Rutting Behaviour in Geosynthetic-Reinforced Unsurfaced Pavements

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ABSTRACT: Design methods for geosynthetic-reinforced unsurfaced pavements are shown to rely on the assumptions of static monotonic failure for design and that aggregate behaviour has no direct influence when predicting rut depths. The results of a full-scale haul-road trial in Scotland are used to illustrate the lack of validity of these assumptions and the importance of aggregate compression and shear deformation in rut development.

1 INTRODUCTION

An important use of geosynthetics in road construction is as a reinforcing element in unsurfaced haul roads constructed on soft subgrades. In this application, the geosynthetic is typically placed on the subgrade surface and aggregate is then placed and compacted above it.

Many design methods have been proposed for this situation (of which only Giroud & Noiray, 1981; Milligan et al, 1989a,b; Sellmeijer, 1990 are mentioned here). The earliest methods use a membrane analysis as the basis for design in which vehicle loading causes surface deflection of the pavement. This generates a downwards deflection of the geosynthetic which is treated as a membrane in tension between the undeflecting shoulders of the pavement. The downward displaced and elongated geosynthetic membrane exerts an upwards force which acts to oppose the loading and thus reinforcement is provided.

Later methods postulated a modification to the subgrade stress regime which increases the load-carrying ability of the soil (Milligan et al, 1989a,b) or a more sophisticated membrane approach in which material stiffness and strain compatibility become important (Sellmeijer, 1990).

2 BEHAVIOUR OF UNREINFORCED SYSTEMS

In the unreinforced, unsurfaced pavement, failure almost invariably takes place by excessive vertical displacement of the pavement surface beneath vehicle wheels. For efficient use the transient deflections must be small, otherwise the vehicles are, effectively, travelling uphill even when on the level (Douglas & Valsangkar, 1992). This will be an important consideration for high volume haul roads during construction of a major project in which they are used as part of an earth/rock haulage exercise. More usually it will be the permanent deformation due to repeated loading which will be of concern as large ruts increase friction (and thus tyre wear and fuel inefficiency) and decrease manoeuvrability. This is the aspect discussed in this paper.

It will thus be evident that the monotonic strength of the unsurfaced pavement will rarely, if ever, be of prime interest. Instead, the pavement engineer will be concerned with the permanent deformations within the aggregate and subgrade layers which result from repeated transient load applications by the traffic.

Table 1 summarises repeated load triaxial testing of 17 different aggregates by Thom & Brown (1989) and shows that there is no simple ranking relationship between resilient deformation characteristics, permanent deformation characteristics and monotonic shear strength for different aggregates.

In an unsaturated aggregate, permanent deformation will result from :
- material compaction (volumetric compression) leading to a lowering of the surface beneath the wheel path.
- shear strains leading to displacement of material from beneath the wheel path to the unloaded parts of the pavement either side which will thus move upwards.
- material dilation (volumetric expansion) causing local heave either side of the wheel path. This is particularly associated with shear.

Similar mechanisms will operate in the subgrade, although volumetric strains, in particular, will probably be considerably smaller.

3 APPLICABILITY OF DESIGN METHODS

3.1 Static Failure Analysis

The design methods for geosynthetic-reinforced, unsurfaced pavements mentioned in the Introduction all assume some form of static equilibrium in which one or more elements is at its failure condition. This approach has the advantage of simplicity but cannot easily form the basis of a satisfactory surrogate for an analysis of deformation due to repeated loading. Not only is the poor relationship of strength to permanent deformation resistance (Table 1) ignored, but also no allowance is made for soil viscosity because of which, fully or nearly saturated soils can tolerate transient stresses greater than their monotonic failure strength (Brown & Dawson, 1992).

Table 1 Aggregate Performance in Triaxial Tests

Resilient Modulus :	9	12	1	2	5	4	3	6	8	7	10	11	17	15	13	14	16
Shear Strength :	9	1	8	7	17	10	4	2	3	16	12	5	6	15	11	14	13
Permanent Deformation Resistance :	10	5	8	2	3	4	6	1	17	9	7	15	12	16	11	14	13

Note : Each number indicates a particular aggregate.
Performance is ranked - 'Good' to left, 'Poor' to right.

3.2 Load-Deformation Relationship

A static design method predicts the ultimate condition. As the actual failure criterion is a rut depth of a certain, finite amount (defined by the type of pavement and traffic), it is not clear how this rut and static failure might be related. In practice, design methods usually assume that static failure represents the condition at which the allowable rut is developed by a single application of load, P_s. For a load less than P_s, the pavement should take more applications to achieve the same rut and the amount is computed from an empirical relationship such as a power law or that proposed by Hammitt (1970). The relationships (except that due to De Groot et al, 1986) all use information derived from trials on unreinforced pavements.

Table 2 Summary of Aggregate Triaxial Testing

	Crushed Diorite		Sand & Gravel	
Confining Stress (kPa)	20	45	11	50
Poisson's Ratio	0.33		0.4	
Resilient Modulus (MPa)	360	450	325	600
Peak Angle of Shearing Resistance (°)	54		51	

3.3 Aggregate Thickness

A further limitation of all the analytical methods discussed above is the assumption that the aggregate thickness remains constant, the surface rut being mirrored at the subgrade surface. It would be surprising if the mechanisms described at the end of Section 2, above, were inapplicable to reinforced, unsurfaced pavements.

4 TRIAL OBSERVATIONS

A recent experimental unsurfaced road trial at the Science and Engineering Research Council soft clay test site at Bothkennar, outside Edinburgh in Scotland (Dawson & Little, 1990) presented an opportunity to observe the rutting behaviour of 10 reinforced and 4 unreinforced pavement sections.

4.1 Construction

The sub-grade at the site comprised a firm brown very silty clay of intermediate to high plasticity lying just above the Casagrande 'A' Line. Further details of the soil conditions can be found in Hight et al (1992). Undrained strength of the subgrade varied with the season but was typically 75-80kPa at periods of trafficking.

A variety of geosynthetics were used - non-woven geotextiles (heat bonded and needle punched), woven geotextile and biaxially oriented geogrid. These were placed onto the subgrade which was first carefully excavated to remove the relatively unquantifiable grass and topsoil layers from the site. One of two aggregate types was then carefully placed onto the geosynthetic and compacted in three of four layers, no layer exceeding 150mm in thickness. The aggregates were well-graded, crushed diorite and sand and gravel. Compaction was by a 1000 kg/m twin drum vibratory roller. Dry densities of between 2060 and 2240 kg/m^3 were obtained for both aggregates. The unreinforced pavements were similarly constructed.

The aggregate was subjected to repeated load triaxial testing in specimens 280mm in diameter and 560mm high to determine the resilient modulus. Each specimen was then taken to failure under monotonic loading to determine shear strength. The results are given in Table 2. The relatively high resilient modulus of the sand and gravel is in line with the results of Thom & Brown (1989).

The sub-grade was levelled on a 0.5m grid over the length and width of each pavement (20m x 5m) and the final aggregate surface was similarly measured. Thus the actual aggregate thickness was determined with some accuracy (see Column 2 of Table 3 for mean thicknesses). In pavements A to E the aggregate was generally thicker than elsewhere as these pavements were intended to have a longer life.

Geosynthetic samples were taken before construction and after trafficking for laboratory index testing (Little, 1993).

4.2 Loading

The pavement was subjected to 1115 passes of a vehicle comprising a rear axle weight of about 80kN and a variable front axle of 30-56kN, followed by 1000 further passes of the same vehicle with 126.35kN and 50.03kN axles. (This represents 1191 and 6376 standard 80kN axles assuming a fourth power load equivalency relationship).

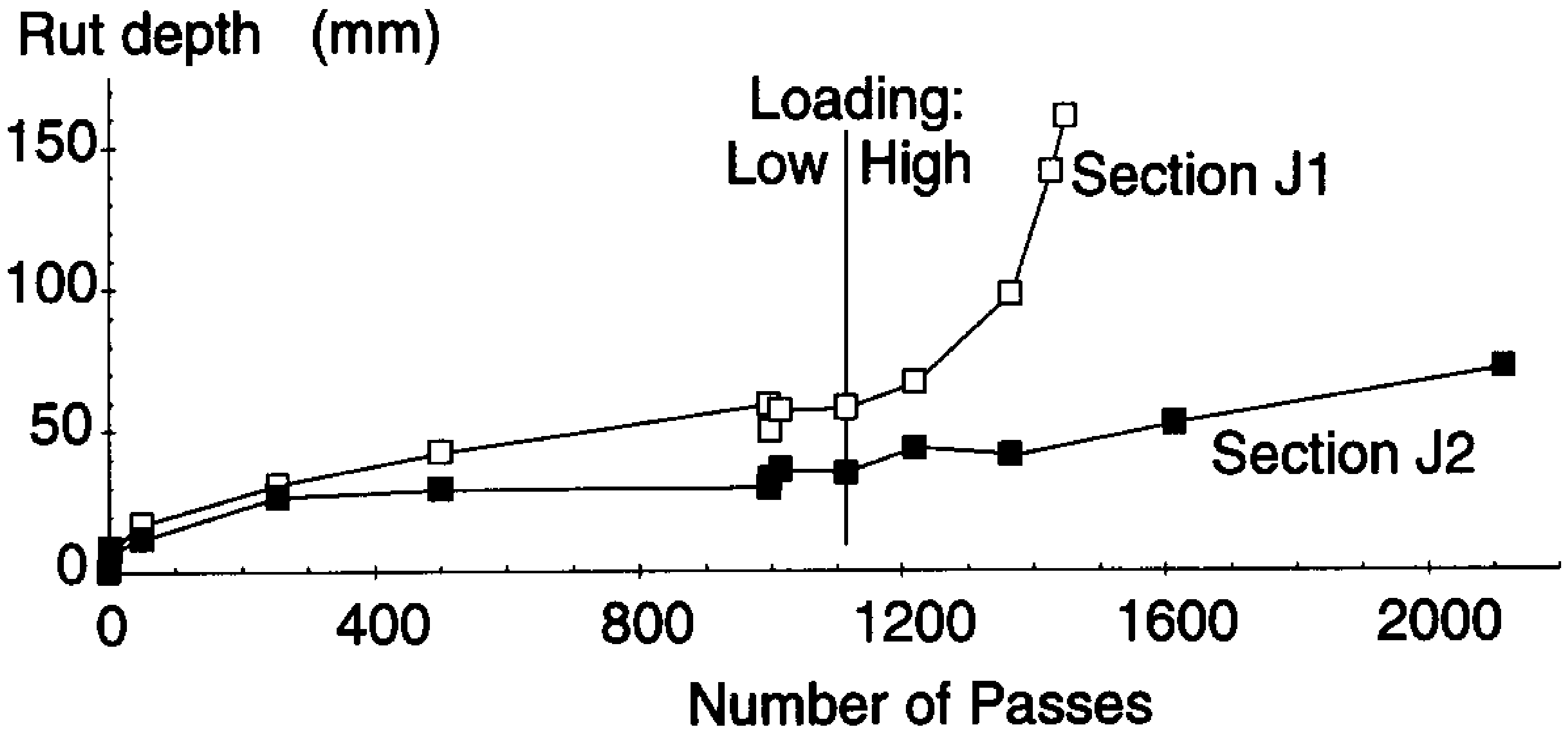

Figure 1 Rut Development, Pavement J

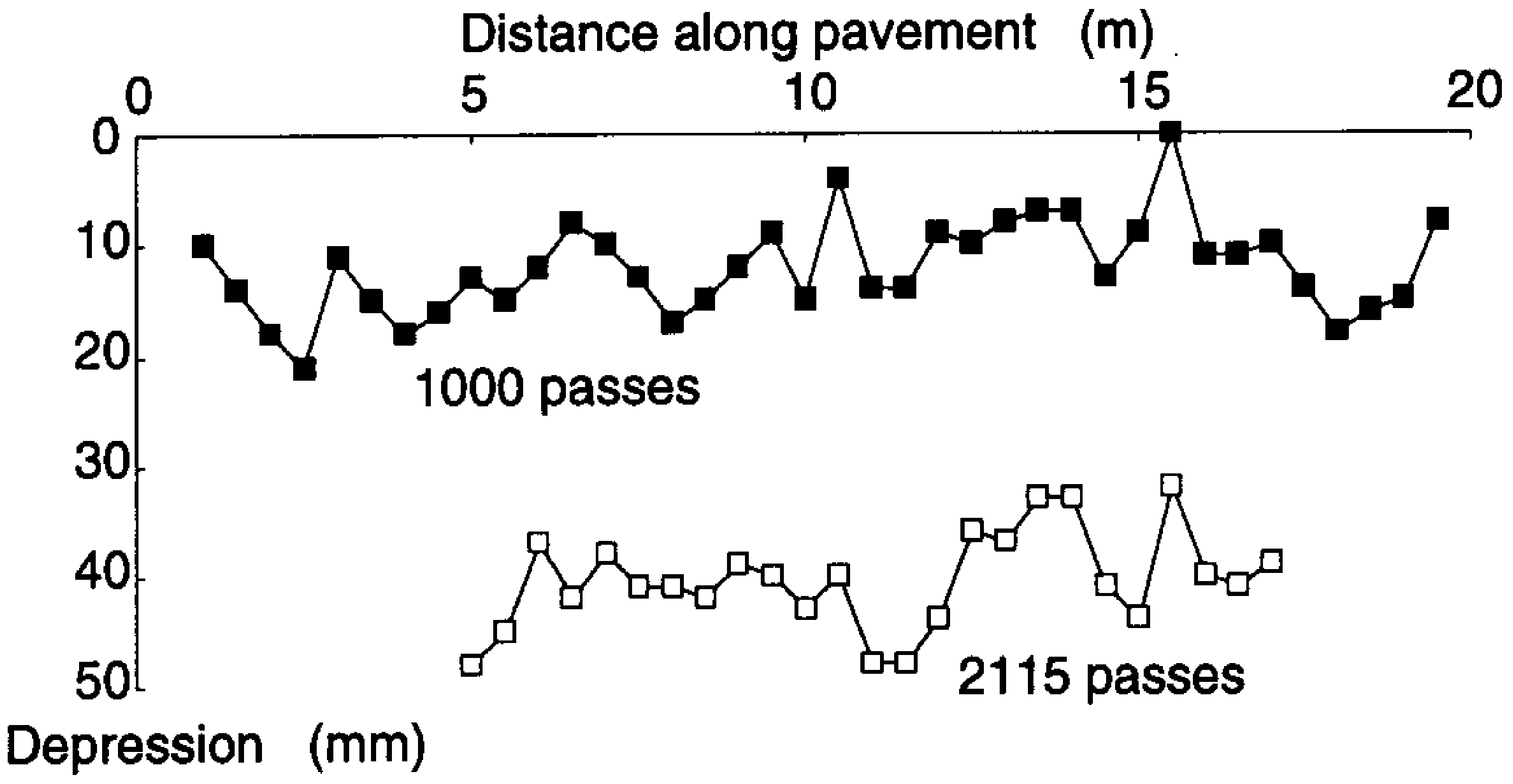

Figure 2 Vertical Depression of Pavement F

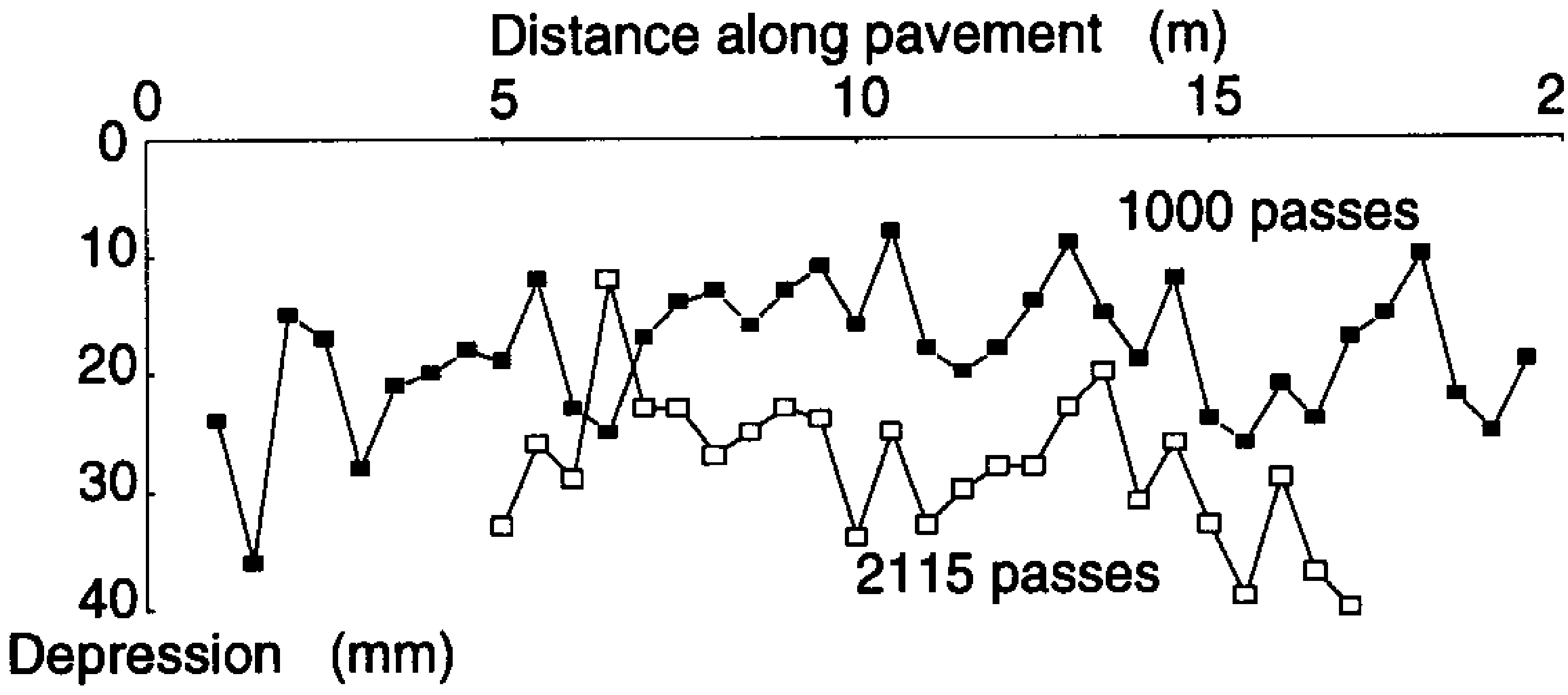

Figure 3 Vertical Depression of Pavement L

4.3 Results

The results of the trial are summarised in Table 3 and Figs. 1 to 4. Fig. 1 gives typical results showing the development of rutting (measured by careful surveying) at two locations (J1 and J2) from a pavement with a woven geotextile. It will be noted that :

a) There was a rapid initial rut development. This parallels triaxial testing on aggregates in which large permanent deformation is observed in the first few repetitions of loading.

b) Rut development was broadly linear until onset of failure and was not proportional to the logarithm of number of load applications (as usually assumed). Rut depth development in the non-failing pavements varied between 0.003mm and 0.025mm/pass, either increasing with the higher loading or remaining unchanged. Aggregate type did not appear to have much influence on the rate of rut development.

c) When excessive deformation occured it was rapid and accelerating (J1).

d) Two notionally similar constructions (J1 and J2) behaved very differently.

Fig. 2 shows the profile along the wheel path in pavement F (geogrid). The longitudinal roughness increased with trafficking and there was significant vertical depression of the aggregate surface. Fig. 3 gives the longitudinal profile for pavement L (needle-punched geotextile) which had a greater roughness but lower vertical depression at the higher applied loading.

Table 3 summarises the rut depth, the vertical displacement of the bottom of the rut relative to a datum and the mean pavement aggregate and soil vertical strains beneath the wheel path at the end of trafficking. A large value for the ratio in the sixth column indicates that the wheel path depression is much less than the rut depth (hence indicating significant heave adjacent to the wheel path.) Thus, pavement E (woven) has undergone significant volumetric compression whereas pavement N (geogrid) shows significant aggregate heave. The fifth column in the Table indicates how representative the cross-section results are of the whole pavement.

The vertical strains (obtained using inductive coils at the base of the aggregate and at the top of the subgrade) at the end of trafficking indicated that the relative contribution of

Table 3 Final Vertical Permanent Deformation Results

Pavement &	Deformation (mm)				Vertical Strain[3] ($\mu\varepsilon$)	
thick. (mm)	Rut[1]	Vert[1]	Mean[2] Vert	Rut/Vert	Aggregate	Subgrade
A 430	48	50	43.2	0.96	18800	7600
B 495	49	40	40.1	1.23	19700	11800
C 527	28	33	32.0	0.85	15800	2900
D 580	28	26	21.8	1.08	16400	-2300
E 536	18	28	29.0	0.64	8800	4400
F^{S} 436	35	39	40.5	0.90	30800	18900
H^{S} 428	34	19	21.2	1.79	-	-
I^{S} 350	failed	failed	-	-	48000	21900
J 262	failed	failed	-	-	97300	28350
K 394	24	22	19.5	1.09	14800	5100
L 354	41	28	28.0	1.46	24400	9000
M 372	24	21	17.6	1.14	5200	6800
N 332	32	17	21.2	1.88	8500	15600

Notes 1 Measured at 6 instrumented cross sections.
2 Measured along wheel path throughout pavement length.
3 Measured at 2 instrumented cross sections.
S Pavements in which sand and gravel aggregate used.
Vert = Vertical depression of surface relative to datum.
Rut = Maximum vertical height difference across surface.

the aggregate to that of the soil to permanent deformation varied but that it was often large (even though the strain is measured at some depth below the wheel loading). Large strains were associated with pavements which experienced higher surface deformations except that the strains were reduced when the aggregate was thicker. This reduction may result because the strains were measured at a non-constant depth from the loaded surface, suggesting that high strains may still occur in the middle of a thick aggregate layer and large internal aggregate deformation could then be expected.

4.4 Exhumation

Eight of the pavements were carefully exhumed and the final cross-sectional shapes and dimensions measured. Fig. 4 gives a typical result (pavement L with a needle-punched non-woven geotextile). It shows the depression of the aggregate, the lesser depression of the subgrade under the wheel path and the heave due to shear of the aggregate either side of the wheel-path which exceeds the heave in the subgrade. In this case the aggregate has thinned by around 10mm and heaved by 25-50mm. Overall the subgrade depression is responsible for 67-100% of the surface depression (mean 79%), but this falls to 11-91% (mean 51%) when rutting is considered. Pavements L and N have the largest ruts as a proportion of soil depression.

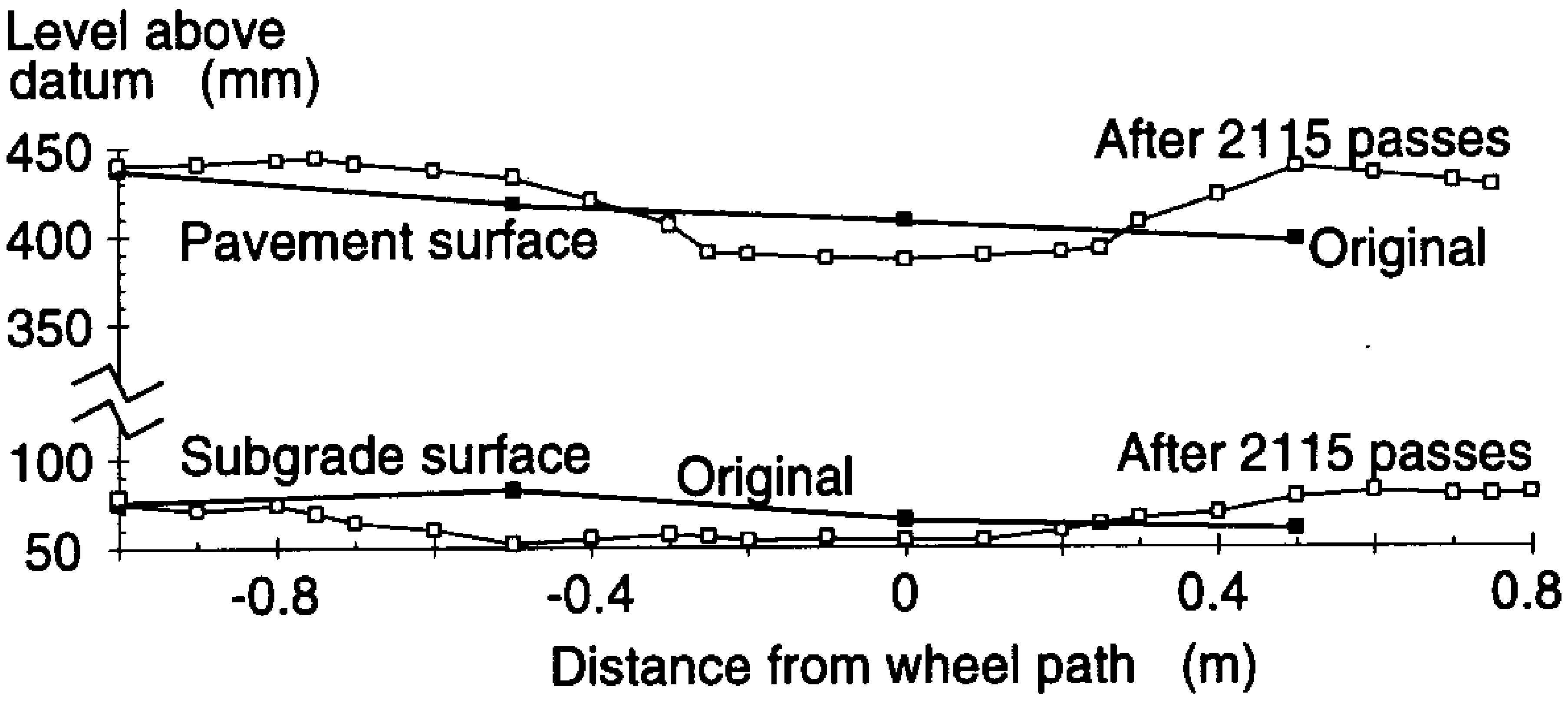

Figure 4 Original & Final Cross Section, Pavement L

5 CONCLUSIONS

It is concluded that present analytical design methods are not capable of making a valid prediction of the load to a defined rut depth - the normal design case. Aggregate behaviour is an important influence on rut build-up and is not readily modelled solely by an ultimate shear strength parameter. In particular, at the trial site on a relatively firm subgrade, rutting has been shown, in broad terms :

- to involve significant variability due to increasing surface roughness and other (unknown) factors. This introduces uncertainty into prediction of rut depths.
- to be due, principally, to aggregate thinning due to aggregate compression and/or shear, to aggregate shoulder heave due to shear and to subgrade depression.
- to be (approximately) equally due to subgrade and aggregate deformation.
- to develop linearly with load application, prior to onset of rapid failure, after an initial 'set'.

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