The Behaviour of Unpaved Roads Under Large Rutting Conditions

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ABSTRACT: This paper presents and discusses the results of model reinforced and unreinforced unpaved roads subjected to large ruts caused by continuous maintenance. The presence of the reinforcement increases the bearing capacity of the road even for poor quality fill material. A change in the failure mechanism developed was identified as a function of the road height. Load spreading throughout the fill and pore pressures in the foundation were also assessed.

1 INTRODUCTION

Unpaved roads are of major importance for undeveloped and developing countries's economies. In Brazil, for example, they are responsible for the transportation of 95% of the economy's primary goods. The use of geosynthetic reinforcement in this type of work has increased markedly during the last years mainly due to savings in fill material consumption, improvement in reinforcement materials' properties and environmental reasons.

This paper presents the results of model tests as part of a research programme to study the mechanics of reinforced unpaved roads on very soft foundations subjected to large rutting conditions due to continuous surface maintenance.

2 EQUIPMENT USED IN THE TESTS

The tests were performed in a 800 x 250 x 300 mm rigid steel box with a frontal perspex wall to allow for strain measurements and failure mechanisms observation in the soil mass. Figure 1 shows schematically the layout of the tests. A layer of fill material was placed by pluviation on the soft kaolin foundation previously consolidated. A rigid steel plate, 50 mm wide, covering the entire width of the box applied the vertical pressure on the fill surface under undrained conditions. Load and displacement transducers were used to measure loads and displacements of the loading plate. Pore pressure measurements at a depth of 35mm from the clay foundation surface was accomplished by a pore pressure transducer.

Loading stages were applied to the road until the footing vertical displacement reached a stabilised value (rut depth, r). Then the fill surface was repaired and a new loading stage applied. Maintenance of the fill surface was made by levelling it to the original position by further pluviation of fill material, as shown in Figure 2. Subsequent loading stages and surface maintenance at stabilised rut depths were performed up to the end of the tests. Values of rut depths of 15 and 25mm were used.

The thickness of the soft foundation was held constant at 200mm while the fill material thickness was varied (30, 45, 60 and 100mm). The undrained strength profile of the soft foundation was obtained by vane tests. Figure 3 shows the envelope of vane test results

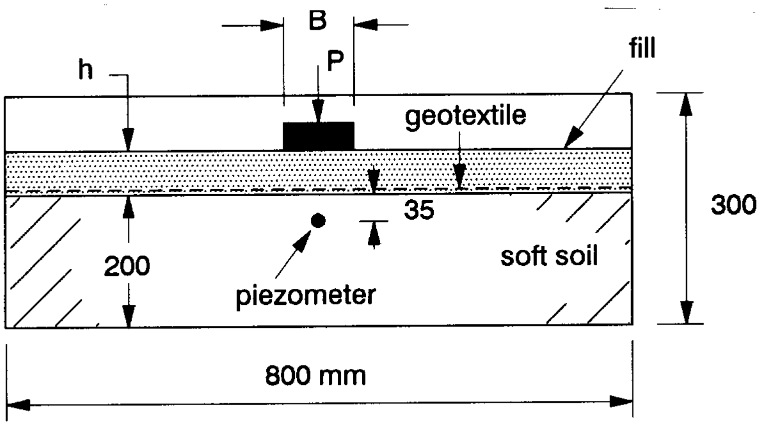

Fig. 1 Schematic view of the model tests performed.

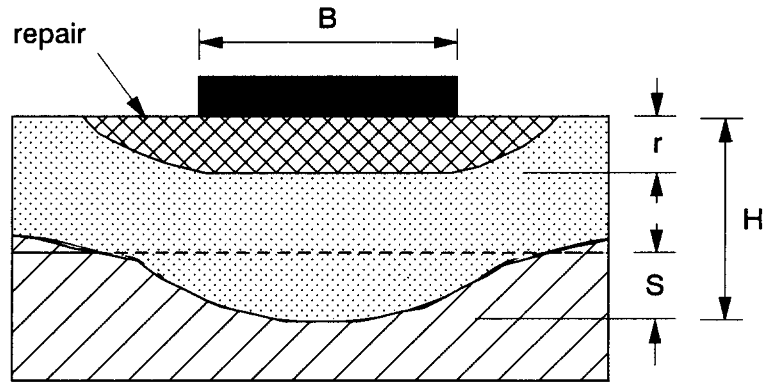

Fig. 2 Maintenance of the fill surface.

for all the model tests performed. Table 1 shows the main characteristics of the three types of fill materials used, ranging from good to poor quality materials for this type of work. In reinforced tests a model non woven, needle punched, geotextile made of polyester was laid between the fill and the soft foundation. Table 2 presents relevant data on the model geotextile.

Table 1 Characteristics of Fill Materials

Type	D_{50} (mm)	CU	γ (kN/m^3)	c (kPa)	ϕ (deg.)	ϕ_{cv} (deg.)
A	0.65	36	18	2.93	50	38
B	0.13	17	16.5	1.44	35	31
D	1.20	1.6	16	0	45	36

Notes: D_{50} = mean particle diameter, CU = coefficient of non uniformity, c = cohesion, and ϕ and ϕ_{cv}= peak and critical state friction angles.

Table 2 Geotextile Characteristics

μ (g/m^2)	t_{GT} (mm)	T_f (kN/m)	ε_f (%)	J (kN/m)
75	0.5	3.3	70	4.9

Notes: μ= mass per area, t_{GT}= thickness, T_f= tension at failure, ε_f= strain at failure, J = tensile stiffness.

Additional details on equipments and materials are presented in Ferreira Jr. (1994).

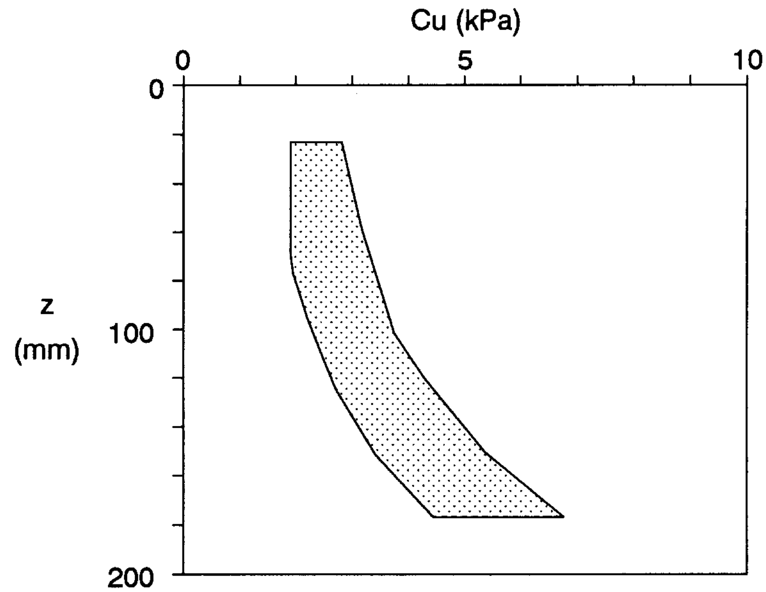

Fig. 3 Undrained strength envelope for all model tests performed.

3 RESULTS OBTAINED

Figures 4 and 5 present results of footing pressures (p), normalised by the clay undrained strength (C_u) at a depth equal to 50mm (= B), versus footing vertical displacement (δ), normalised by the footing width (B), for reinforced and unreinforced tests with fill material A. The marked effect of the presence of the reinforcement on the strength of the road can be observed in these two figures. Similar benefit brought by the reinforcement was also observed for the poor quality fill material B, as shown in Figure 6. Similar results in an earlier stage of this research programme were also obtained by Cunha (1991) and Palmeira & Cunha (1993). A punching failure mechanism occurred in unreinforced tests while a generalised failure

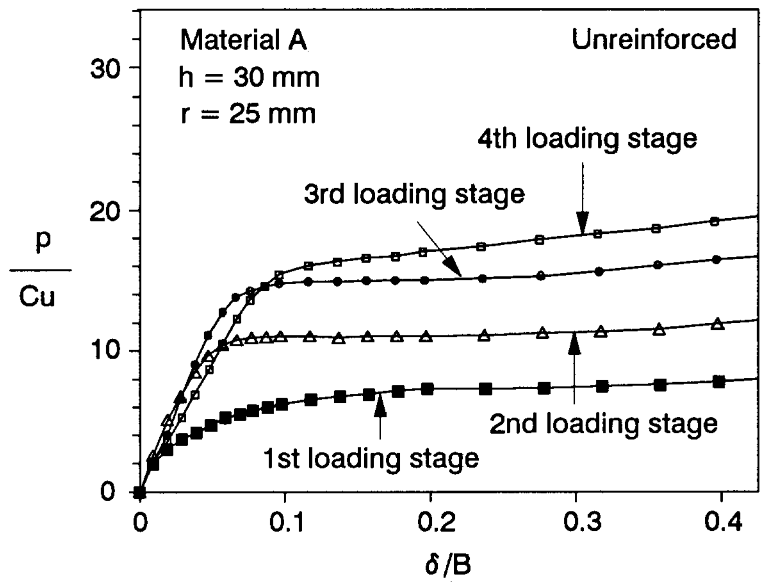

Fig. 4 Normalised footing stresses versus normalised footing displacements - fill material A, unreinforced.

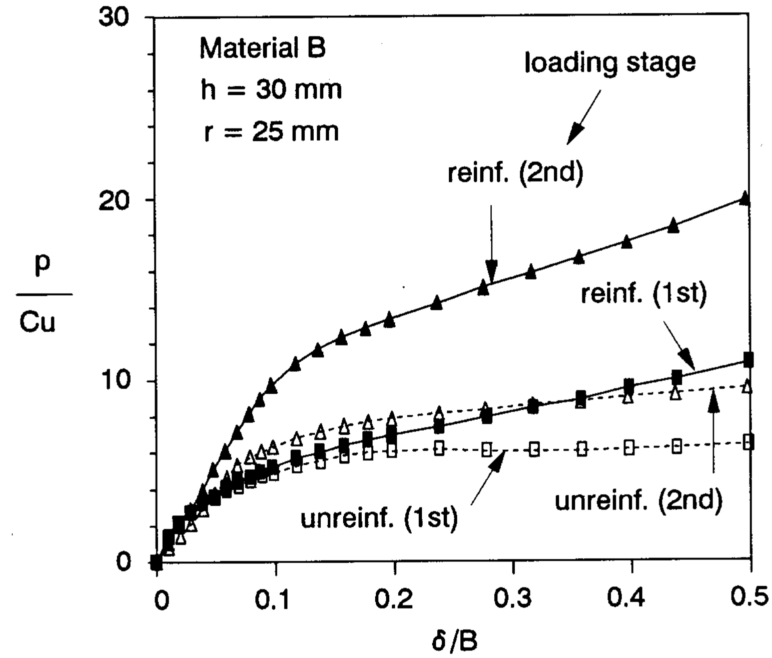

Fig. 6 Normalised footing stresses versus normalised footing displacements - fill material B.

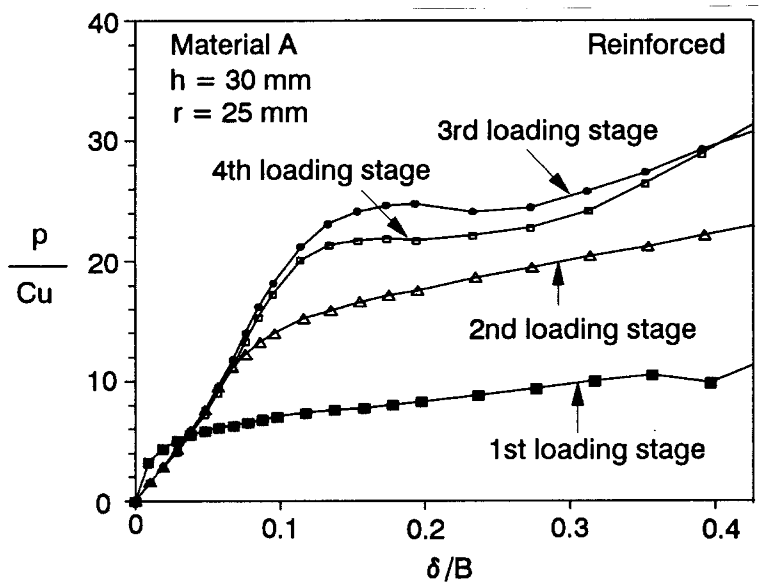

Fig. 5 Normalised footing stresses versus normalised footing displacements - fill material A, reinforced.

mechanism was observed in reinforced ones.

From Figures 4 and 5 it can also be noted that the results for the 3rd and 4th loading stages (after the 2nd and the 3rd surface maintenance, respectively) were very close. This was due to the fact that for these loading stages failure occurred in the fill material. For roads with an initial height $h \leq (1.5$ to $1.8)B$ it was observed that failure mechanisms were developed predominantly in the fill layer for H/B (fig. 2) ratios greater than 1.3 in reinforced tests and greater than 1.8 in unreinforced tests. For roads with $h > 1.8$ B the failure mechanism occurred in the fill.

Figure 7 shows pore pressure increments (Δu), normalised by the footing pressure, versus δ/B during the first loading stage for reinforced and unreinforced tests with fill material D. Peak pore pressures occurred in the early stages of unreinforced tests, probably associated with fill failure. In reinforced tests peak pore pressures occurred slightly later in the test. The pore pressure increment remained positive throughout reinforced tests but it became negative during unreinforced tests due to suction caused by the lateral outward movement of the soft foundation on both sides of the footing.

Figure 8 presents values of vertical pressure spreading angle (θ) against fill friction angle (ϕ), inferred from the deformed shapes of black sand lines placed in the fill in contact with the box perspex wall. Additional data collected in the literature are also presented. In spite of the large scatter of the data it can be observed that there is a significant increase in load spreading in reinforced unpaved roads compared to unreinforced ones.

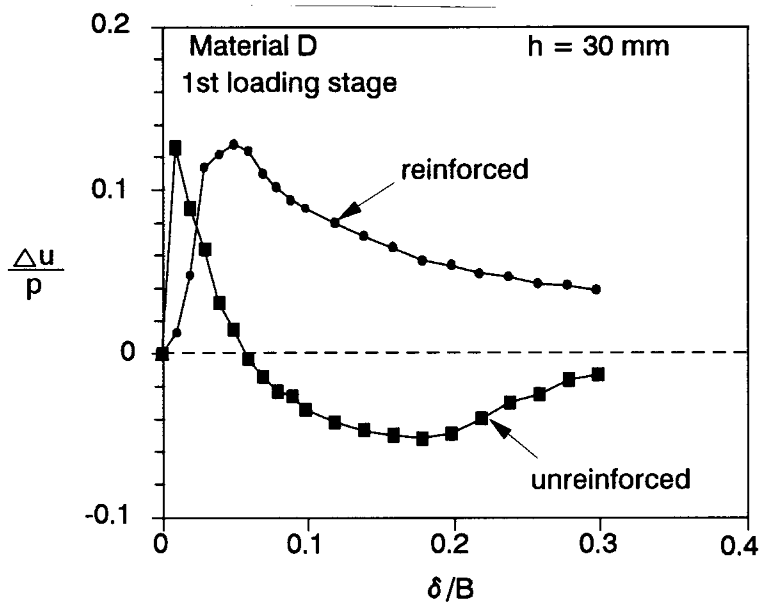

Fig. 7 Pore pressure increments in the foundation - fill material D.

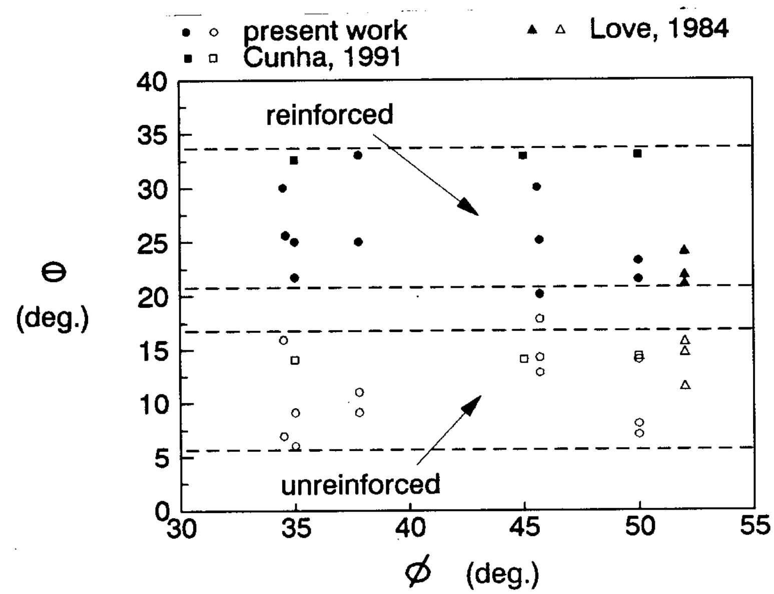

Fig. 8 Load spreading angles versus fill friction angle.

4 CONCLUSIONS

The performance of unpaved roads after surface maintenance is significantly improved by the presence of the reinforcement. This fact should be taken into account in cost calculations somehow, because in this case an initially more expensive reinforced road might be more cost effective in the medium/long term than an unreinforced one. It should be pointed out that as the fill thickness beneath the footing increased after maintenance to ratios H/B (Fig. 2) of approximately 1.3 for reinforced and 1.8 for unreinforced tests the failure mechanisms took place in the fill layer. The same happened from the 1st loading stage on for initial fill heights h > 1.8B.

In most of the tests performed the load spreading angle in reinforced tests was about twice the value observed in unreinforced tests.

A marked difference in pore pressures developed close to the foundation surface was observed in reinforced and unreinforced tests.

Very commonly in unpaved roads constructed on soft soils the fill material is compacted by the construction machines and by the traffic itself. Therefore, the construction process is a continuous repair of large ruts caused by these vehicles until a stabilised final fill height is achieved. The field conditions are certainly more complex than the ones approached in the present work. Because of that for very soft subgrades the current unpaved road design methods are likely to underestimate the final operational road height. A preliminary approach to estimate the load capacity of unpaved roads after maintenance was presented by Palmeira & Cunha (1993) and is currently being updated in view of the additional data presented in this work.

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