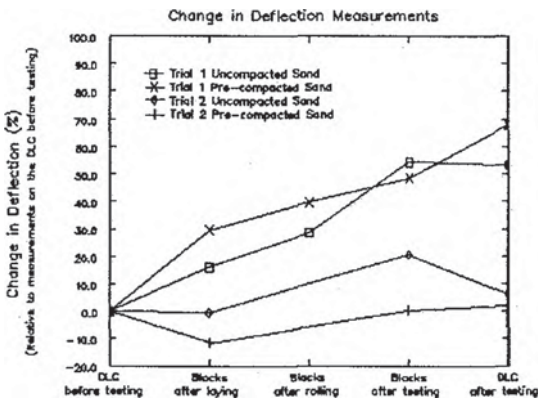


Figure 7. Changes in Deflection Beam Measurements relative to the DLC before testing. Trials 1 and 2.

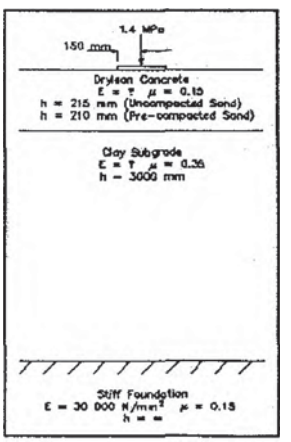


Figure 8. Pavement model for Elastic Analysis.