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Behavior of Woven Fabrics Under Simulated Railway Loading

Comportement d'un géotextile tissé sous l'action représentant une charge de poids de chemin de fer

SUMMARY

The effects of placing a geotextile between a railway base course and a fine-grain subgrade were evaluated by performing a series of cyclic triaxial tests. Each test specimen was subjected to 5000 cycles of simulated railway car wheel loading; resilient modulus and permanent strain were recorded per cycle of loading. Two geotextiles were used during the program: PPS45 and Propex 6062. Both are woven fabrics comprised of polypropylene oriented split film. Tests were also conducted in which a 3 cm layer of sand was placed between the geotextile and the fine-grain soil. Results of the test series showed that the resilient moduli of samples with the geotextile were higher by 10 to 50 percent than if the geotextile was not included. The accumulated permanent strain decreased by 30 to 60 percent when the geotextile was introduced. Finally the geotextile reduced the amount of fine-grain migration into the base course.

SOMMAIRE

Les effets du placement d'un géotextile entre un ballast de chemin de fer et un sol de fondation cohérent ont été evalués en faisant une série d'essais cycliques triaxiaux. Chaque échantillon a été soumis à 5000 cycles de chargement typique d'un roue de wagon de voie ferrée; le module de rebondissement et la deformation permanente ont été enregistré pour chaque cycle de chargement. Deux géotextiles ont été utilisés dans le programme: PPS45 et Propex 6062. Les deux tissus étaient fait de pellicule de polypropylene coupée et orientée. Plusieurs essais ont été fait avec une couche de sable de 3 cm intercalée entre le géotextile et le sol cohérent. Les résultats de la série d'essais ont montré que le module de robondissement du sol avec le géotextile était plus élevé (10 à 50 pourcent) que sans l'utilization du géotextile. La déformation permanente accumulée a baissé de 30 à 60 pourcent quand le géotextile a été utilisé. Enfin le géotextile a diminué la quantité de migration du sol dans le ballast.

INTRODUCTION

During the past 100 years, railways have been located in virtually every climatic condition and on virtually every type of soil. The rail-tie system was originally placed directly on native soil with little consideration given to soil behavior. Subsequently as rail loads and track speeds increased and as maintenance costs rose, more refined analytical procedures involving basic concepts in geotechnical engineering evolved. Today railways tracks are constructed on composite foundations which are dimensioned to satisfy various stress and deformation criteria (1, 4, 7, 8).

One of the foremost considerations in the current design of railway foundations, such as shown in Figure 1, is the migration of fine-grain native soils into the base course and ballast, a process which is commonly called fouling (7, 8). Fouling of the ballast and base course results as dynamic wheel loads "pump" the fine-grain material upward through the pore spaces in the coarser material. This pumping phenomenon is particularly prevalent in silt-size soils, which are fine enough to migrate through the base course and ballast and which have little or no unconfined shear strength. As the ballast and base course are fouled with fine-grain soils, the track undergoes larger deformations for given wheel loadings. Secondary considerations such as drainage and frost susceptibility also become more critical (7). Eventually significant maintenance costs may be incurred.

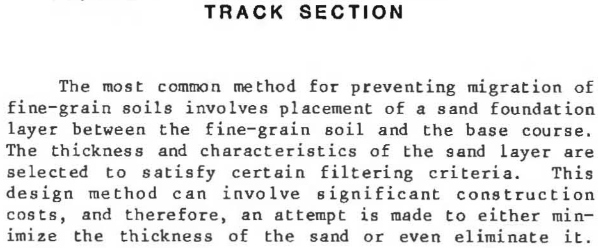

FIGURE 1 TYPICAL EUROPEAN TRACK SECTION

The most common method for preventing migration of fine-grain soils involves placement of a sand foundation layer between the fine-grain soil and the base course. The thickness and characteristics of the sand layer are selected to satisfy certain filtering criteria. This design method can involve significant construction costs, and therefore, an attempt is made to either minimize the thickness of the sand or even eliminate it.

Another potential approach to solving the migration problem involves the use of geotextiles (2, 5, 6). The geotextile offers two significant benefits: 1) it can be used as a filter between the fine-grain soil and the base course and 2) it provides some additional reinforcement to the base course during wheel loading. Furthermore the cost of the geotextile on a unit area basis can be competitive with a sand filter if labor, material and long-term maintenance costs are considered.

Although the potential benefits of using the geotextile are fairly evident, acceptance by the rail industry has been slow. This slowness can be attributed to the limited data base upon which to judge the benefits. In an effort to enhance this data base, a laboratory testing program was conducted for the purpose of investigating the effects of geotextiles on 1) fine-grain soil migration and 2) base course strength during dynamic wheel loading.

TESTING CONCEPT

A wheel-foundation interaction problem is very complex, by virtue of the foundation geometry and the transient wheel loading if nothing else. Consequently a number of simplifications were made during this study to investigate the effects of geotextiles on soil migration and base course strength. Although some of these assumptions may limit the applicability of the results, it is felt that the trends obtained from the testing program provide valuable support for the use of geotextiles as a means of preventing fine-grain soil migration and increasing base course strength.

The first simplification involved the use of a two-layer triaxial specimen to represent conditions at the base course-subgrade interface (Figure 2). Whereas the triaxial sample does not provide an exact replication of the field, particularly from a scaling standpoint, it offers a simple means for evaluating the effects of repeated loading cycles under known stress and drainage conditions. For this study the upper half of the specimen was the base course material; the lower half was the fine-grain subgrade. As noted previously, silts have been most susceptible to migration; hence a silt was selected to represent the subgrade.

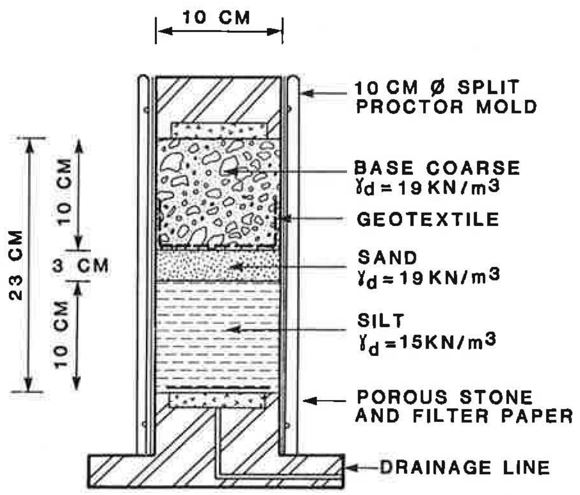

FIGURE 2 CROSS-SECTION OF TRIAXIAL TEST SPECIMEN

Another important consideration is the water conditions within the foundation system. The migration problem has been most noticeable when the subgrade is saturated. The ballast, in turn, is generally very porous and above the natural ground water level, and hence, is normally in a drained condition. For this study it was assumed that the silt would be soaked, with a phreatic head at the level of the base course-silt interface.

The next simplification involved the stress conditions under geostatic and transient wheel loading. The geostatic stress at the base course-silt interface was assumed to be 35 kN/m^2 based on the unit weight of the ballast and the dead-weight loading from the tie and rail. The transient loading was represented by a half-sine wave (Figure 3) with a maximum transient stress of 50 kN/m^2. This stress level corresponds to the passage of an axle load of approximately 90 kN at a depth of 50 cm below a concrete tie (7). The period for the transient loading was 0.8 seconds. This period would result from a railway car travelling at about 40 km/h for an average axle to axle spacing of approximately 8 m. This loading rate was less than might be expected for many situations; however, it was thought that it would maximize the opportunity for pumping (i.e., faster loading would be completely undrained).

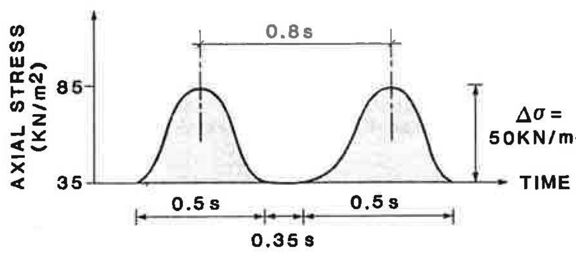

FIGURE 3 TYPICAL WAVE FORM FOR TRANSIENT LOADING

SOIL AND GEOTEXTILE PARAMETERS

Three soils were used during the course of the investigation: a coarse foundation material (base course), a fine to medium sand and a silt. Grain-size distribution curves for each soil are presented in Figure 4. The silt was slighty plastic; the liquid limit, plasticity index and natural water content (during testing) were 42, 15 and 20 percent, respectively. The sand was used during three tests as a supplemental filtering material. The grain-size distribution of the sand was typical of sands used during railway construction. To maintain a satisfactory ratio of particle size to sample diameter, the maximum particle size of the base course was limited to 15 mm.

Two geotextiles were used during the testing program: Propex 6062 and PPS45. These geotextiles are designated as Geotextile 1 and Geotextile 2, respectively. Both are woven fabrics comprised of polypropylene oriented split film. The characteristics of each geotextile are summarized in Table 1. The two geotextiles are generally similar in characteristics. Different tensile strengths and permeabilities result from the different weaving patterns.

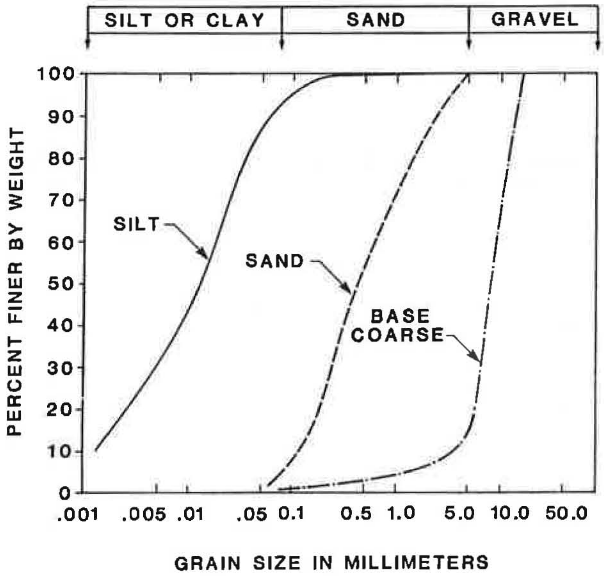

FIGURE 4 GRAIN-SIZE DISTRIBUTIONS OF TEST MATERIALS

TABLE 1. SUMMARY OF PROPERTIES FOR GEOTEXTILES

	Geotextile 1	Geotextile 2
Equivalent Opening Size (95)	0.11 mm	0.17 mm
Percentage Open Area (Est.)	7%	5%
Thickness at 20 kN/m^2	0.50 mm	0.37 mm
Weight	190 g/m^2	140 g/m^2
Tensile Strength	1700 N/5cm	1125 N/5cm
Failure Strain	16%	12%
Permeability	17 L/m^{2}s	10 L/m^{2}s

TESTING PROCEDURE

As shown in Figure 2, the top of each test specimen was a base course, and the bottom was a silt. Methods used in preparing, testing and evaluating samples are described below.

Sample Preparation. Each sample was prepared by compacting the silt in a 10 cm diameter by 23 cm high Proctor split mold using a 2 kg hammer. Approximately 25 blows per layer were applied; layer thicknesses were about 1.0 cm. Once the midheight of the specimen was reached, about 10 cm, one of the following four procedures was followed.

1) A 3 cm layer of sand and a layer of geotextile were placed on the fine material and then the coarse material was compacted using the same procedure (Tests 1 & 2).

2) A 3 cm layer of sand was placed on the fine material after which the coarse material was compacted (Tests 3).

3) A layer of geotextile was placed on the fine material and then the coarse material was compacted (Tests 4 & 5).

4) The coarse-grain material was compacted directly on the fine material (Test 6).

The unit weights of the silt, sand and base coarse after compaction were approximately 15, 19 and 19 kN/m^3, respectively. Figure 5 provides a summary of the test cases.

SETUP						
GEOTEXTILE	1	2		1	2	
TEST NO.	1	2	3	4	5	6
SYMBOL	○	□	⬡	◇	▽	△

FIGURE 5 TEST CASE SUMMARY

After the specimen was tamped to its 20 to 23 cm height, it was weighed and then transferred to a triaxial test cell. Each sample was "capped" with a plaster compound to assure a flat sample top. The test specimen was then consolidated overnight under a pressure of 35 kN/m^2. This duration of confinement was more than sufficient to allow complete consolidation of the fine-grain soil. A phreatic head was maintained at the top of the silt layer throughout consolidation and testing.

Sample Testing. Each sample was subjected to 5,000 cycles of loading. An MTS cyclic loading device was used to apply the loading sequence. The MTS device was operated in a controlled-stress mode to impose a constant cyclic axial stress. A load cell mounted just above the triaxial chamber was used to monitor cyclic loads. Sample deformations were measured with an LVDT (linear variable differential transformer). During cyclic loading sample drainage was closed at the bottom and open at the top of the test specimen.

Load and deformation measurements were recorded with an oscillograph (light-beam type) and an x-y recorder. From these measurements it was possible to define plastic creep and elastic rebound during each loading cycle. These data were used to define the resilient modulus for each cycle of loading. By definition (8) the resilient modulus is the ratio of the cyclic deviator stress divided by the recoverable portion of axial strain (Figure 6).

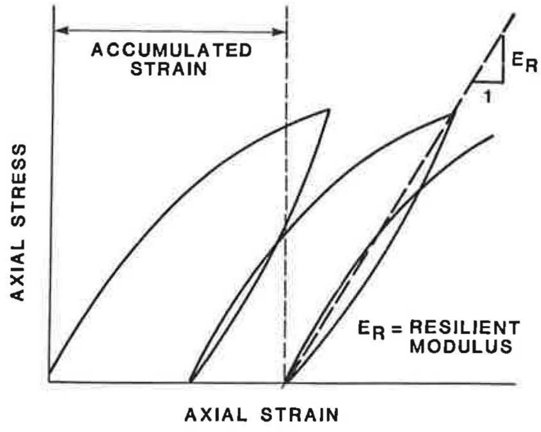

FIGURE 6 IDEALIZED SOIL RESPONSE

Post-Test Evaluation. At the conclusion of each test, the test setup was disassembled and the sample was carefully inspected. Grain-size analyses were performed on several samples to determine if particle breakdown or fine-grain soil migration had occurred. For Tests 1, 2, 4 and 5 the woven fabric was inspected with a microscope to determine if any evidence of fabric deterioration existed.

TEST RESULTS

Resilient modulus values (E_r) obtained during this testing program are plotted in Figure 7. This plot shows both the variation of E_r with cycles and with different interface conditions. It is clear from these results that resilient modulus generally decreased with cycles of repeated loading and that for any given number of load applications a consistently higher resilient modulus occurred when the geotextile was used. A noticeable difference in resilient modulus also resulted when a thin layer of sand was placed between the base course and the silt and between the geotextile and silt.

Accumulated plastic strains for the six cases are plotted as a function of loading cycle in Figure 8. This plot shows that plastic strain increased with the number of loading cycles. However, the plastic strain for a test specimen with a geotextile was always smaller for a given number of load applications than if the geotextile was excluded.

Visual inspection of the soil specimens following Tests 3 and 6 revealed that some fine-grain soil migration occurred. As would be expected, migration was reduced when a geotextile separated the two materials (Tests 1, 2, 4 and 5). There was no evidence of geotextile deterioration from the repeated cycles of loading.

DISCUSSION

Several trends can be noted from the data shown in Figures 7 and 8. First the rate of resilient modulus decrease appears to end after about 1000 to 5000 cycles of loading for samples containing the geotextile. No change in the rate of decrease seems to occur for samples without the geotextile. This response suggests that the geotextile ultimately may prevent further deformation. The plastic strain plots in Figure 8 tend to support this observation, i.e., accumulated strains for tests with the geotextile appear to stabilize (must be inferred for Tests 1, 2 and 4). This probably reflects an incremental stiffening of the sample by the geotextile wherein the sample can no longer undergo unrestricted lateral deformations (3). As deformations are restricted, the volumetric change per cycle of loading decreases, and hence, the asymptotic behavior.

The effects of geotextiles on resilient modulus and accumulated strain also form a consistent response. Resilient modulus for a given number of load applications is always higher when the geotextile is included. Likewise accumulated strains are smaller by up to 60 percent when the geotextile is used. The sand layer between the geotextile and the silt causes a noticeable increase of moduli. This latter result suggests that more resistance is developed on a sand-geotextile interface than on a silt-geotextile interface, which may in turn reflect a higher coefficient of friction for the sand-geotextile case.

Different characteristics of the geotextiles also led to different resilient moduli and accumulated strain. Moduli are lower, and accumulated strains are higher for the more flexible geotextile (PPS45). Again, the difference in specimen response is attributed to the different engineering properties of the geotextiles.

CONCLUDING REMARKS

The results of this testing program were by necessity limited. A number of questions still exist regarding the behavior of geotextiles during cyclic loading. For example the effects of larger stress pulses certainly merits additional consideration. The effects of loading rate and millions of cycles of loading would also be of interest. Despite these questions, the testing program successfully demonstrates that a geotextile can be used to increase the resilient modulus of a base course-subgrade system by as much as 10 to 50 percent for typical railway ballast loading conditions. Accumulated strains in turn could be 30 to 60 percent lower. By placing a geotextile between the subgrade and base course, some reduction of fine-grain soil migration also results.

These three observations support the use of geotextiles in railroad ballast design. A reduction in the accumulated strain is particularly important in railway track design in that the formation of ballast pockets in proximity to the rails would decrease. Water tends to accumulate in these ballast pockets, thereby reducing the supporting strength of the subgrade material and causing deterioration of track supporting capacity. The increase in foundation stiffness may also allow for a reduction of the thickness of the ballast or base course. Finally the reduction in fine-grain soil migration, particularly when combined with a thin sand blanket, should lead to better long-term behavior of the track-foundation system.

Although these results are promising, additional studies are still required to confirm trends noted herein and to investigate various uncertainties. The main uncertainty deals with the effects of millions of cycles of loading under a variety of environmental conditions, particularly temperature fluctuations. In

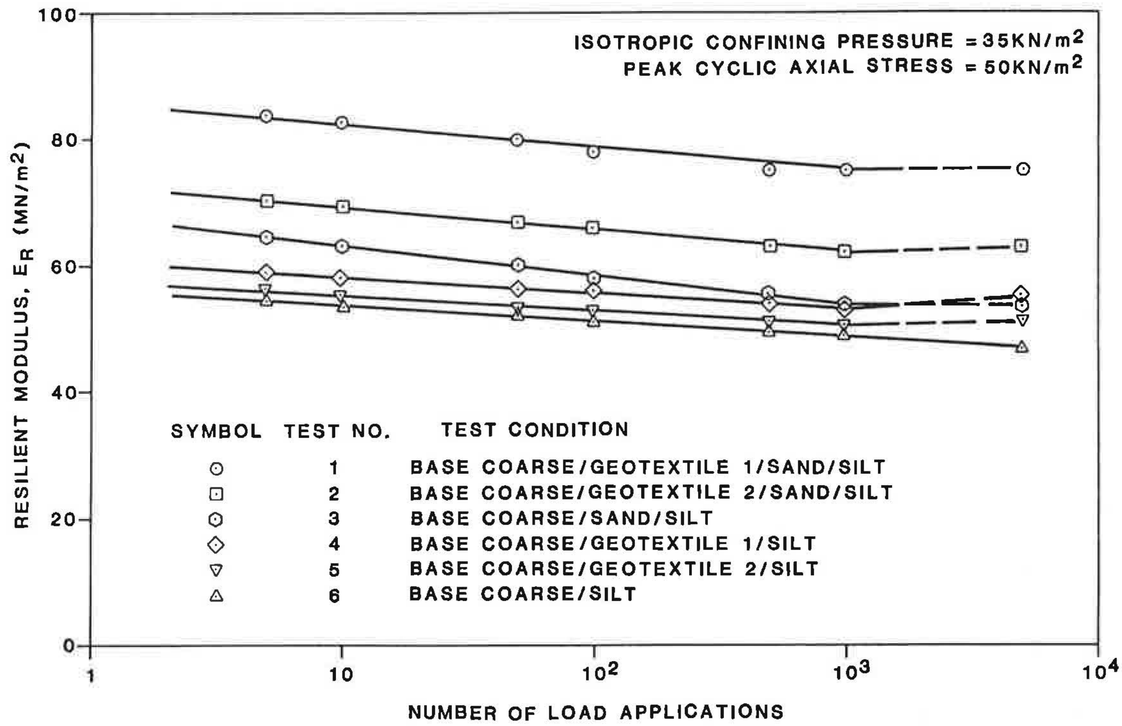

FIGURE 7 RESILIENT MODULUS VARIATION WITH NUMBER OF LOAD APPLICATIONS

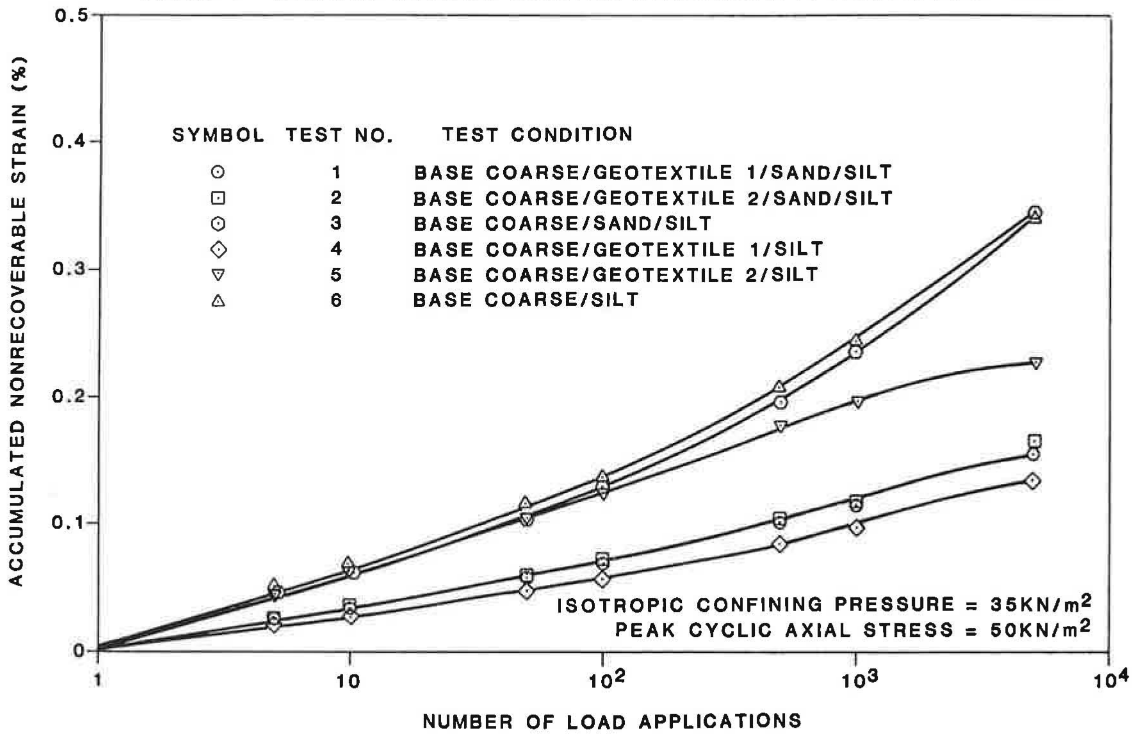

FIGURE 8 ACCUMULATED NONRECOVERABLE STRAIN VARIATION WITH NUMBER OF LOAD APPLICATIONS

all likelihood this uncertainty will not be completely resolved in the laboratory but will require long-term field experimentation. Inasmuch as the benefits of the geotextile are potentially significant, such field experiments are highly recommended.

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