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Geotextile Performance at an Access Road on Soft Ground near Rio de Janeiro

Comportement d'un géotextile dans une voie d'acces sur sol compressible près de Rio de Janeiro

This paper presents a case history on performance evaluation of a non-woven textile as a reinforcement at the base of a low embankment access road, constructed across a very soft soil. Four test section, in which the geotextile type and installation method were varied, were built. The instrumentation installed in each test section allowed the observation of vertical and horizontal displacements. The number of trucks passing on each test section was recorded. Borings were dug through the fill for the definition of its thickness. The results were compared with similar measurements made at sections with no reinforcement. Measured geotextile performance, expressed in per cent reduction of fill material consumption seems to vary between 10 to 24% in volume. This difference seems to depend mainly on the way the geotextile was laterally fixed. An economic evaluation, considering local costs, has shown that this geotextile application would not be economically advantageous unless the reduction in volume of fill material exceeds 30%.

Cet article présent la description de la construction et du comportement d'un remblai de basse hauteur construit sur un sol très compressible utilisant un geotextile non-tissé pour son estabilisation. Quatre sections experimentales variant le type et la méthode d'installation du geotextile ont été construites. La instrumentation instalée permetait la determination des déplacements horizontales et verticales sous le remblai. Le nombre de camions passant sur le remblai etait precisé et son épaisseur determinée plusiers fois. Les resultats ont été comparées avec ceux d'un remblai construit directement sur le sol argileux. L'influence du geotextile, indiqué par la reduction de volume necessaire de remblai, fait de 10 a 24% en function de la forme de fixation du geotextile à coté du remblai. Une étude économique a indiqué que, pour une application pratique, la reduction de volume devrait etre au moins de 30%.

INTRODUCTION

A comprehensive research program on the behaviour of embankment founded on soft soil has been conducted by a research team from the Federal University of Rio de Janeiro and the Catholic University of Rio de Janeiro with financial support from the Highways Research Institute. In order to carry out full scale experiments. a testing site, located about 10 km north of Rio de Janeiro, was selected where a thick deposit of about 11m deep of a very soft gray clay occurs. This site is a part of a large swampy area, locally known as "Fluminense Plains" covering an area of about 150 km^2 around Guanabara Bay. At this site, two main instrumented trial embankments have already been built (see figure 1 and 2). The first one was builtin December 1977 and reached failure. An analysis of the observed field behaviour was made by Ramalho Ortigão (1980) and is also presented by Ramalho Ortigão, Lacerda & Werneck (1982).

Following the scheduled research program, a second trial embankment was recently constructed aiming at testing different types of sand and prefabricated vertical drains. Field measurements are still being conducted and will be presented by Collet (1982). This trial embankment is about 360m long, 35m wide, and 2.5m high, comprising 5 sections in which vertical drains were installed in a square area of 35m x 35m. Two additional end sections were built at the embankment ends to allow comparisons and evaluation of vertical drainage performance. In order to provide access for installation of the foundation instrumentation, placement of 0,5m thick sand mat and the installation

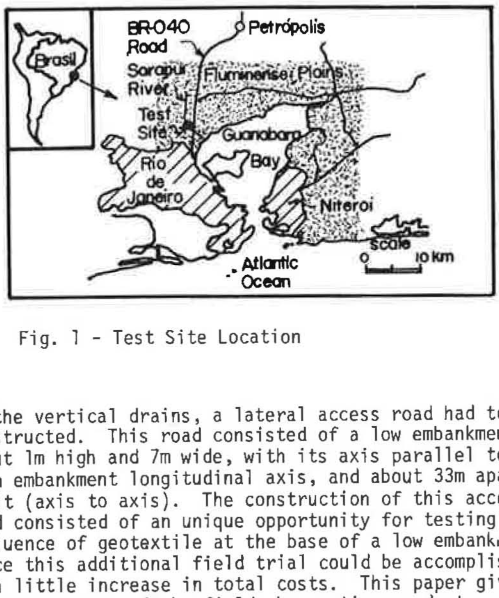

Fig. 1 - Test Site Location

of the vertical drains, a lateral access road had to be constructed. This road consisted of a low embankment, about 1m high and 7m wide, with its axis parallel to the main embankment longitudinal axis, and about 33m apart of it (axis to axis). The construction of this access road consisted of an unique opportunity for testing the influence of geotextile at the base of a low embankment, since this additional field trial could be accomplished with little increase in total costs. This paper gives a brief picture of the field observations made to evaluate geotextile performance. A complete description can be found in Palmeira (1981).

SOFT FOUNDATION PROPERTIES

The foundation soil consists of a 11m deep deposit of soft Rio de Janeiro Gray clay overlying sandy layers. Clay properties were studied by Pacheco Silva (1953) and recently covered in more details by Lacerda et alii (1977), Werneck et alii (1977), Costa Filho et alii (1977), Ramalho Ortigão and Costa Filho (1982), among others.

Figure 3 summarizes geotechnical properties. Liquid limit varies from 150%, near the top, to 90% near the bottom, the in situ water content being slight higher than these values. Plasticity index is about 80%. Field vane tests results ranging from 5 to 15kPa have shown a decrease in undrained strength at the clay crust, the minimum value being recorded at a depth of 2.5m, below which the undrained strength seems to increase linearly with depth. A mean value of undrained strength is about 10 kPa. Field vane tests also indicates the clay sensitivity is in the order of 2 to 4. Stress history was evaluated from several high-quality oedometer tests, which have shown the over-consolidation pressure to be slightly higher than the in situ vertical effective pressure, as shown in figure 3.

TEST SECTIONS

From an initial suggestion by Rhodia Company (the Brazilian subsidiary of the French Rhône Poulenc Group) the experiment was subsequently designed. It comprised four sections, in which the geotextile and installation method were varied. Two geotextiles were employed at the test sections. They consisted of non-woven needle punched polyester fabric types OP-30 and OP-40, commercially known as BIDIM, and their main characteristics are as follows:

TABLE 1 - GEOTEXTILE PROPERTIES

	OP-30	OP-40
mass per unit area (g/m^2)	300	400
thickness (mm)	3.5	3.8
Monodirection tensile strenth (kN/5 cm)	0,80	1,05
elongation at failure (%)	50-70	50-70
Bidirection tensile strength (kN/m)	23	31
elongation at failure (%) 2-D test	27-30	27-30
approximate local price in US dollars per m^2 (Jan. 1981)	1,20	1,60

Each test section comprised an area 7m wide, 20m long at the base of the embankment. At the first test section, named S1, the geotextile type was OP-30, while at the others sections, named S4,S5 and S6, the OP-40 type was laid down at the base of the embankment. Two additional instrumented sections, names S2 and S3, were set up with no geotextile in order to provide data for evaluating geotextile influence. Figure 4 shows the way the geotextile was laterally fixed in each section.

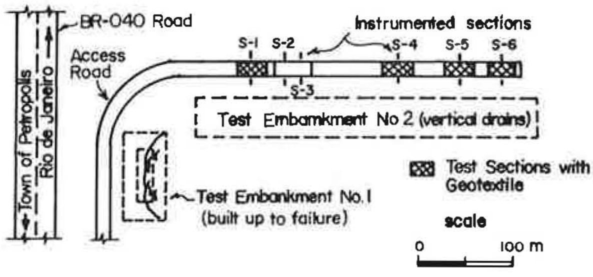

Fig. 2 - Test Site

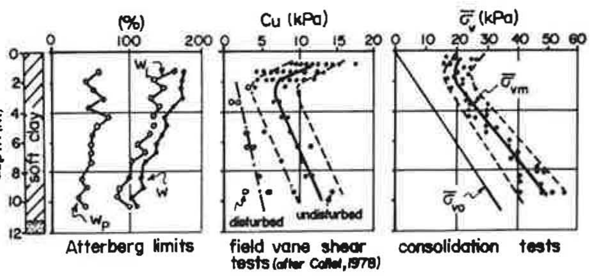

Fig 3 - Summary of Geotechnical Properties - Rio de Janeiro Soft Gray Clay

ROAD EMBANKMENT DESIGN AND CONSTRUCTION

Main characteristics for the design of the access road were as follows: lane width about 4m and truck load of 71kN. Entering this information plus the necessary foundation data in the design charts available from geotechnical manufacturers, this generally yielded embankment thickness as low as 30cm,when geotextile re-inforcement was adopted. A similar value for the embankment thickness was also obtained through Giroud & Noiray's -1981) charts. Such a small thickness, following design recommendations, could only be accomplished if aggregate material was employed in order to better distribute truck load to the soft foundation. However, at the test site, the type of fill material available at a reasonable cost differed too much from the recommended one. It consisted in a residual clayey soil of gneissic origin, excavated from a borrow pit about 20km away from the test site. Its main characteristics are as follows:

$w_L \cong 49\%$, $w_P = 31\%$, $\gamma_t = 20.5$ kN/m^3 and $w = 20 \pm 4\%$ at placement conditions. Grain size distribution, has shown 67% in weight finer than 0,075mm in diameter. Sites where an easily available softer fill material is used, rather than a costly aggregate, are not uncommon. In such a situation, current design recommendations for geotextile reinforcement do not apply. Therefore, the devised field trial was also an opportunity for the evaluation of the efficacy of geotextile reinforcement applied to a relatively soft embankment material. Prior experience at the test site indicated that minimum height to support low traffic was about 0,8m. This was then,the designed height for the access road.

Placement was accomplished by means of a light bulldozer and no direct compaction was exerted on the fill. It was difficult to keep the road level under an accurate control, since the only available placement equipment, a light bulldozer, was not the most appropriated equipment to level the embankment. In addition, as construction progressed, maintainance had to be exerted of the road, already crossed by the trucks which delivered fill material to the placement area. Indeed, the actual road level was always kept to minimum necessary to support traffic load, since embankment maintainance refilling operation was carried out as necessary only to ensure trafficability.

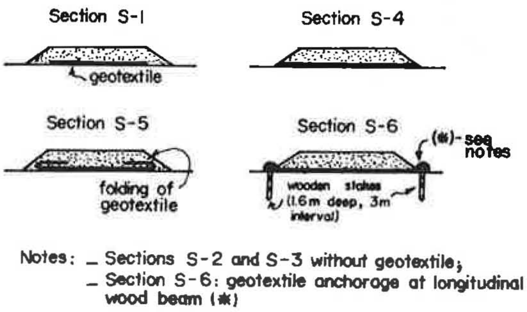

Fig. 4 - Geotextile Installation

INSTRUMENTATION

An instrumentation was installed to observe embankment deformation. The relatively small dimensions of the embankment cross section limited the type of instrument that could be employed for monitoring field behaviour. An horizontal magnetic extensometer and a profilometer (a full profile settlement gauge) were, then, chosen to monitor horizontal and vertical displacements, respectively. A typical lay-out of an instrumented section is presented on figure 5. Plastic plates 30 cm x 30 cm containing a built-in magnetic ring were laid down around a plastic access tubing, allowing the slide of a magnetic sensor to locate the position of the magnets. This permitted the calculation of horizontal displacements in the foundation soil just below the geotextile. In addition, magnetic rings around another plastic access tubing, were directly attached to the fabric allowing measurements of geotextile horizontal displacements.

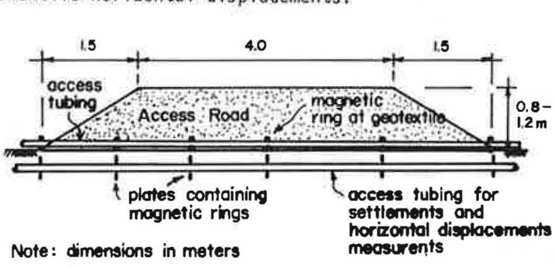

Fig. 5 - Typical Instrumented Section

A vertical displacement profile was obtained by sliding the profilometer sensor device through the same access tubing of the magnetic extensometer. This instrument, which was specially devised for this work, (Palmeira & Ramalho Ortigão, 1981), was hydraulically operated, and yielded good results. Prior experience with the described instruments allows an evaluation of the accuracy of the measured deformation. Accuracy of horizontal displacements is in the order of ± 3mm, while the accuracy of vertical displacements is estimated to be in the ± 17mm range, with a confidence level of 95% (Palmeira & Ramalho Ortigão, 1981). In addition to instruments monitoring, field data included recording the thickness of the embankment through boreholes drilled through it. The number of trucks passing on each test section was also recorded during six months after construction of the access road.

FIELD OBSERVATIONS

Many initial readings were carried out, on the instrumentation prior to fill placements. However, at the placement of the first layer, which had a minimum thickness of about 50cm, necessary to support the bulldozer load, some disturbance, or sometimes damages, ocurred to the instrumentation. As a result a new rezeroing operation had to be conducted in all the instruments. At section S3, initial placement provoked a major damage to the instrumentation and, thus, this section had to be abandoned.

An important observation was made through the comparison of field horizontal displacements obtained from magnetic rings attached to the geotextile and magnetic plates of the same position. It was observed that the effect of fill placement was more evidenced by the magnetic plates. Also, these plates have shown a more pronounced deformation at the first passage of the bulldozer or a truck than the magnetic rings. This behaviour was atributed to relatively large dimensions (30cm x 30 cm) of the plates when compared to the low embankment height. The above observation was made at the test sections which were firstly built. This has led to a modification of the instrumentation of the S6 section, the last one to be constructed. In this section, in addition to the magnetic rings attached to the geotextile, some other rings were installed with no attachment at all, just embedded in the fill material above the geotextile. By comparing the results of the horizontal displacements of the fixed and free rings, no significant difference could be detected. Therefore sliding at the fill-geotextile interface was supposed to be negligible.

Field data processing included preliminary plots of horizontal and vertical displacements against time and against the number of trucks passing on each section. Time was initially taken into account since heavy traffic was mainly concentrated in the last three months of the observation period. However, these plots have shown that measured displacements were mainly traffic dependent. Time effect was therefore disregarded in the analyses.

From another set of plots, it was observed that the calculated strains at the base of the embankment, rather than the measured displacements, presented a more consistent pattern of its distribution accross the embankment section. Therefore, horizontal displacements data will not be shown in this paper.

Main field observations carried ou up to 6 months after the completion of the access road, are then, summarized in figures 6 and 8, and in table 2. Figure 6 shows settlement and horizontal strain profiles for an increasing number of trucks (50, 100 and 200) which crossed each test section. The following observations can be drawn from this figure:

1.- Maximum measured settlements were about 150-200 mm and horizontal strains reached values of about 10 per cent, maximum values generally taking place under the tracks of the wheels;

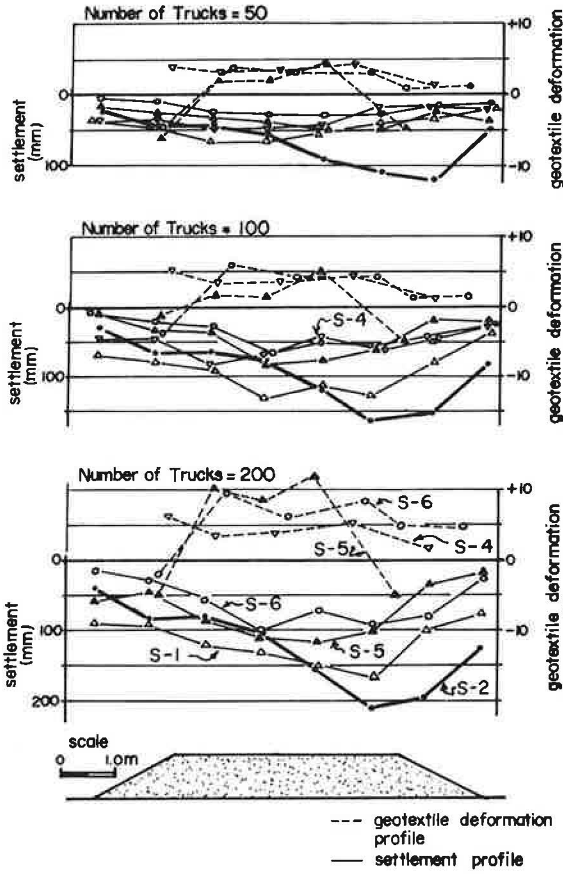

Fig. 6 - Settlements and Geotextile Deformation Profiles versus Number of Trucks at Test Sections

2.- The geotextile installation method, as employed in section S6 (with wooden stakes)yielded more uniform distributed tensile strains, as recorded along the whole cross section and reaching lateral stakes at the foot of the embankment;

3.- The occurrence of a local failure can be observed in section S2 (no geotextile) as evidenced by the large settlements on the right part of the cross section;

4.- Local failure also seems to have taken place on section S1 (geotextile only beneath the embankment platform), where fabric installation method seems not to be efficient;

5.- Other sections with geotextile (S4, S5, and S6) seem not to present a local bearing failure, and this can be attributed to the effect of the geotextile reinforcement.

The observation made can be further emphasized by plotting mean settlement versus the number of trucks, as done in figures 7 and 8. In these plots, settlement distribution was averaged along the full cross section

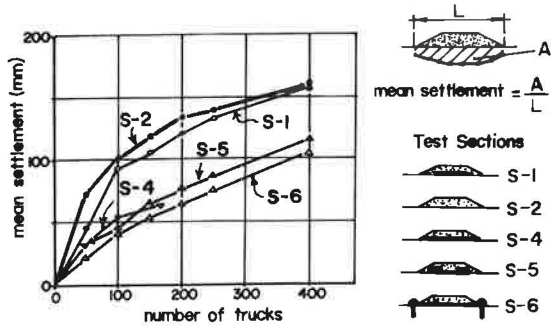

Fig. 7 - Mean Settlement versus Number of Trucks at Test Sections (Full Section)

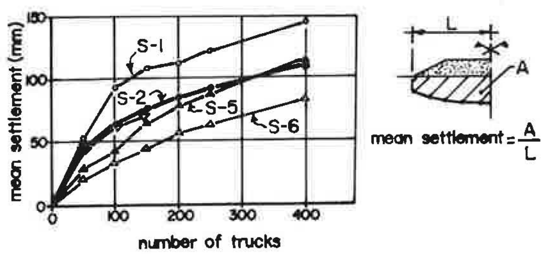

Fig. 8 - Mean Settlement versus Number of Trucks (Half-Section, without Local Failure)

(fig.7) or only for half-sections (fig.8) without local yield. Figure 7 indicates that in sections without geotextile (S2), or where the geotextile was poorly installed (S1), the mean settlement is greater than the settlement at sections where geotextile was extended beneath the embankment shoulder (S4, S5 and S6). On the other hand, when local failure does not seem to occur as at the half-sections shown on figure 8, geotextiles loses efficiency and its application is not worthwhile for minimizing settlements.

Another measurement carried out at the end of the period of observations has been the measurement of the thickness. This was accomplished by drilling Ø 150 mm boreholes through it. These boreholes were located at the tracks left along the access road by the wheels of the trucks. Nine determinations of fill thickness were performed in each test section and the results have been indicated in table 2. This table includes the mean value and the standard deviation of data. The difference between mean values are small, however a simple statistical test have shown with a level of confidence on 95% that all these distributions of embankment height are different from each other. This difference assumed to be due to different reinforcements. Data in table 2 also show the greater meam value of fill thickness taking place where no reinforcement was present (S2 - section). On the other hand, at section S6, where the geotextile was laterally fixed with stakes, and where tensile strains were more uniformly distributed over the fabric, the minimum mean value of fill thickness was recorded. Now, comparing the reduction of mean fill thickness in each section with the results of section S2 (no reinforcement) the following data is obtained.

TABLE 2 - MEASUREMENTS OF EMBANKMENT HEIGHT

Section Nº	Mean Value	Standard Deviation (m)
S1	1.04	0,10
S2	1.15	0.09
S4	0.97	0.04
S5	0.94	0.05
S6	0.89	0.06

TABLE 3

Sections w/ reinforcement	Reduction in mean emb. height (%)
S1	9.6
S4	15.7
S5	18.3
S6	22.6

The main difference in the reinforcement application in section S1 to S6 is that lateral anchorage or lateral fixing of the geotextile is increased, as the section reference number increases (see figure 3). It follows, therefore, that differences in data in the above table can be regarded as a measure of reinforcement efficiency. In fact, in section S6, where the geotextile seemed to be best laterally anchored, a more uniform distribution of horizontal strain was observed and this test section yielded the greater reduction of mean fill thickness. The lowest reduction was achieved in section S1, in which the geotextile was not extended beneath the embankment shoulders, yielding, thus, the poorest reinforcement efficiency. This latter conclusion related with test section S1, disregards the fact that the geotextile at this section was type OP-30, which is thinner and can carry less load than type OP-40 employed at other sections. However, this fact seems to be less important to the overall geotextile efficiency than the way the geotextile was applied (with more or less lateral anchoring).

ECONOMIC CONSIDERATIONS

In addition to technical evaluation,the economic efficiency will play, of course, a major role in the decision of employing or not the geotextile. For the conditions prevailing at the test site, circa at early 1981, fill material cost was evaluated in US$ 5.36 per m^3, which includes: excavation at the borrow pit area, 20 km of transportation distance to the test site and placement. This value was mainly influenced by the cost of transportation.
The cost of the geotextile was shown in table 1. Those values should be added to labour costs for reinforcement installation, which at local prices and due to the type of work, are minimal.

Considering these points, final costs of access road per unit length in each test section were evaluated as shown in table 4.

TABLE 4 - EMBANKMENT COSTS

Section number	Emb. Vol. m^3/m	% vol saved	Emb. cost US$/m	Cost of Reinf. US$/m	Total cost US$/m	Total cost ratio
S2 *	7.2	0	38.59	0	38.59	1.00
S1	6.5	10	34.84	8.40	43.24	1.12
S4	6	17	32.16	11.20	43.36	1.12
S5	6	17	32.16	11.20	43.46	1.12
S6	5.5	24	29.48	14.40**	43.88	1.14

(*) without geotextile (**) Includes cost of wooden stakes

Data shown in table 4, reflecting conditions strictly prevailing at the test site, shows that the geotextile application increased the total costs in 12 to 14%. On the other hand, a simple calculation shows that the geotextile reinforcement, as installed in section S4. would be cost-effective only if savings in fill material exceeds 30% in volume.

CONCLUSIONS

Many observations and conclusions were drawn from the full scale instrumented field trial previously described. Main features will be reviewed below:

1. - An instrumentation for measuring vertical and horizontal displacements at the base of the road was successfully accomplished by means of a profilometer and a magnetic horizontal extensometer.

2. - Experience with the instrumentation and the observations made indicated that the magnetic rings, rather than plates containing rings, should be used as targets for the horizontal extensometer, in order to minimize the effect of shocks at fill placement.

3. - Field observation have shown that the geotextile reinforcement seems mainly to prevent local yield to take place at the foundation, thus minimizing fill material consumption.

4. - Maximum technical efficiency of the geotextile reinforcement was achieved by means of wooden stakes. This implied in the minimum fill material consumption per meter of road length.

5. - The installation methods consisting of laterally folding the geotextile (section S5) or laying it to cover the whole embankment cross section base (section S4), yielded similar results.

6. - Field measurements have shown that geotextile applications have saved 10 to 24% of volume of fill material, this difference depending on the installation method, i.e., the way the geotextile was laterally extended.

7. - An economic evaluation considering local prices have shown that the geotextile reinforcement would be cost-effective only if savings of fill material exceeds 30% in volume.

8. - An effective numerical modelling of such a field trial should consider local yielding at the foundation and the effect of traffic. A first attempt by Palmeira (1981), employing a Finite Element program considering linear-elastic materials and a bar element for the geotextile, did not yield good results.

9. - Available design charts, as those published by Giroud and Noiray (1981), have been developed only for stiff embankments made of aggreagte, not considering the effect of a softer material as employed in this field trial.

ACKNOWLEDGEMENTS

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