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Membranes in layered soils beneath pipelines

A.F.L.Hyde
University of Bradford, UK

K.Yasuhara
Nishinippon Institute of Technology, Fukuoka, Japan

ABSTRACT: Pipelines laid in reclaimed areas consisting of fill materials of varying strength often undergo unacceptable differential settlements causing joint failure. Laboratory tests have been carried out to investigate a method of reducing settlements by placing a geosynthetic membrane below the pipe bedding material. It was shown that geotextiles particularly of the grid type when used as a separator between rounded aggregate pipe bedding and an underlying soft clay lead to reduced settlements and increased bearing capacities.

1. INTRODUCTION

A common form of failure of jointed pipes laid in trenches takes the form of differential settlement causing opening and sometimes fracture of the pipe joints. This type of failure often occurs in pipelines laid in reclaimed areas consisting of fill materials of varying strength. It is common practice to support pipes on beds of rounded pea gravel. Tests have therefore been carried out on the effects of a separating geosynthetic layer on the load deformation characteristics of a plate bearing on a rounded gravel overlying a soft clay subgrade. The purpose of the tests was to investigate a method of reducing pipeline differential settlements by placing a geosynthetic membrane below the pipe bedding material.

2. REINFORCED LAYERED SOIL

Considerable work has been carried out on the effects of geotextile layers in both bound and unbound road pavement systems and embankments on soft soils.

Many researchers studying the effects of a geotextile layer beneath the unbound granular layer in a road pavement have found that these materials lead to a reduction in the required design thickness of a granular layer. (Barenberg et al, 1975, Brown, 1978, Ruddock, 1977) While Brown (1978) also showed that geotextiles induced enhanced stress distributing characteristics in pavement structures. In addition Jesberger (1977) studying a sub-base over silt and Jarret et al (1977) and Sorlie (1977) studying a sub-base over peat all showed an increased bearing capacity by the introduction of a geotextile layer. Clearly if geotextiles can reduce design thicknesses and increase bearing capacities then under similar conditions they should lead to reduced settlements under loading. Giroud et al. (1984) demonstrated this while Barvashov et al (1977) showed that pre-tensioning reduced displacement even further. In the case of embankments, Belloni and Sembenelli (1977) among others found that geotextile reinforcement led to reduced settlements.

Theoretical elastic analyses of geosynthetic layers by Brown (1978) seemed to suggest that the strains were reduced because of the increased modular ratio between the different layers. Using both empirical data and elastic analyses design charts have been produced for different types of geosynthetic layers. For example Giroud and Noiray (1981) present design charts for the thickness of a granular layer in a road structure as a function of the strength of the subgrade a geotextile modulus and number of load applications.

3. PIPE BED DESIGN

Pipe bedding is normally a single size granular material the purpose of which is to provide uniform support for pipes when laid and hence prevent structural failure due to surface loads. The field strength of a pipe is dependent on its position relative to the natural ground level, its depth, the shape of the trench, the density of the fill and the position of the water table. Walton (1970) defines the laboratory strength of a pipe as 80% of the ultimate force required to crush the pipe. A pipe bedding factor F_b is defined as the ratio of the field strength to the laboratory strength. Walton gives tables of bedding factor values for different loading conditions ranging from F_b=1.1 for a pipe laid directly onto the bottom of a trench and having a soil backfill to F_b=4.8 for a pipe having a 180° granular cradle with reinforced concrete laid over the top of the pipe and then a soil backfill. Waltons tables therefore give guidance to the designer on the choice of bedding material, thickness and placement geometry according to the loading conditions and position of the pipe.

4. EXPERIMENTAL METHODS

Assuming that load from a pipe is distributed to the underlying bedding material over an area given by a 60° cone from the centre of the pipe then a 350mm diameter pipe will apply a load over a strip 200mm wide. Since it was desired to model the settlement under a differentially loaded joint a loading plate 200mm x 200mm was chosen. Walton (1970) recommends a minimum granular bedding for a typical bedding factor F_b=1.5 of 100mm and therefore this depth of granular material was used in all tests.

The diameter of pipe considered is commonly manufactured in lengths of 1200mm. It is considered that a joint rotation of 5° would cause failure. The maximum allowable displacement under the joint is therefore 1200 x tan2.5°=52mm.

Materials

The subgrade consisted of Keuper Marl a silty clay (W_L=36%, W_P=19%, G_S= 2.7) A standard compaction test gave an optimum moisture content of 16.2% and an optimum dry density of 1.75 Mg/m³. For testing purposes the subgrade was mixed to a moisture content W=21% in order to produce a soft subgrade. This moisture content was well wet of optimum and core samples taken from the compacted subgrade gave quick undrained triaxial shear strengths C_u=15kPa. Shear vane tests carried out in the testing box agreed with this value. The bulk density in the test box was 2.07Mg/m³ and the dry density 1.72Mg/m³.

The single sized rounded aggregates were chosen to model typical pipe bedding materials. The gravels used were 5mm, 10mm and 20mm maximum sizes.

Three different types of material were used to separate the gravel and subgrade. These were Netlon a polyethylene grid, Terram a melded fabric and polythene sheeting. Four types of Netlon were used and these together with some of their properties are listed in table 1. The CEIII material was a low density polyethylene while all the others were high density.

The Terram used was a fibre mat comprising of a ramdomly oriented matrix of melded bicomponent filaments. The type used had a weight of 140 grammes/m² and while forming a continuous sheet was nonetheless water permeable. Terram is recommended for use in many situations including a separator for temporary roads.

Finally sheets of 1000 gauge polythene were used. This material being impermeable would not normally be used as a separator between the subgrade and bedding material but was tested for comparitive purposes as a low friction low strength material.

Table 1 Netlon properties

	CE111	CE121	CE131	CE152
Mesh aperture mm	8 x 6	8 x 6	27x27	74x74
Mesh thickness mm	2.9	3.3	5.2	5.9
Tensile strength KN/m	2.00	7.68	5.80	4.82
Strain at maximum load	41%	20.2%	16.5%	23.2%
Load at 10% extension KN/m	1.32	6.8	5.2	3.83

Procedure

Silty clay was compacted in a stiffened container having dimensions 0.95m x 0.71m x 0.5m deep. The marl was mixed to a moisture content of 21% and compacted in 100mm layers to a depth of 400mm. On top of this was laid the membrane as appropriate and a further 100mm of aggregate bedding material. (Figure 1)

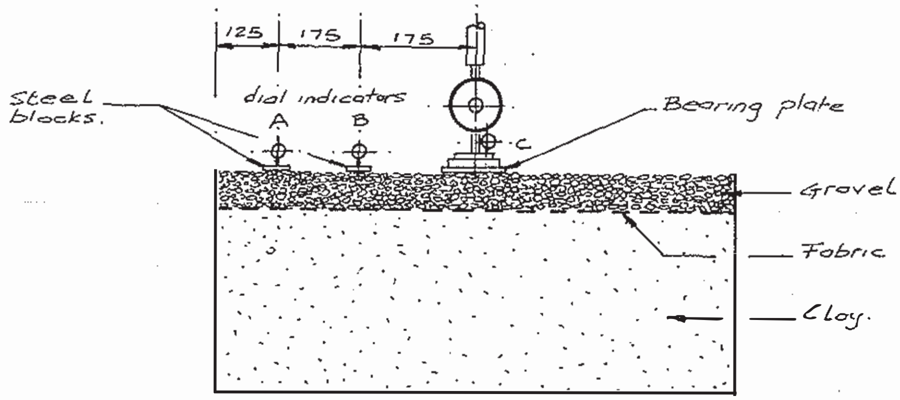

Figure 1 Testing arrangement

The layered system was then loaded by a hydraulic ram through a 200mm x 200mm square plate. It was estimated that the ratio of the size of the plate to that of the container would mean that the boundary effects were negligible. The tests were carried out under strain controlled conditions and each test was carried out in increments of 6.25mm penetration. Each value of penetration was maintained for ten minutes to allow creep and stress decay effects to stabilise. The penetration was limited to a maximum of 50mm which was regarded as the deflection value at which joint failure occurs. After the load was released the aggregate or bedding material was removed from the test container. Observations were made of any contamination of the aggregate and measurements were made of the final deformed surface profile.

5. TESTING PROGRAMME

To obtain a comparison between the different fabrics and gravels used it was decided to test each type of fabric with the three different aggregates in turn as a three layer system except that the large mesh CE152 Netlon was not used with the 5mm gravel. In addition to this the clay was tested with the three different gravels without fabric as a two layer system.

6. RESULTS

Tests were carried out to determine the load settlement characteristics of unreinforced layers of gravel overlying the clay. Results of these tests are presented in Figure 2. It is clear that increasing the size of the bedding material has a beneficial effect. The settlement at a plate bearing stress of 60 kPa is reduced from 30mm for a 5mm gravel to 22mm for a 20mm gravel, a 27% reduction.

The introduction of a geosynthetic membrane reduces the settlement even further. For 5mm gravel, Figure 3, the Netlon grids have a more beneficial effect than the sheet separators. While polythene sheet reduces the settlement by 9% at a bearing stress of 60 kPa the corresponding reduction for Terram is 27% and for the grids from 37% to 55%. For 5mm gravel there is a marked and clear difference between the effects of each of the separators. However as the size of the gravel is increased to 10mm, Figure 4, the difference between each of the materials is not so clear and at some stress levels the sheet materials have as beneficial an effect as the grid separators. The reduction in settlement at 60 kPa is from 17% to 39%. Finally for 20mm gravel, Figure 5, although a membrane clearly reduces the settlement and increases the stiffness of the layered system the load deflection curves for the reinforced layers lie close to each other in a band. In this case the reduction in settlement at 60 kpa is from 18% to 32%.

The bearing capacity of all the layered systems was increased by the introduction of membranes and the percentage increase relative to the unreinforced bearing capacity at 50mm settlement is shown in table 2. It is clear that the stiffer high density polyethylene grids CE121 and CE131 have the greatest beneficial effect on bearing capacity although Terram worked well with the larger 20mm

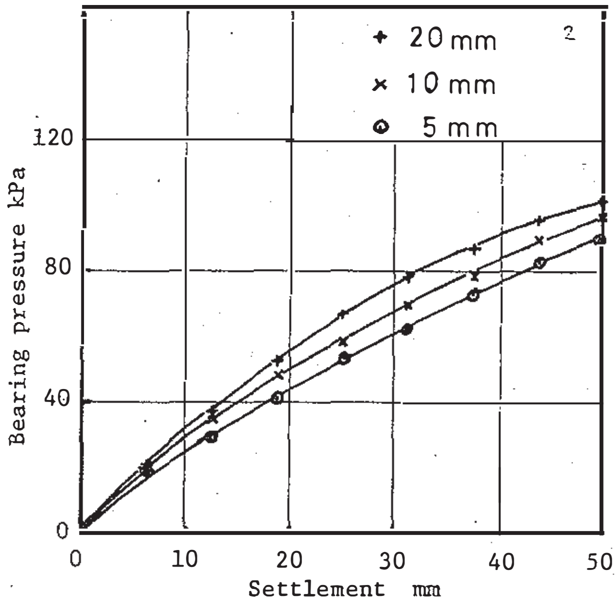

Figure 2 Unreinforced gravel overlying soft clay

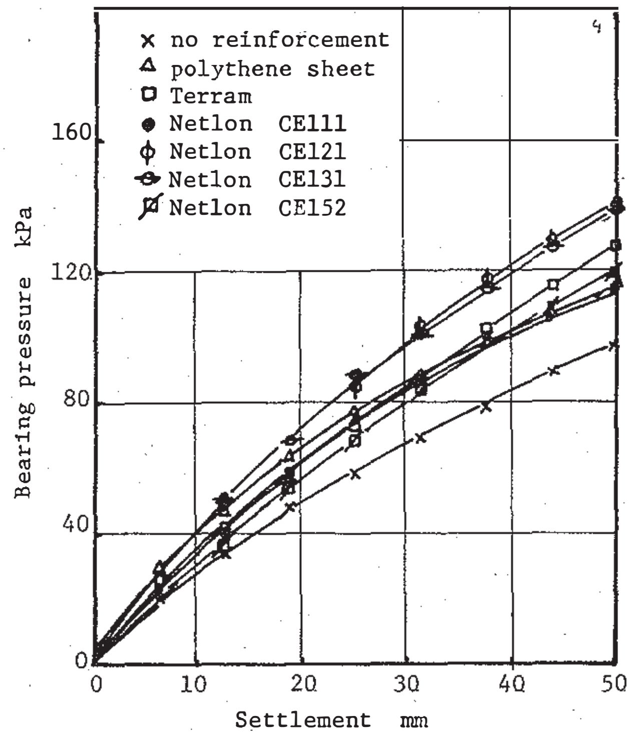

Figure 4 10mm gravel underlain by geosynthetics

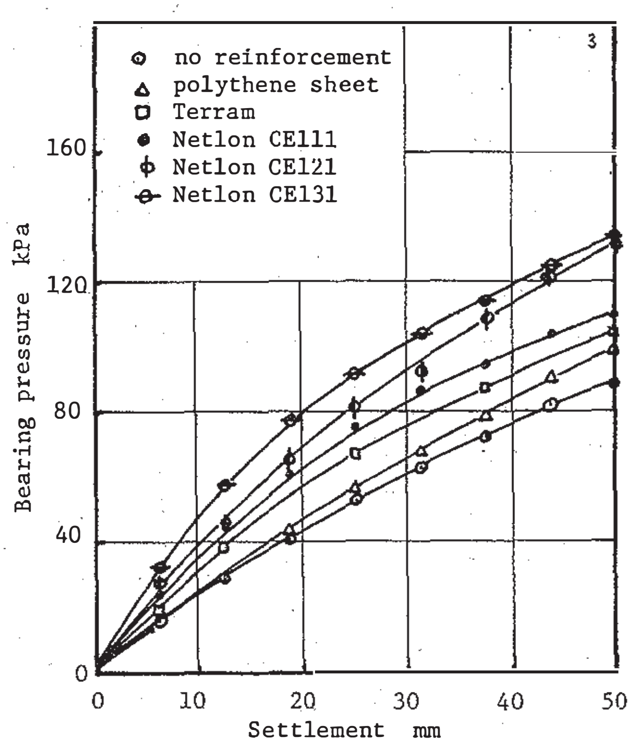

Figure 3 5mm gravel underlain by geosynthetics

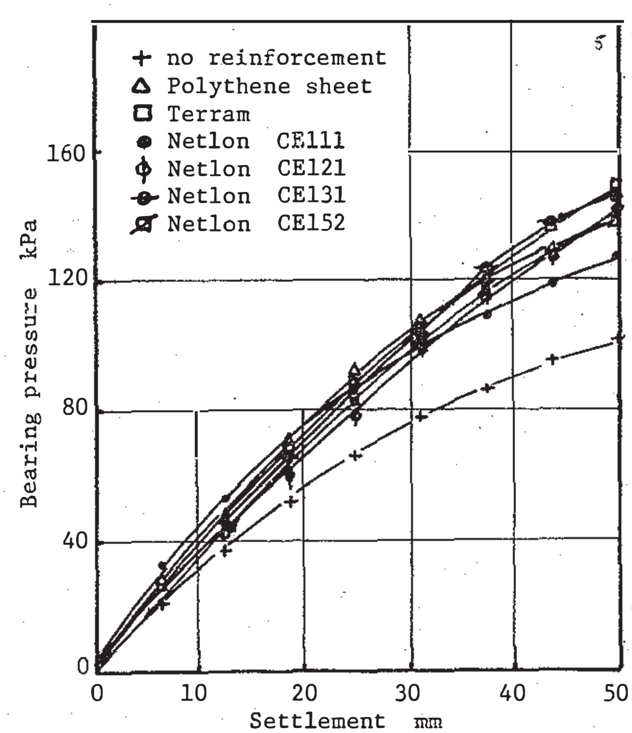

Figure 5 20mm gravel underlain by geosynthetics

Table 2 Percentage increase in bearing capacity at 50mm settlement

	Size of Aggregate		
	5 mm	10 mm	20 mm
POLYTHENE	11	21	38
TERRAM 140	17	32	48
CE 111	24	22	26
CE 121	48	46	40
CE 131	39	44	45
CE 152		23	39

aggregate size.

Measurements of the clay profile after testing showed an increase of the depressed area of about 50%-60% for all reinforced sections. This would appear to indicate greater load spreading as the membranes take tensile stresses at the interface between the granular bedding and the soft clay.

7. CONCLUSIONS

Geotextiles particularly of the grid type when used as a separator between rounded aggregate pipe bedding and an underlying soft clay lead to reduced settlements and increased bearing capacities. These materials therefore seem to offer the potential of reducing severe differential settlements in pipelines laid in variable fill materials thus helping to prevent pipe joint failures.

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