STABILITY OF UNPAVED ROADS ON SOFT GROUND

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A full scale field trial was carried out to investigate the performance of different geosynthetics in unpaved road construction over soft ground. The test site comprises five 16 m long, by 4.5 m wide test sections, built on a subgrade with an undrained shear strength of approximately 40 kPa. One section is unreinforced and serves as a control section in the study, three sections include a geotextile, and one includes a geogrid. Each test section incorporated a variable thickness of sand gravel base course material, between 25 and 50 cm thick, and was trafficked by a vehicle of standard axle load. Results indicate a better performance in the reinforced sections than the unreinforced section. The performance of the unreinforced section shows good agreement with other well-documented field data at large rut depths, between 10 and 15 cm, but not at small rut depths. Although the four geosynthetics exhibited a broad range of stiffness and material properties, the general performance of the four reinforced sections was similar on the thicker base course layers. This attributed to a reinforced mechanism governed by stiffness and separation, and all materials appear adequately stiff for the site condition and vehicle loading. On the thinner subgrades, a tensioned-membrane effect is mobilized, and a significant difference is observed between the geosynthetics.

INTRODUCTION

Geotextiles and geogrids have been used successfully in unpaved road construction over soft ground for many years. Over the past two decades a considerable amount of research on geosynthetic reinforcement of layered soil systems has been carried out internationally. These activities have included field, model and analytical studies, and have supported the development of design procedures for unpaved road construction over soft ground. Although most of the design procedures are similar in their approach, different assumptions are made with respect to vehicle traffic, bearing capacity formulation, the effect of anchorage, and the mechanism of stabilization, particularly the relative importance of a tensioned-membrane effect.

The concept of a tensioned-membrane effect due to the geosynthetic which develops as the road undergoes deformations is illustrated schematically in Fig 1. Many design methods consider the role of the tensioned-membrane effect important to the increased bearing capacity of reinforced unpaved roads, and place emphasis on the need for anchorage of the geosynthetic outside the loaded area to mobilize it.

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Few well-controlled field trials have been performed to examine the influence of geosynthetics in unpaved roads. Early work, to which much reference is made in more recent design methods, is that of the U.S. Army Waterways Experiment Station (Webster and Watkins, 1977, 1977; Webster and Alford, 1978). Results showed the performance of the reinforced sections was significantly better than the unreinforced section, and provided some of the first evidence that using geosynthetics in construction of unpaved roads on soft ground leads to a significant improvement in the trafficability.

Other field trials are reported (Potter and Currer, 1981; Sowers et al., 1982; Ramalho-Ortiago and Palmeira, 1982; Ruddock et al., 1982; Delmas et al., 1986; de Gardiel and Javor, 1986; Austin and Coleman, 1993) which vary in their construction procedure, base course and subgrade soil properties, and imposed trafficking. Yet they all have one thing in common: the reinforced sections perform significantly better than unreinforced sections.

Several design methods for unpaved roads incorporating geosynthetics have been published over the last two decades. Many have been developed for specific commercial products, but others are intended to be generic. Giroud and Noiray (1981) developed a design procedure based on theoretical considerations and data from field trials. Their approach has become the basis for many current design methods: it includes a tensioned-membrane effect and incorporates, for the reinforced system, a bearing capacity failure in the subgrade that is one of general shear failure rather than a local shear failure. The approach was later modified to incorporate geogrids (Giroud et al., 1984).

Few data are available from well-controlled field trials to evaluate the application of the Giroud and Noiray (1981) model. This paper describes a field trafficking trial that was performed on a soft ground site in the Lower Mainland. Objectives were to observe the benefit of using geosynthetics, contrast the relative improvement mobilized by geotextiles of different strength, and contrast the behaviour of those geotextiles with a geogrid. The response to trafficking of the unreinforced system, and the reinforced systems, is compared to the predictions of the Giroud and Noiray (1981) model. Implications of the field observations for selection of geosynthetics are discussed.

TEST SITE DESCRIPTION

The site is located on the eastern part of Lulu Island, see Fig. 2. It is bounded to the north and west by Highway 91/91A, and to the south and southwest by a main drainage ditch that runs due north, see Fig. 3. The site area is approximately 100 m long and 10 m wide, and located about 350 m east of the Hamilton Interchange.

Subgrade Soil Properties

The final location of the test site was selected to give a reasonably uniform near surface statigraphy along the unpaved road test section, which was 80 m long and 6 m wide. Following a review of borehole logs in the general area, a detailed site investigation was conducted that included test pits, laboratory tests and field vane tests. The site investigation was done to establish the uniformity of soil stratigraphy and to determine the variation in physical properties of the subgrade soil both spatially and with depth. Locations of the test pits and sampling points are illustrated in Fig. 4. A total of 9 test pits were dug that varied in depth from 0.5 m to 2.0 m, and 10 field vane tests were performed.

The subgrade was a soft-to-firm, organic clayey silt, with a trace of sand. A particle size distribution curve is illustrated in Fig. 5. The variation of plastic and liquid limit, and the natural water content of the soil, with depth below grade are reported in Fig 6. The values were determined at 0.2 m, intervals and represent average values from the three deeper test pits. The values of all three indices increases uniformly to a nearly constant value at a depth of 1 m.

The undrained shear strength of the subgrade material was determined using a field vane: locations of the seven profiles within the test section area are shown in Fig. 4. For comparison purposes, unconsolidated undrained triaxial tests were also performed, and the location of the undisturbed sampling for these UU-tests are also shown in Fig. 4. The field vane tests were performed at 0.5 m interval for the first 4.2 depth and thereafter at 1 m intervals. Results show the profile of strength with depth is nearly uniform, see Fig. 7, and between 30 and 40 kPa. There is a slight increase in strength near grade level which is attributed to the lower water content of the soil in this zone. The average sensitivity is about 6.

Results from the unconsolidated undrained triaxial tests were in good agreement with the field vane tests. Undisturbed samples for the UU-test were taken at about 10 - 25 cm below grade level at the locations shown in Fig. 4. A total of nine UU-test were performed, three from each hole, giving an average undrained shear strength value of 41 kPa.

Test Section Layout

The test site comprises five test sections. One is unreinforced, three sections include a geotextile and one includes a geogrid, see Fig. 8. Each was trafficked in sequence by a vehicle of known axle loading. The basic design criterion, apart form the subgrade properties, was the number of passes to be applied by the vehicle: the sections were intended to have a lifetime of a minimum of 100 passes and a maximum lifetime less than 1000 passes.

Lifetime is defined with respect to a serviceability type of failure, and taken to be a rut depth at which the vehicle can no longer traffic the structure. An important governing parameter for each geosynthetic is the influence of base course thickness on the relationship between number of passes and rut depth. Therefore each section incorporated a variable thickness of base course aggregate.

Each section was 4.5 m wide and 16 m long. Details of the base course layer are shown in Fig. 9 The thickness varies in each test section between a minimum value of 25 cm and a maximum value of 50 cm. The 25 cm layer is 3 m long, and increases in thickness to 50 cm over a length of 5 m, giving a slope gradient of 5 %. This longitudinal geometry was based on the area at disposal, specifically the total length, the length of the loading vehicle, and a desire to assess the repeatability with regard to the layer thickness within each section.

Properties of the geotextiles are reported in Table 1, and the geogrid in Table 2. It should be noted that the Texel Geo 9 is a reinforced non-woven geotextile that exhibits a significant tensile stiffness.

The base course material, see Fig. 5, was found to have a maximum dry unit weight of 21.5 kN/m^3 at an optimum moisture content of 7.1%. After placement and final compaction in-situ, the water content was measured using a nuclear densometer: at the in-situ dry unit weight of 20.7 kN/m^3 , the water content was 6.7% with a standard deviation of 1.25.

Construction of the test sections started with removal of the topsoil and excavation to grade. Construction equipment was not permitted to traffic the road subgrade, therefore all excavation and grading was done from the sides of the trial section. The surface of the clayey silt subgrade was leveled to a elevation of 0.06 m +/- 1.5 cm. The geosynthetics for the reinforced sections were placed directly on the prepared subgrade surface. Each geosynthetic was placed to overlap the adjacent test sections by 50 cm in the longitudinal direction. The geotextiles were 4.5 m wide, and did not require overlapping in the transverse direction. The geogrid, which was 4.0 m wide, was overlapped in the transverse direction by about 1 m through placement of an additional 1.8 m wide strip along the complete length of one side of the test section.

The base course aggregate was also placed from the sides of the test sections in several lifts. The first base course layer was placed to a 15 cm loose thickness and compacted using a small vibrating plate to a finished thickness of approximately 12.5 cm. A small vibrating plate was used in all compaction work in order to minimize subgrade disturbance. After compaction of the first lift, the second lift was placed raising the finished thickness up to 25 cm, which is the minimum thickness in each test section. Measurements were taken to ensure uniformity of compactive effort using a nuclear densometer. The specification was a minimum value of 90% of Standard Proctor. The 5% slope gradients were achieved by placing and compacting a wedge of gravel in two layers. The final surface was then leveled to the targeted elevation after compaction to 96% of Standard Proctor: the final surface was graded to the target elevation +/-5 mm using manual labor.

The final stage of the construction involved digging a small drainage ditch on both sides of the test section. Since the elevation of the subgrade of the test area was slightly lower than the surrounding ground surface, due to the excavation to grade level, ditches were necessary to prevent water from draining into the test section.

FIELD TRAFFICKING

The vehicle used to traffic the test sections was a single axle, dual wheel truck, with a standard axle load P=80.3 kN and a tire inflation pressure P_c = 620 kPa. It was driven in a forward, and then reverse, direction over the entire length of the test section at an average speed of 7 km/hour. Traffic was recorded in terms of number of passes of a standard axle load. Based on equivalent standard axle load relationships, the front single-axle of the test vehicle has a negligible effect on the road performance and was therefore ignored when reporting the number of vehicle passes.

Field testing took place between mid-December 1992 and late June 1993. A total of 500 passes were made with the loading vehicle during this time. In the early stage of traffic loading only a few passes were made each day, and measurements were taken frequently in order to get a better feel for the behavior of the reinforced soil-aggregate system and to determine the initial trend of base course and subgrade deformations. Complete details of the field test, instrumentation and measurements are reported by Sigurdsson (1993).

FIELD DATA

Surface Profiles

The field observations of surface deformation, Fig. 10, indicate a clear symmetry between the dual wheels for each base course thickness and with increasing rut depth. Heave is localized between the wheels, and no significant vertical displacement occurred at the longitudinal centerline.

From surface deformations,rut depth is defined as the difference between the initial average base course elevation, before trafficking, and the elevation measured in the developed rut. When determining the rut depth, four measurements were taken at a cross-section, two on each dual wheel path, one in the inner wheel path and another in the outer wheel path.

The development of rut depth with number of passes for the five test sections is shown in Figs. 11 to 15. Curves for the unreinforced section, Fig. 11, show two distinct general shapes. One defines a rapid development of rut at low passes followed by a nearly constant, but slightly increasing value with further trafficking. The other defines the same initial trend of rapid development of rut at low passes, but is followed by continued rutting to a value of approximately 20 cm, which is considered a serviceability failure.

The five different test sections, unreinforced and reinforced, all show the same two general shapes of curves which characterize a response to trafficking which is termed either unstable or stable. Although there is a definite relationship between rut, number of passes and base course thickness for the reinforced sections, with less rutting in the thicker subbase layers, it is not as consistent as that in the unreinforced section.

All of the 25 cm thick reinforced sections were loaded to a serviceability failure. Although there is a considerable difference in rut development between the reinforced sections, they all demonstrate a significant improvement in behaviour over the equivalent unreinforced section: test sections 2, 3, 4 and 5 failed at average rut depths of 21.6, 21.6, 21.3 and 20.1 cm, after 300, 190 140 and 150 passes respectively.

The 30 cm thick sections tended toward an unstable response, but did not reach the condition of a serviceability failure after 500 passes. The curves show some periodic variations in the relationship between average rut depth and the number of passes, see for example the 30 cm thick section in Fig. 15. The behavior is attributed to the sequence of trafficking. It is felt some dissipation of excess pore pressure generated by vehicle loads took place during waiting periods between trafficking days. This would lead to an increase in undrained shear strength, and therefore a slightly greater resistance to the onset of the next loads. This behavior was observed when the elapsed time between trafficking periods exceeded two weeks.

The remaining reinforced test sections between 35 and 50 cm thick all show a stable response, and an average rut depth at the end of the field trial that is less than the equivalent unreinforced section. A comparison of the reinforced sections shows the magnitude of the rut depth is very similar for the 35, 40 and 50 cm thick sections, although there is some indication of slightly less rutting in the geogrid section. It would appear that the performance of these thicker sections, at 500 passes, is essentially independent of the type of geosynthetic. There is a difference in rut depth between the reinforced sections and the unreinforced section that is less significant for all of the test sections.

Influence of the Geosynthetics

Comparison of the average measured rut depth versus number of passes in the test sections for each base course thickness indicates all of the 25 cm thick sections are unstable, where unstable is defined as a rapidly increasing rut with increasing number of passes. However, there is significant difference in behavior between the unreinforced and the reinforced sections, particularly for the Texel Geo 9 geotextile.

Examination of the number of passes at the same average rut depth, shows the Texel Geo 9 takes between 8 to 10 times more vehicle passes than the unreinforced section; the other reinforced sections take between 3 to 4 times more passes than the unreinforced section.

The varying nature of the improved response of the 25 cm thick section is attributed to a contribution from the geosynthetics which differs for each material. The Geo 9 material shows the greatest improvement, even at a very low numbers of passes. The other three geosynthetics exhibit a very similar trend up to about 50 to 75 passes, after which some difference in performance is observed. The response of the geotextiles is consistent with their tensile strength and is attributed to their stiffness. The biaxial geogrid, BX 1100, shows a similar response to the TS 600 and 700 geotextiles up to about 50 passes, at which point the rut development accelerated. It is felt the separation function is of great importance when the base course thickness is relatively small. The initial performance of the geogrid is attributed to its higher stiffness and an ability to resist lateral spread of the base course aggregate by interlock. As subgrade intrusion occurs, the interlock is reduced and with it the mechanism of lateral restraint.

All of the 30 cm thick sections are also categorized as unstable since there is a fairly rapid rut development with increasing number of passes. Comparison shows that the unreinforced section gives a slightly better performance than the unreinforced 25 cm section, but the reinforced sections improve significantly. Although the relationship between geosynthetic stiffness and performance is less obvious, the stiffest geotextile still gives the best performance. It is felt that separation is still of some importance, but less so than for thinner base course. This is apparent in the relative performance of the geogrid, which is better than two of the three geotextiles. Interestingly the test section with the stronger, TS 700, geotextile developed a poorer response to trafficking at less than 150 passes than the Polyfelt TS 600. It should be noted that after about 120 passes, a tear occurred in Polyfelt TS 600 fabric in the left wheel path. The tear occurred where a non-uniformity in thickness was observed before installation. All of the 35 - 50 cm test sections developed a stable response characterized by a rut depth that is almost constant or slightly increasing with increasing number of passes. Although there is a significant difference in performance of the unreinforced and reinforced sections in the 35 cm thick section, there is no significant difference between the geotextile reinforced sections, and a very small improvement in the geogrid reinforced section over those with geotextiles. This behavior appears to be independent of stiffness, and therefore is attributed to a better interlock between the base course layer and the geogrid, which tends to reduce lateral displacements of the aggregate.

The difference between the unreinforced and the reinforced sections reduces with increasing base course thickness, and little significant difference is observed in the 50 cm thick section. Application of linear regression to the observations suggests there would be no difference between them for a base course thickness of 60 cm at 500 passes.

COMPARISONS WITH THEORETICAL DESIGN CURVES

Unreinforced Performance

A curve that establishes the minimum design thickness of an unreinforced base course layer for different numbers of vehicle passes was proposed by Hammit (1970), based on a full scale field trial. The equation that described the curve was then modified by Giroud and Noiray (1981) to include various axle loads and rut depths. Three sets of curves, for a standard axle load, using Giroud and Noiray's proposed equation are shown in Fig. 16. Three different values of undrained shear strength were used that bound the strength of the subgrade at the site of this research study, and two values of rut depth were used that bound the displacements mobilized by traffic loading in this study. The curves of base course thickness versus number of passes are very sensitive to the thickness and a small increment in base course thickness changes significantly the number of passes.

The field data from this study are plotted together with the Giroud and Noiray curves. The independence of rut depth and base course thickness is shown clearly for the case of a 5 cm rut depth and few vehicle passes ($N<10$) in this study. With increasing rut depth, when the dependence on the base course thickness is mobilized (at a rut depth of 15cm), there is considerable agreement with the empirical equation: although the magnitude is slightly different the trend is the same. It would appear the empirical equation does, however, predict more vehicle passes at a given rut depth than observed from the field trial.

Reinforced Performance

The performance of the reinforced sections is compared with Giroud and Noiray's design procedure, see Fig. 17. The input parameters used in developing this chart, following the Giroud and Noiray semi-theoretical design procedure, were based on the material properties and the loading vehicle used in the field trial: c_u = 40 kPa; P = 80.3 kN; p_c = 620 kPa; a geometric factor e = 1.83 m; and a stiffness factor K = 15 kN/m. Once again it is apparent that development of the 5 cm rut is relatively independent of the base course thickness, likely as a result of initial compaction of the base course layer. For the 10 and 15 cm rut depths, the trend between base course thickness and number of passes for the field data shows good agreement with the semi-theoretical design chart. However, the absolute magnitude of the predicted ruts is slightly different, causing the design approach to over-predict the performance of the field trial. This difference is in part attributed to the compression of the base course, which is not taken into account in the design procedure.

CONCLUSIONS

Results from this full-scale field trial indicate a much improved performance from the reinforced sections than the unreinforced section for unpaved roads over soft ground. However the performance of each of the four different geosynthetics was similar with respect to failure, where failure is defined as an unacceptable rut depth or a serviceability failure.

The performance of the unreinforced section shows reasonable agreement with the minimum design thickness proposed by Hammit (1970) at large rut depths but not at small ruts. No significant variation of subgrade properties was observed along the test site, therefore the behavior at small rut depths is attributed to early compression of the base course layer, and the rut depth is relatively independent of base course thickness. Thereafter rut development is more dependent on base course thickness, and at this point the dependence of rut on thickness revealed a trend with increasing vehicle passes that compares well with Hammitt. However this does not occur until rut of about 15 cm, which in many cases would be unacceptable and considered close to a serviceability failure.

The reinforced data compare reasonably well with theory (Giroud of Noiray, 1981), considering the trend of rut versus number of vehicle passes, but again the theory overpredicts performance. The field performance of the reinforced test sections suggests a particular stabilization mechanism was taking place. In the 25 and 30 cm thick sections the tensioned-membrane effect seems to be mobilized, especially in the 25 cm section where there is a clear difference in performance between the geotextiles. The difference in performance is attributed to tensile stiffness, with the Geo 9 geotextile providing the greatest improvement in traffickability. Separation appears to be very important in the thinnest sections, and the geogrid does not perform so well: as base course thickness increases, the geogrid performance gets much better, which is attributed to maintenance of a good interface bond with the base course material. As base course thickness increases, the evidence of a tensioned-membrane effect is negligible at the given number of vehicle passes and moderate rut depths: stiffness and separation are the main factors contributing to the better performance of the reinforced system. For those base course layers 35 cm thick or greater, the geogrid consistently shows less rutting than the geotextiles. While this may be attributed to its ability to take up outward acting shear stresses on the surface of the subgrade below the vehicle wheel paths, all of the geosynthetics behave in a similar manner. This similar performance, at up to 500 passes, might be a consequence of the geosynthetics exceeding a threshold stiffness for these site conditions and vehicle loading.

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Table 1 Properties of the geotextiles

Test Method	Unit	Texel GEO-9	Polyfelt TS 600	Polyfelt TS 700
Mass per unit area (ASTM D3776)	g/m^2	310	204	268
Thickness (ASTM D1777)	mm	1.8	1.8	2.3
Wide-width strength				
(CMD)	kN/m	7.0 @ 10%	10.5 @ 50%	14.0 @ 50%
(MD)	kN/m	7.0 @ 10%	12.3 @ 95%	15.8 @ 95%
(ASTM D4595)				
Burst strength (ASTM D3786)	MPa	2.4	1.6	2.2
Apparent opening size (ASTM D4751)	μm	100	250	210
Cross-plane permeability (ASTM D4491)	cm/s	3.1×10^{-1}	3.2×10^{-1}	3.0×10^{-1}

Table 2. Properties of the geogrid

Test Method	Unit	Tensar BX 1100
Mass per unit area (ASTM D3776)	g/m^2	215
Thickness		
• ribs, junctions	mm	0.8, 2.8
Aperture size		
• MD x CMD	mm	25 x 33
Wide-width strength		
• CMD (ASTM D4595)	kN/m	8.3 @ 5%

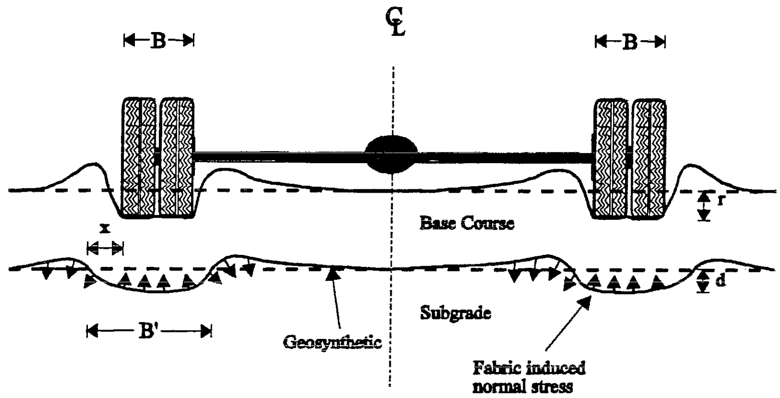

Figure 1 Membrane action of geosynthetic unpaved road

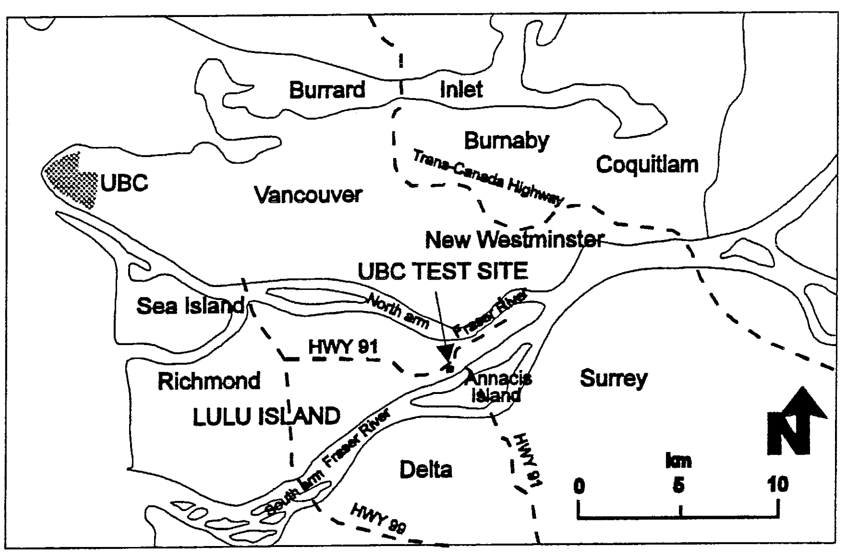

Figure 2 Location of the research site

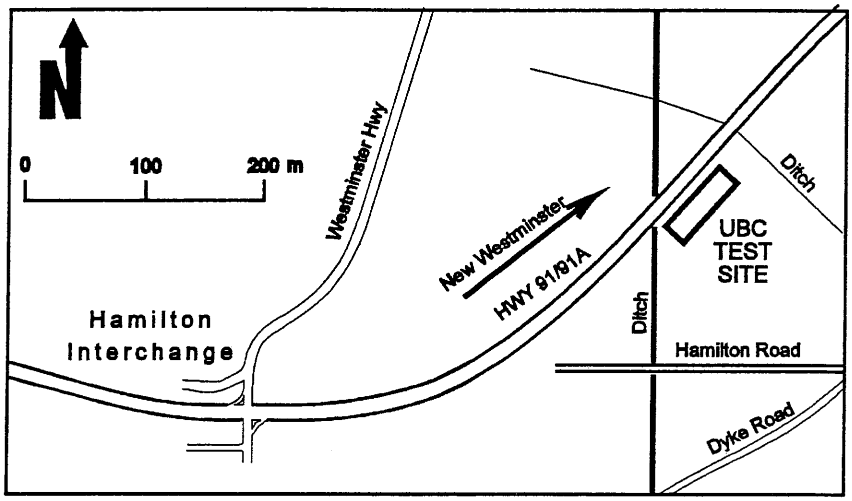

Figure 3 General research site details

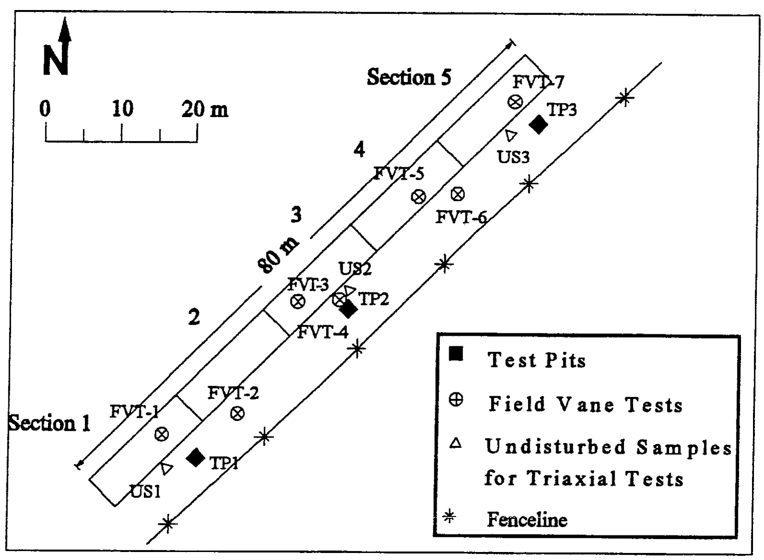

Figure 4 Location of tests

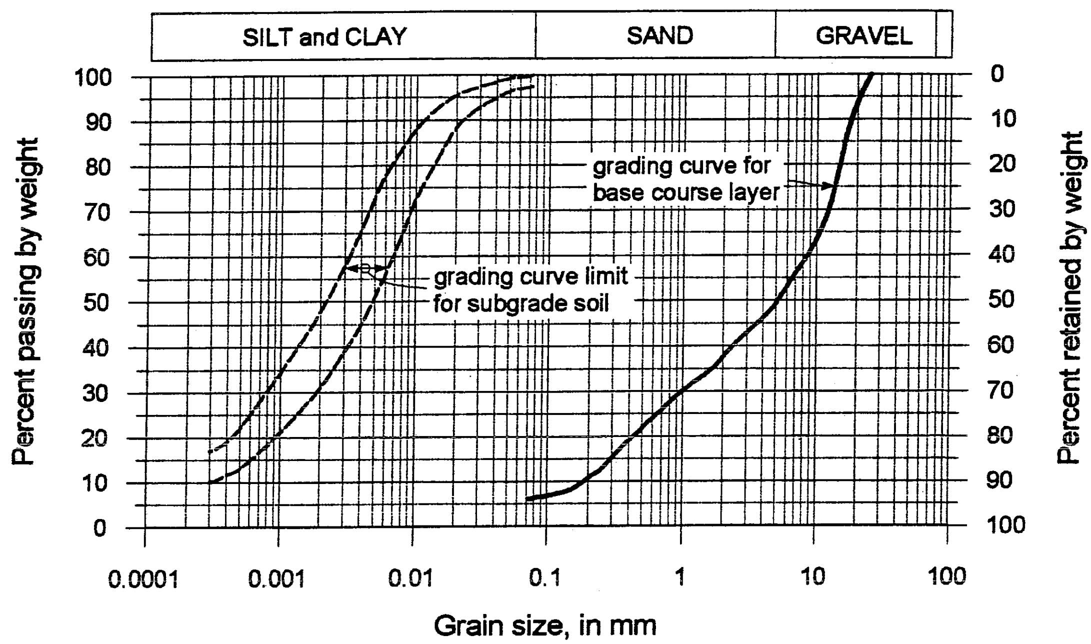

Figure 5 Subgrade soil and base course material

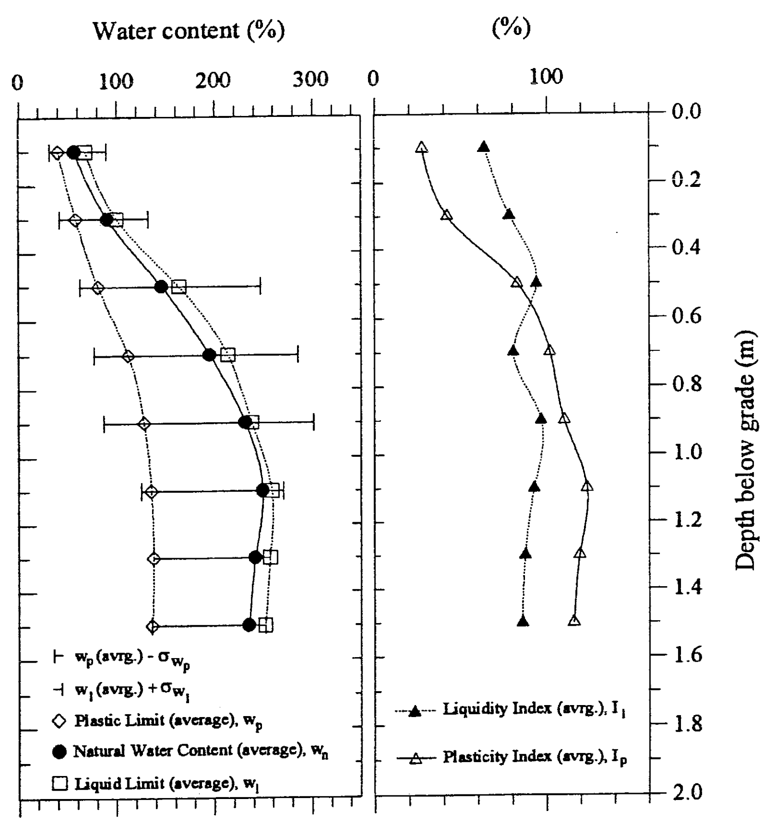

Figure 6 Atterberg limits and indices - test results

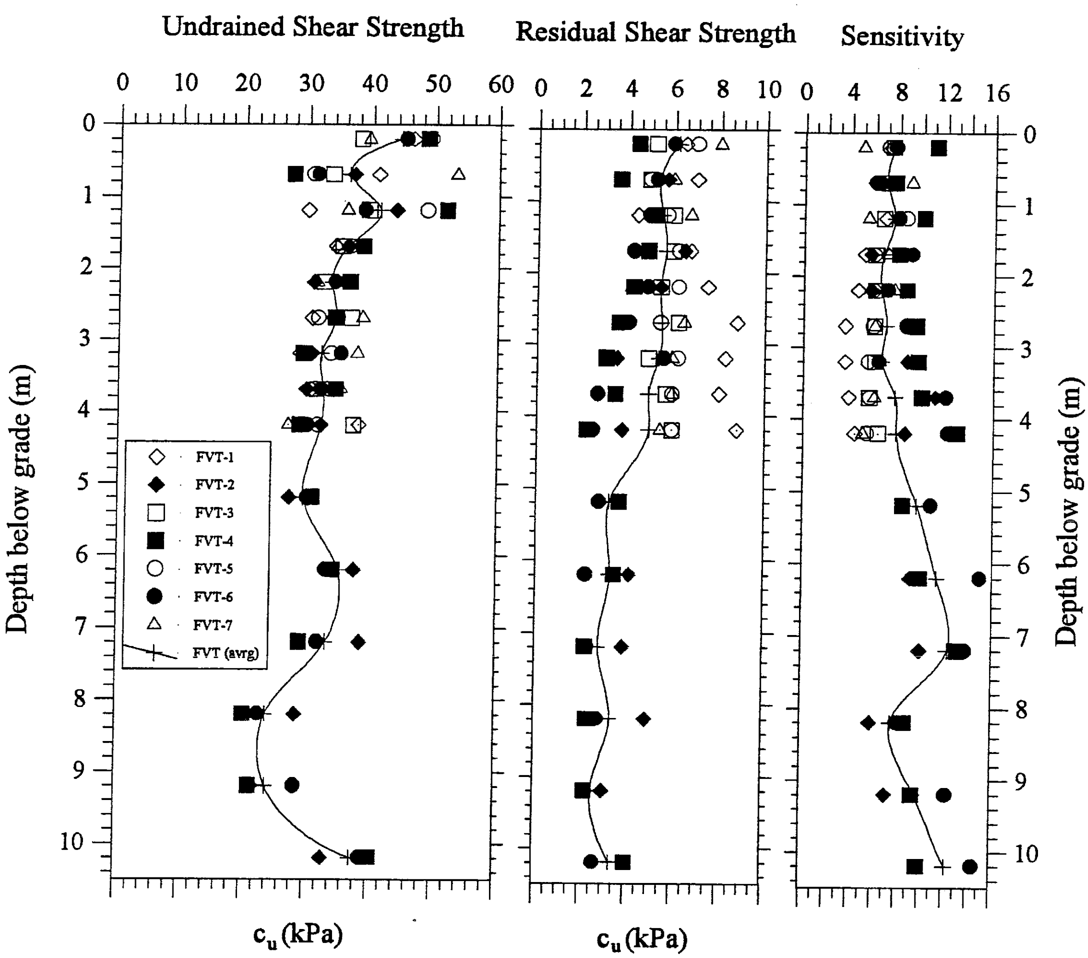

Figure 7 Field vane shear test results

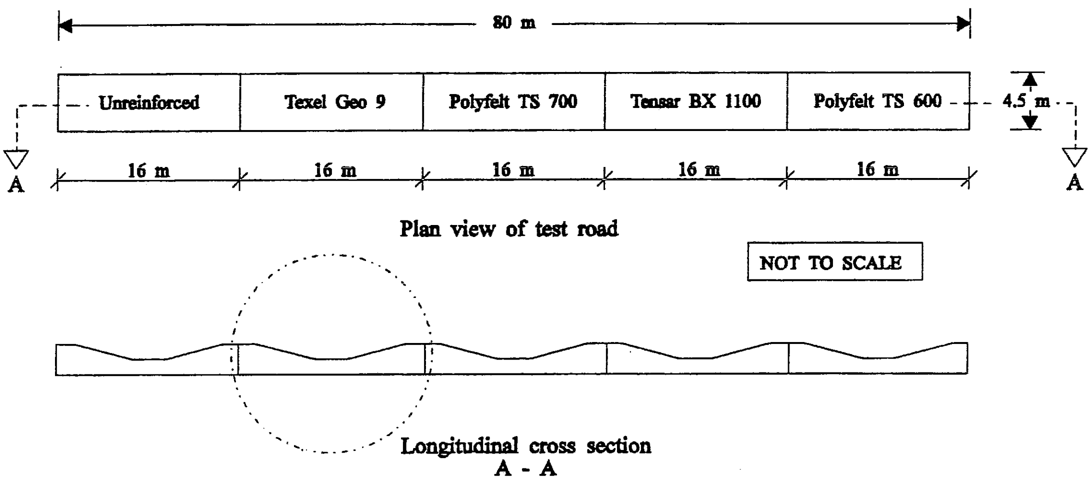

Figure 8 Test section layout

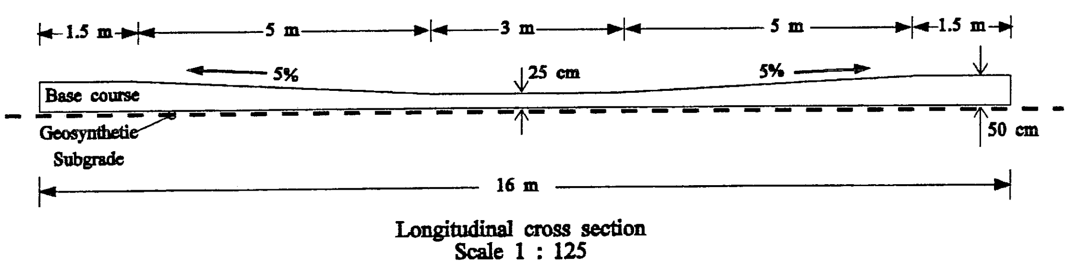

Figure 9 Test section geometry

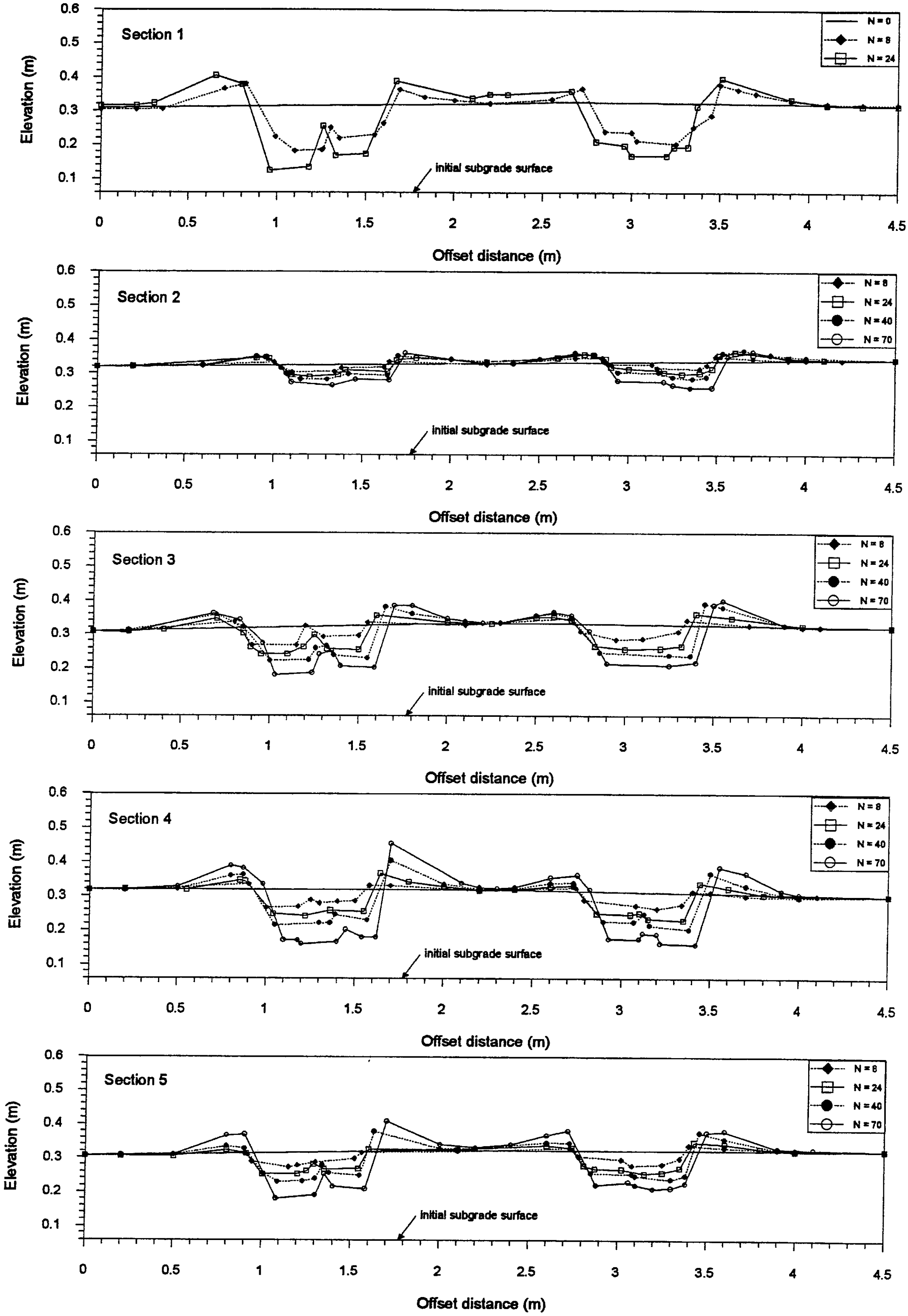

Figure 10 Surface profiles at cross-section h = 25 cm, tests sections 1 to 5

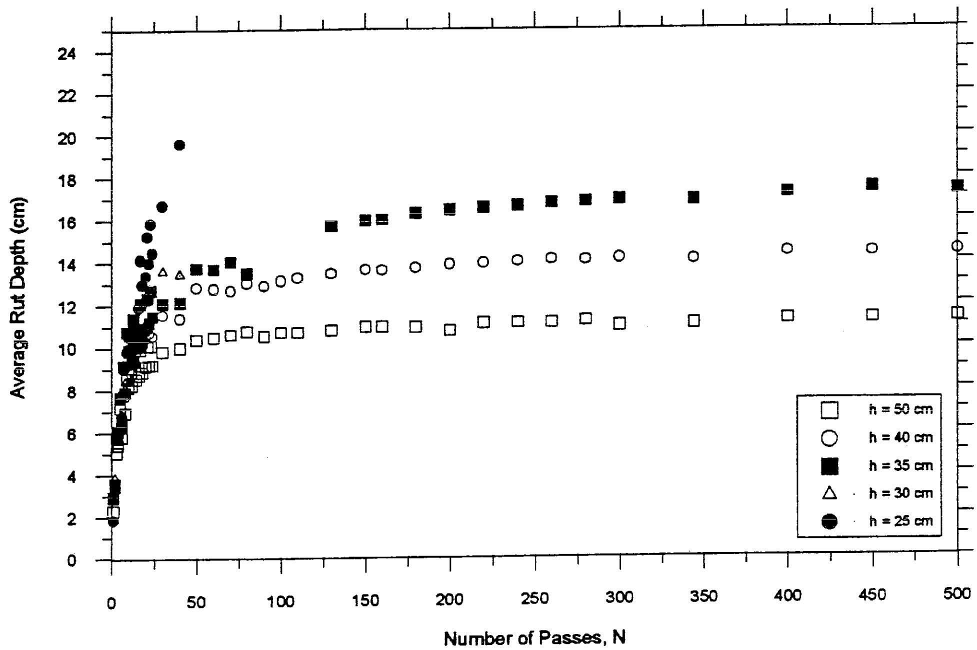

Figure 11 Average rut depth versus number of passes - Unreinforced data

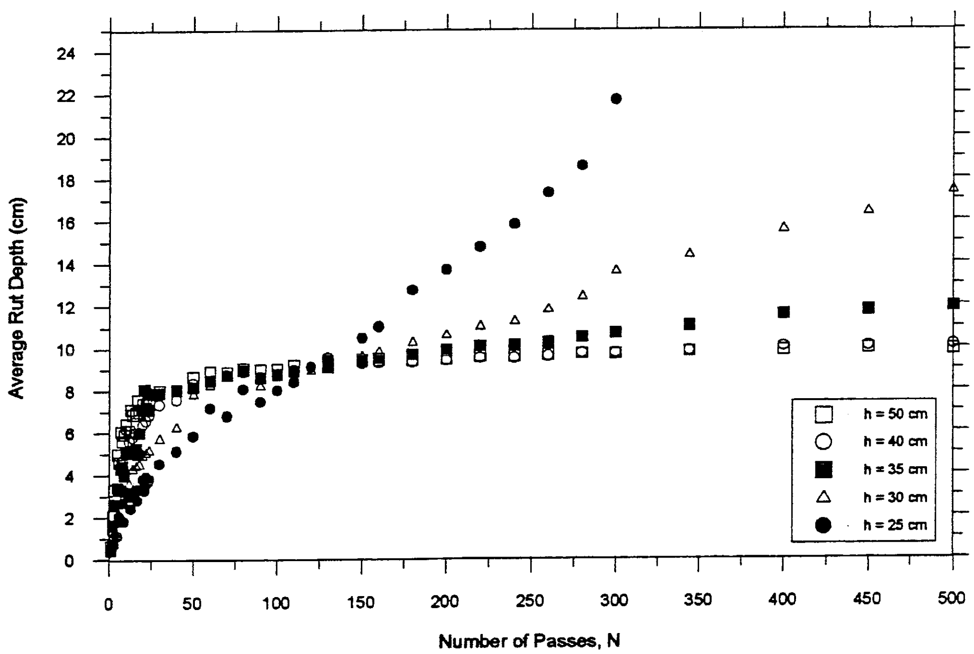

Figure 12 Average rut depth versus number of passes - Texel Geo 9 data

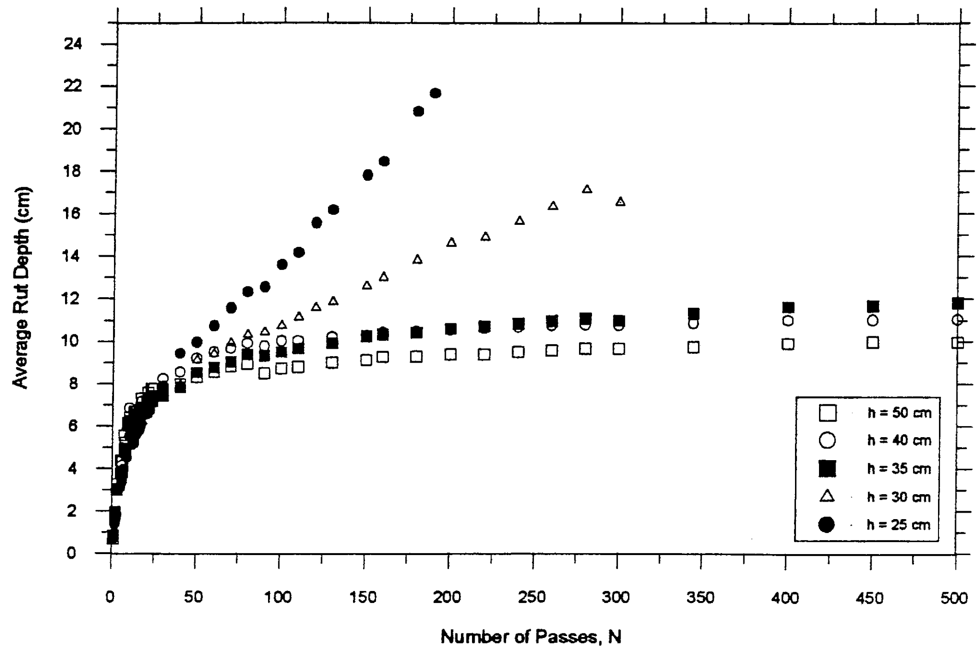

Figure 13 Average rut depth versus number of passes - Polyfelt TS 700 data

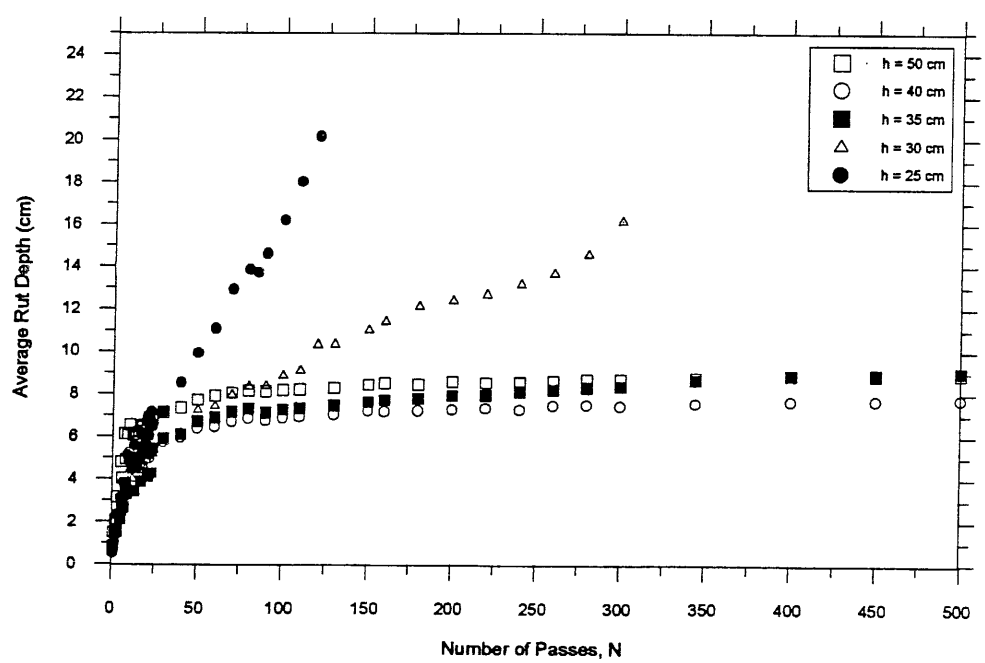

Figure 14 Average rut dpeth versus number of passes - Tensar BX 1100 data

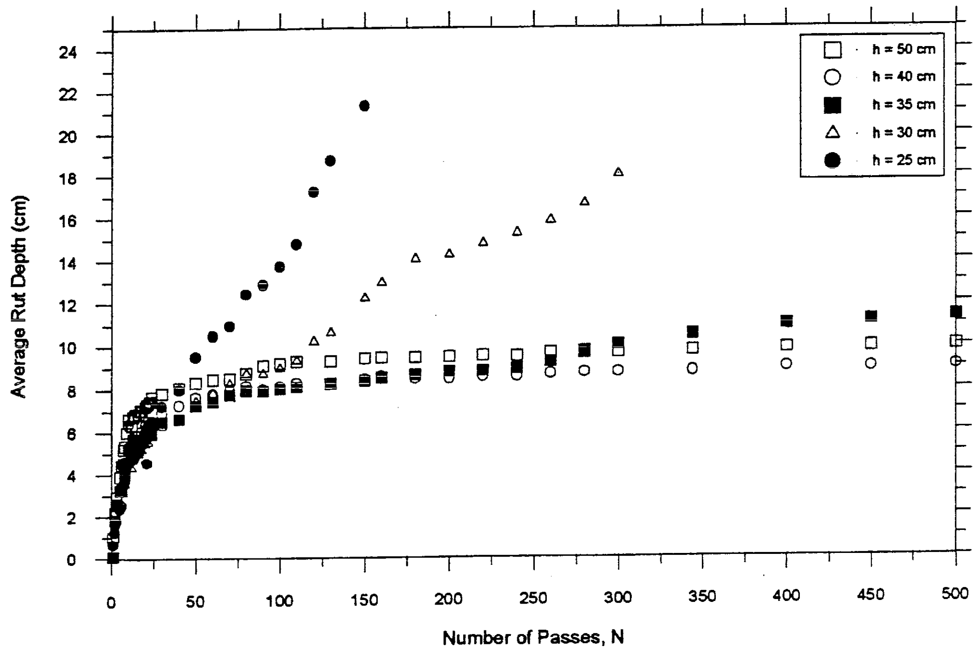

Figure 15 Average rut depth versus number of passes - Polyfelt TS 600 data

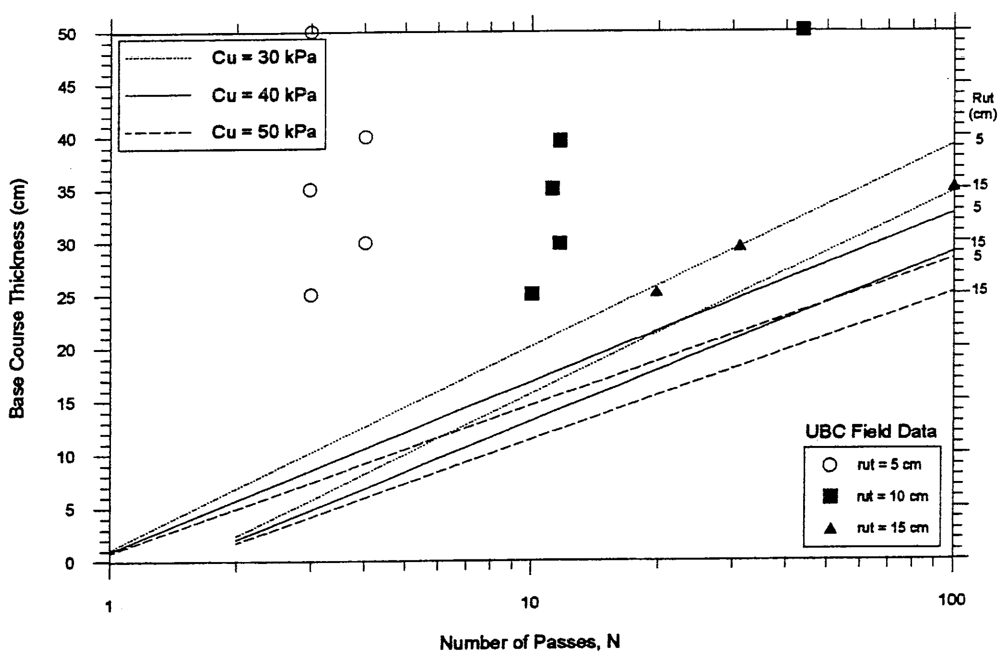

Figure 16 Unreinforced data comparison

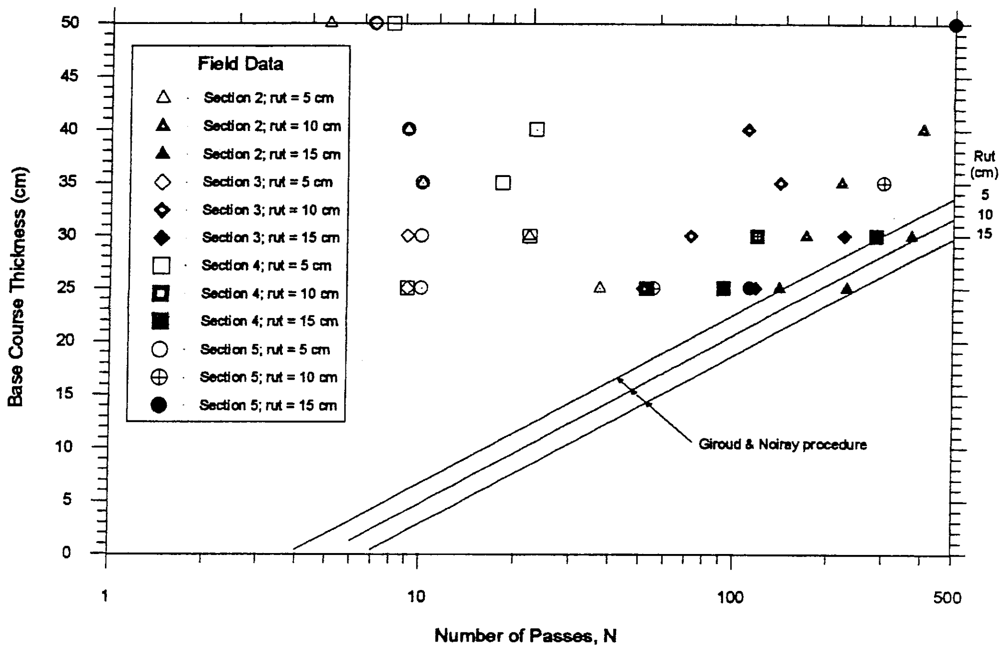

Figure 17 Reinforced data comparison