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Behaviour of a Geogrid Reinforced Embankment over Waste Material

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SYNOPSIS: The paper deals with the monitoring of a geogrid reinforced embankment, 5.0 m high and 600 m long, built to contain additional waste material in the municipal landfill in Modena (Northern Italy).
The embankment was founded directly over the waste already placed in the landfill, consisting of compressible and dishomogeneus material, varying from solid urban waste to muddy industrial material. The geotechnical parameters assumed to characterize the fill soil and the waste material of the foundation soil are described.
The settlements of the embankment and the forces and strains in the geogrids were monitored from the beginning of the construction until some months later. The instrumentation used in order to perform this control is described.
The actual results are compared with those obtained from the design model and with other field tests concerning geogrid reinforced structures.

FOREWORD

The works presented in this paper are related to the construction and to the monitoring of an earth embankment for the urban waste disposal facility in Modena (Northern Italy).
In successive times, a series of dikes, starting from the filled level of the existing landfill, was and will be built, in order to contain additional waste material up to a total height of about 15 m.
The embankments, 5 m high, have a constant shape in their longitudinal development and for the 3 successive levels: until now, only the first embankment was built.
This embankment was founded directly over the urban waste of the landfill, consisting of compressible and dishomogeneus material; only a little part of the embankment was founded on industrial wastes, consisting of inert muddy materials.

The embankment was reinforced with horizontal layers of high density polyethilene uniaxially oriented geogrids, and was designed with a sort of "foundation beam", constituted by a layer of soil totally wrapped in a geogrid. The geogrids used were Tenax TT1 manufactured in Italy by RDB Plastotecnica.
The use of geogrids as reinforcement allowed to improve the geotechnical characteristics of the fill: the factor of safety against rotational failure, for a 1:1 slope as the instrumented one, calculated according to the Fellenius modified method, was 0.9 without reinforcement and 2.5 with geogrid reinforcement (Pagotto - Rimoldi, 1987).

DESIGN

Geotechnical characteristics

The geotechnical characteristics of the foundation material and of the fill soil for the embankment were measured by means of tests, carried out both on site and in laboratory. The main results obtained are as following:

-foundation material: the plate loading tests were carried out in a certain number of points on the waste disposal area. The average of the values, obtained for the urban solid waste, compared to the results obtained by Cancelli and Cossu (1985) on the same type of material, have given results similar to those typical of organic soils:

- unit weight $\gamma_f = 10$ kN/mc
- cohesion $c'_f = 30$ kPa
- internal friction angle $\phi'_f = 22$ degrees
- primary compression index $C_c = 0.6$
- secondary compression index $C_\alpha = 0.1$

-fill soil for the embankment: grain size analysis, Atterberg limits, consolidation tests, triaxial tests (U.U. and C.D.) and permeability tests (by oedometer) were carried out, obtaining the following results:

- unit weight $\gamma_e = 18$ kN/mc
- liquid limit $W_L = 65\%$
- plastic limit $W_p = 24\%$
- cohesion $c'_e = 25$ kPa
- internal friction angle $\phi'_e = 25$ degrees
- permeability coefficient $k = 3 \times 10$ E-11 m/s

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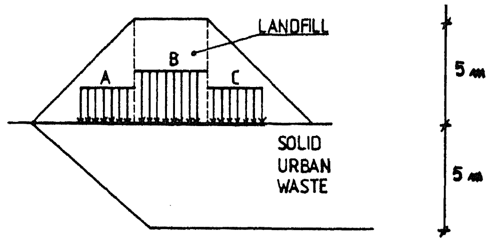

Fig. 1 : Scheme of the load distribution for the settlement evaluation without geogrid reinforcement.

Evaluation of the settlements without geogrids

The embankment standard cross-section was divided into sectors of unitary thickness in order to calculate the settlements: three different loads have been defined, as presented in Figure 1.
The settlements were estimated using the oedometric theory by means of the formula:

$$S = H \cdot \frac{C_c}{(1+e)} \cdot \log \frac{\sigma_o + \Delta\sigma}{\sigma_o} \qquad (1)$$

The results obtained for the section founded on urban solid waste were as follows:

$S_A = 0.32$ m $S_B = 0.40$ m $S_C = 0.35$ m $S_{average} = 0.36$ m

For the section founded on muddy wastes the settlement, calculated according to the same method, gave an average value of 1.05 m.

Design parameters for the reinforced embankment

The design of the embankment was carried out on the base of the following parameters:

- height $H = 5$ m
- slope angle max $\beta = 55$ degrees
- surcharge $q = 10$ kPa
- maximum tensile strength of geogrid $\alpha_f = 66$ kN/m

The factors of safety were assumed as following:

- FS global = 1.1
  (well known geotechnical parameters);
- FS time = 1.35
  (medium difficulty and duration of the work);
- FS construction = 1.35
  (soil used not suitable as fill material);

- FS grid = FS global x FS time x FS construction = 2.00

The design parameters were assumed as follows:

- reduced friction angle $\phi'^{*} = \mathrm{arctg}(\mathrm{tg}\phi'_c/\mathrm{FSglobal}) = 23°$;
- allowable tensile strength $\alpha_a = \alpha_f$ /FS grid = 33 kN/m.

The final configuration of the embankment cross-section, according to the design method presented by Jewell et al. (1984) and revised by Rimoldi (1987), is shown in Fig. 2a.

Design model

Since the reinforced embankment was built on a compressible foundation, settlements in the waste disposal area were important, so that the geogrid placed at the base of the embankment was expected to be bent and tensioned.
In order to calculate the embankment settlements and the distribution of tensile forces in the base geogrid a model based on a Winkler scheme was developed. In fact the lower layer of soil, totally wrapped in the base geogrid, acts as a beam on a Winkler soil characterized by the modulus of subgrade reaction k_s, as shown in Figure 2b.
Therefore the beam length is assumed equal to the embankment width and the beam width equal to 1 m corresponding to the geogrid transversal dimension; a possible plate structural behaviour was not considered, in favour of safety. The beam has an height of 0.9 m and is loaded with a trapezoidal surcharge given by the shape of the embankment cross-section.
The modulus of subgrade reaction k_s is a parameter which takes into account the average compressibility of the waste layer which forms the embankment base. Consequently, the modulus was calculated as follows:

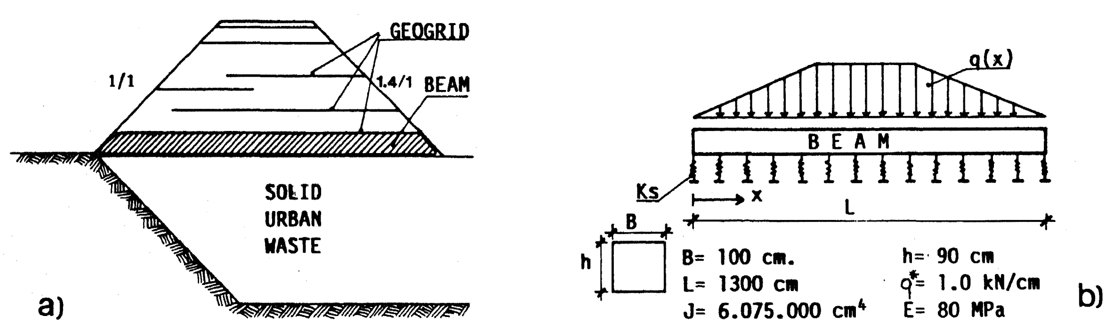

Fig. 2 : a) Cross-section of the embankment reinforced with geogrids.
b) Scheme adopted for the Winkler model.

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$$k_s = \frac{q^*}{S} \cdot F_g = 0.1 \div 0.3 \;\; N/cm^3 \qquad (2)$$

where: q^* = maximum pressure on the waste disposal

S = average settlement (see Eq. 1)

F_g = factor which takes into account the presence of the base geogrid.

The value of F_g, equal to 1.08÷1.13, was determined with loading tests on plates to evaluate the elastic response of the soil formed by the actual compacted waste under the load.
The minimum value of k_s (0,1 N/cmc) was obtained in presence of the muddy material, while the highest value of k_s (0,3 N/cmc) was recorded for solid urban waste, normally compacted.
Assuming the values presented in Figure 2b, and taking into account an elastic modulus E of the clay equal to 80 MPa, the settlements and the moments along the beam axle were calculated, using a standard computer program for beams on Winkler soil.
The tensile stress σ_g in correspondence of the base geogrid was given by:

$$\sigma_g(x) = \frac{M(x) \times 0.9h}{J} \qquad (3)$$

and the tensile force in the geogrid was obtained by the equation:

$$\alpha_g(x) = \sigma_g(x) \times T_g \qquad (4)$$

where: T_g = average thickness of the geogrid (2 mm)

The above formulas allowed to obtain the values of the forces $F_g(x)$ and the settlements S(x) in two situationsof foundation, as plotted in Figure 3. Site 1 is referred to the urban solid waste foundation material, while Site 2 is related to the muddy foundation material.
Until now no evidence of significative deformations of the embankment body has occurred, so it seems that the "foundation beam" and the geogrid reinforcement allow the embankment to withstand also important settlements.

INSTRUMENTATION

The parameters directly measured with instruments placed in the body of the embankment were the settlements of the base, the tensile forces and the strains in the geogrids.
The settlements of the base of the embankment were measured in 4 points by means of the most simple instrument: a steel plate, having a diameter of 60 cm, directly laid on the base geogrid; the plate presented a steel tube welded on it in vertical position, which was incremented with elements, 1.0 m long, as the embankment construction went on. The steel tube was inserted in a plastic tube, to avoid lateral friction. The tubes came out of the embankment just on the inner edge of the crest, in order to avoid any disturbance due to the passage of trucks.

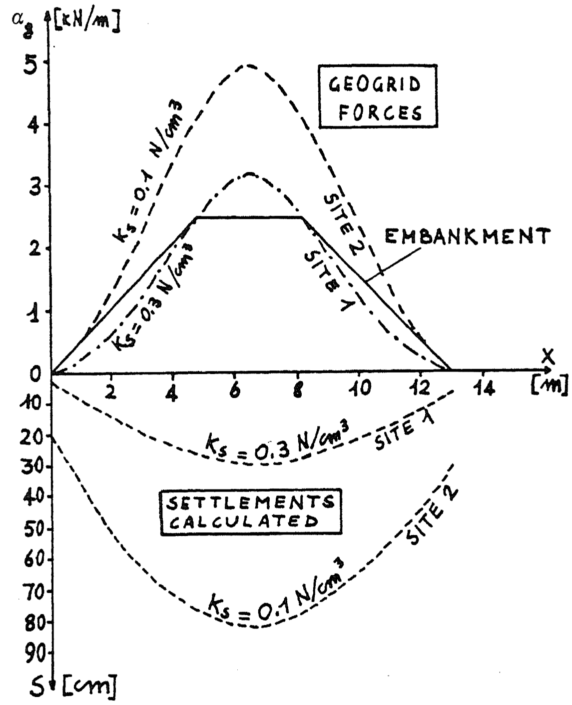

Fig. 3 : Distribution of the forces in the base geogrid and of the embankment settlements resulting from the calculations based on the Winkler model.

After the end of construction the vertical position of the portion of steel tube over the crest was measured periodically with topographic methods.
Both tensile forces and strains were measured in the geogrids, also in order to control if significant creep phenonema occur.
The tensile forces in the geogrids were measured by load cells: the geogrid was cut transversally and the two edges were fixed in steel clamps specially manufactured and firmly connected to the load cells, as shown schematically in Figure 4.
The forces in the load cells were read with a small digital dynamometer, instantly connected to the signal wires with a jack, giving directly the values of tensile forces.
The strains were measured on single longitudinal ribs in the center of the geogrids, by means of two extensometers for each position, one on and one under the strand in order to have a compensation for flexure (Bathurst et al., 1987). The extensometers used were SHOWA (Y11-FA-5-120), which can support a maximum deformation of about 20%. The signal wires were collected into a concrete box together with the load cells ones. The strain values were measured periodically, connecting each signal wire to the appropriate reading unit.

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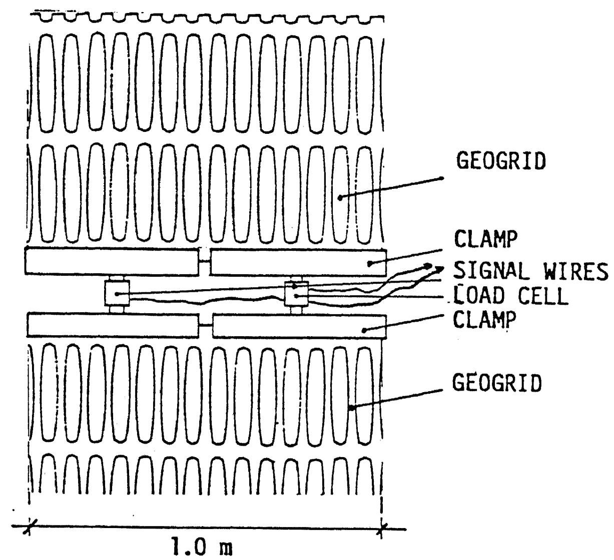
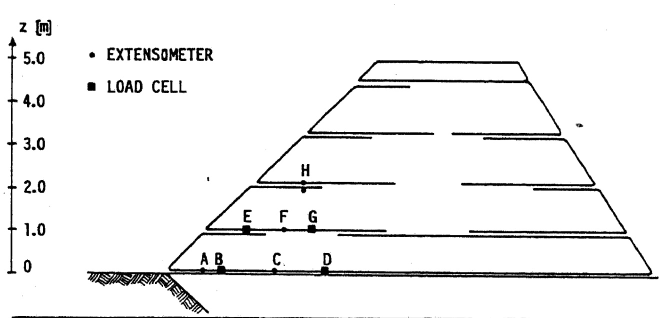


Fig. 4 : Scheme of the device used for the measurement of the tensile forces in the geogrid.

All the load cells and the extensometers were concentrated in a length of 3 meters along the embankment, in order to have all measurements related to the same effective situation.
The selected measuring section was placed on a zone of highly compacted waste, in order to have only small settlements, which actually were about 5 cm: in this way the measured values are directly comparable to other field tests having a solid base under the geogrids reinforced block.



INSTRUMENT	A	B	C	D	E	F	G	H
DISTANCE FROM SLOPE [m]	0.80	1.20	2.50	3.70	1.00	1.80	2.50	1.00

Fig. 5 : Instrumented cross-section.

Figure 5 shows the measuring cross-section with the position of instruments.
Due to the presence of waste material, it was not possible to place instruments in the internal part of the embankment, that is near the steepest slope (55 degrees = 1,4:1). Anyway, the external slope of 1:1 allows to achieve some interesting information on the behaviour of a steep reinforced slope made with a cohesive soil.

RESULTS OF MEASUREMENTS

Due to the particular situation of the test site, there were some problems during the period of stress-strain measurements. The main one was vandalism: two weeks after the installation of instruments, during the night, some vandals destroyed the offices of the waste disposal facility and cut the signal wires in the concrete box. It was possible to repair only few instruments, so some measures are incomplete. Anyway the behaviour exhibited in the first two weeks seems to be very important, because at the moment of vandalism the situation was about asymptotic. After this vandalism act, only settlements were measured without problems, thanks to the simplicity of the device.
The results of these measurements, shown in Figure 6, range from an average settlement of about 30 cm, in Site 1, to an average settlement of about 85 cm, in Site 2. Sites 3 and 4 are composed of mixed wastes.
The values of the settlements calculated in the two different foundation situations were similar to the actual settlements occurred after the embankment construction. The points, for the actual measurement of settlements, were placed in correspondence to 4 different waste material:

- Site 1: urban solid wastes (k_s = 9.3 N/cmc)
- Site 2: muddy material (k_s = 0.1 N/cmc)
- Sites 3 and 4: mixed waste (with k_s varying between the above values).

The results of measurements with load cells and extensometers are shown in Fig. 7, Fig. 8 and Fig. 9. It's interesting to note that the maximum tensile forces in the geogrids occur during the compaction of the layer of soil directly placed on the geogrid (first layer). The soil was in fact compacted in a single layer, 45 cm thick.
Figure 10 shows an extrapolation of force and strain measured values, in order to obtain the diagram of tensile forces along geogrids: the qualitative behaviour was in good agreement with the theory presented by Jewell et al. (1984) and with other field tests carried out in similar conditions (Yamanouchi et al., 1986). Like in other tests, the values of tensile forces are very small, far from the peak tensile strength of geogrids.
Taking into account the greater settlements obtained from the design model, it seems that the Winkler model has given good predictions of the forces in the base geogrids.

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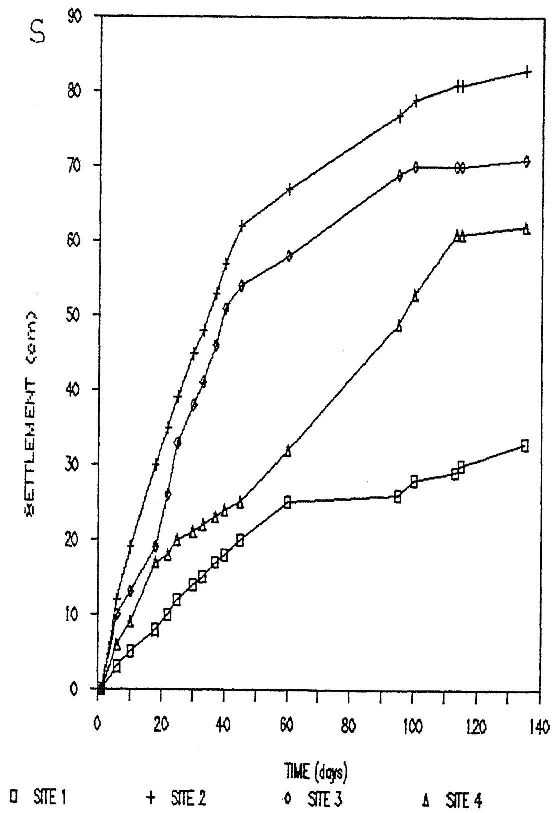

Fig. 6 : Settlements vs. time.

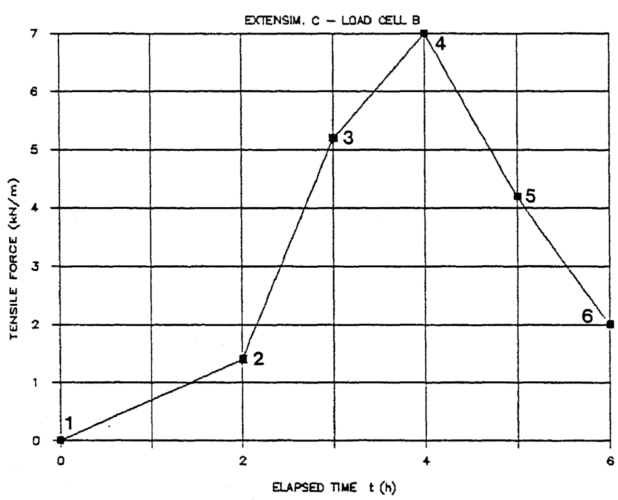

Fig. 7 : Tensile forces in the base geogrid during the construction of the embankment.

1. Start of construction
2. Placement of fill soil: first phase
3. Placement of fill soil: second phase
4. Compaction of the first layer of soil
5. Compaction of the second layer of soil
6. End of construction

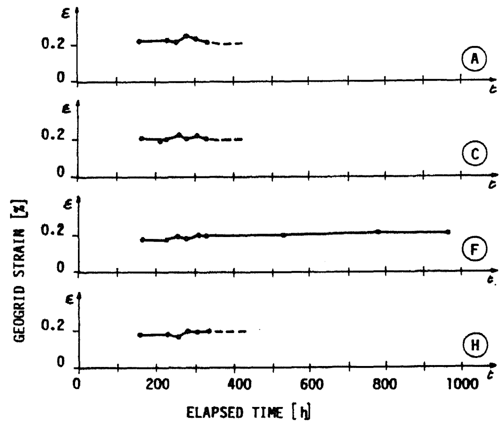

Fig. 8 : Readings from the extensometers A, C, F, H.

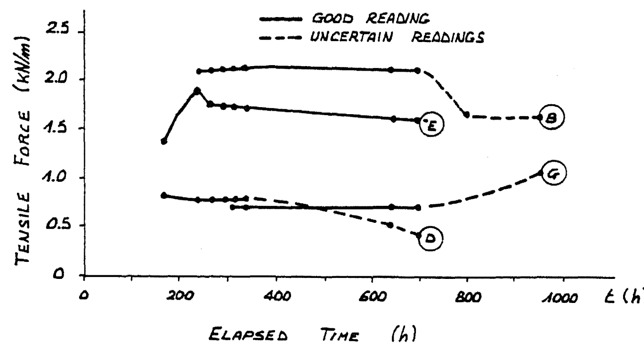

Fig. 9 : Readings from the load cells B, D, E, G.

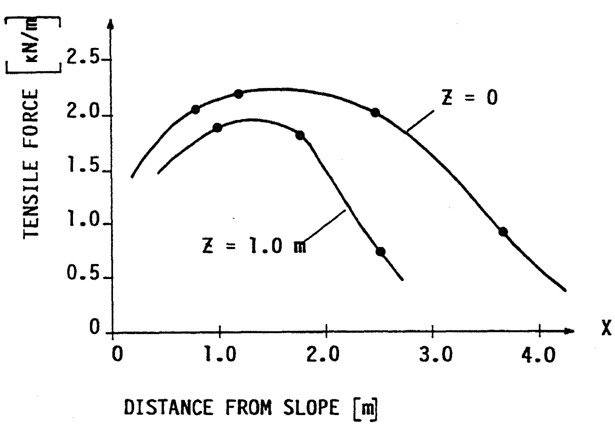

Fig. 10: Distribution of tensile forces for the base geogrid (z = 0 m) and for the upper grogrid (z = 1 m) resulting from extensometers and load cells readings.

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Table 1 shows a comparison of the actual results obtained in Modena with other field tests concerning geogrid reinforced structures.
Three different conditions were considered:

- Design condition (D): design values of the parameters were used to evaluate stresses and strains in the geogrids;
- Calculation condition (C): values of the parameters were used to obtain calculated effective values of stresses and strains in geogrids;
- Measured condition (M): the actual situation.

Indicating with H the height of the slope, with N_{TOT} the total number of reinforcing geogrid layers, and with the subscripts C,D,M the conditions above mentioned, the formulas used to obtain the values described in Table 1 are the following:

- Pore pressure parameter: $R_u = u/\gamma_e \cdot H$
- Fictitious height : $H^* = H + q/\gamma_e$
- Soil pressure parameter: $k^* = f(\phi'_e, \beta, R_u)$ measured from design charts (Jewell et al., 1984)
- Required total tensile force: $T_C = 1/2 \cdot k^*_C \cdot \gamma_{eC} \cdot H^{*2}_C$
  $T_D = 1/2 \cdot k^*_D \cdot \gamma_{eD} \cdot H^{*2}_D$
- Average tensile force per unit width in the geogrids:
  $\alpha_C = T_C/N_{TOT}$
  $\alpha_D = T_D/N_{TOT}$
- Average strain in the geogrids:
  $\varepsilon_C = f(\alpha_C)$
  $\varepsilon_D = f(\alpha_D)$
  measured from the stress-strain curve of the geogrids
  ε_M: measured
  α_M: measured or from the geogrid stress-strain curve

The following factors of safety were introduced:

RFS = α_C/α_M : Real factor of safety
DFS = α_D/α_C : Design factor of safety
TFS = α_D/α_M : Total factor of safety
PFS = α_F/α_M : Peak tensile strength factor of safety
AFS = α_a/α_M : Allowable tensile strength factor of safety

From the values contained in Table 1 the following considerations can be drawn:
- the tensile forces measured in the geogrids are smaller than that ones calculated according to design conditions, allowing very high factors of safety both on the peak (PFS = 11÷30) and the allowable tensile strength (AFS = 4÷13);
- the calculation condition gives results in substantial agreement with the actual values of forces and strains, if the fill soil has a negligible cohesion;
- the high cohesion of the fill soil used in Modena embankment is probably responsible of the difference between calculation and measured conditions, regarding the evaluation of forces and strains in geogrids;
- a research is needed to have a better understanding of the mechanism of reinforcement for high cohesion soils.

TABLE 1: Comparison of different field tests for geogrid reinforced structures

REFERENCE	PAGOTTO-RIMOLDI (1987)			YAMANOUCHI ET AL. (1986)			BATHURST ET AL. (1987)			CARROLL-RICHARDSON (1986)		
TEST SITE	MODENA (ITALY)			KAGOSHIMA (JAPAN)			KINGSTON (ONTARIO)			TUCSON (ARIZONA)		
GEOGRID USED	TENAX TT1			TENSAR SR2			TENSAR SR2			TENSAR SR2		
	C	D	M	C	D	M	C	D	M	C	D	M
H (m)	5.00	5.00	5.00	7.00	6.60	7.00	4.00	4.00	4.00	4.65	4.65	4.65
β (degrees)	45	45	45	78	78	78	90	90	90	90	90	90
q (kN/m^2)	0	10	0	10	10	10	12	12	12	12	12	12
γ_e (kN/m^3)	17.2	20.0	17.2	14.6	17.7	14.6	17.6	17.6	17.6	19.6	19.6	19.6
FS global (-)	0	1.10	–	0	1.70	–	0	?	–	0	1.12	–
ϕ'_e (degrees)	25	23	25	45	30	45	43	?	43	37	34	37
c'_e (kN/m^2)	0	0	25.0	0	0	2.45	0	0	0	0	0	0
R_u (-)	0.0	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
α_f (kN/m)	–	60.0	–	–	78.5	–	–	80.0	–	–	80.0	–
α_a (kN/m)	–	30.0	–	–	31.4	–	–	29.0	–	–	29.0	–
k^* (-)	0.15	0.38	–	0.11	0.27	–	0.18	?	–	0.24	0.28	–
ε (%)	1.2	3.7	0.2	~0.3	~2.0	~0.3	~0.5	?	0.4	~0.3	~0.4	~0.2÷0.6
α (kN/m)	6.4	23.0	2.2	6.6	17.5	2.9÷6.9	8.7	?	~6.0	6.5	7.6	~2.5÷7.0
RFS (-)		2.9			0.9÷2.3			1.4			0.9÷3.2	
DFS (-)		3.6			2.7			?			1.2	
TFS (-)		10.9			2.5÷6.1			?			1.2	
PFS (-)		27.2			11.3÷27.0			13.3			11.5÷32.0	
AFS (-)		13.6			4.5÷10.8			4.8			4.2÷11.6	

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LABORATORY TESTS

A series of tensile tests was carried out at the ENEL-CRIS Special Materials Laboratory in Milano, in order to control the behaviour during the time of the geogrid reinforcements.
A geogrid sample, placed in the embankment, was extracted after more than one year of soil burial; another sample of brand new geogrid, manufactured by the same company, was used for comparative test.
The tensile tests were conducted on a tensile testing machine, under controlled laboratory conditions of 20°C and 65% Relative Umidity, with a constant rate of extension of 50 mm/minute.
Test specimens were cut from the samples three ribs wide and two ribs long and they were prepared for testing by cutting the outer longitudinal ribs, in order to test actually only one integral longitudinal rib (Fig. 11).
The obtained results, summarized in Table 2, are reported to the unit width of the geogrid (Fig. 12).

TABLE 2: Results obtained from tensile tests on geogrids (average values on 5 specimens)

	Peak tensile strength (kN/m)	Strain at yield (%)
New geogrid	44.70	15,7
Buried geogrid	43.96	17,7

The loss of strength after one year of exposure to environment seems to be very negligible; on the contrary, there are some signs of relaxation, in terms of strain at yield.

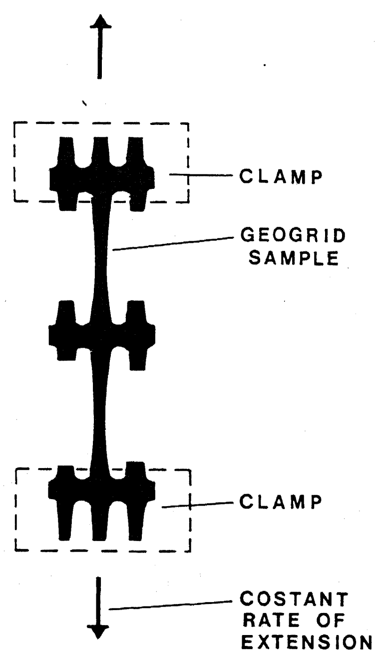

Fig. 11: Scheme of the grogrid tensile test adopted at ENEL-CRIS Laboratory.

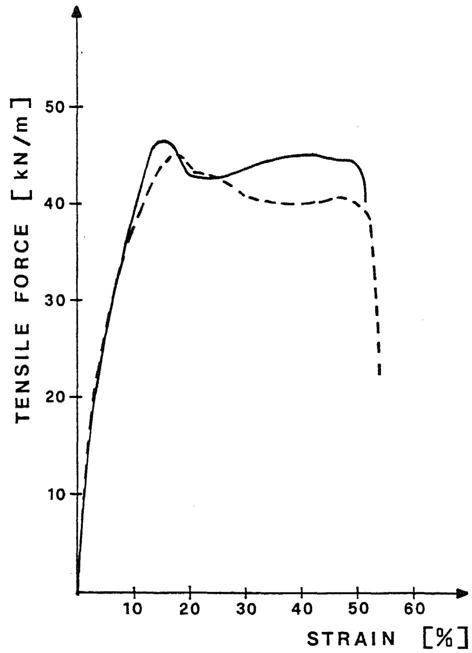

Fig. 12: Tensile test results on Tenax TT1 grogrid:
—— new sample
--- buried sample

CONCLUSIONS

Considering the results obtained from the measurements of forces and strains in the geogrids placed in the Modena embankment, it seems that creep phenomena in geogrid materials are negligible, principally due to the very low tensile forces which actually occur in the reinforcement elements.

The settlements of the embankment and the tensile forces in the base geogrid, calculated according to a Winkler model, are in good agreement with the measured ones: the model seems to be satisfactory for design needs.

The "foundation beam" and the geogrid reinforcement allows the increasing of embankment stability, also in presence of remarkable settlements of the foundation material.

The design method actually used for geogrid reinforcement of steep slopes, as presented by Jewell et al. (1984) and revised by Rimoldi (1987), seems to be conservative according to the results of measures in different field tests: therefore with this method it's possible to design "with confidence".

Mechanical tensile properties of geogrids seem to be little affected by a one-year period of soil burial.

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LIST OF SYMBOLS

The following symbols are used in the paper:

γ_f (kN/m^3)	unit weight of foundation material
c'_f (kPa)	effective cohesion of foundation material
ϕ'_f (deg)	effective angle of internal friction of foundation material
C_c (-)	primary compression index of foundation material
C_α (-)	secondary compression index of foundation material
γ_e (kN/m^3)	unit weight of fill soil
W_L (%)	liquid limit of fill soil
W_P (%)	plastic limit of fill soil
c'_e (kPa)	effective cohesion of fill soil
ϕ'_e (deg)	effective angle of internal friction of fill soil
k (m/s)	permeability coefficient of fill soil
S (m)	embankment settlement
H (m)	embankment height
e (-)	void ratio of foundation material
σ_0 (kPa)	vertical stress in foundation material
σ (kPa)	increment of stress due to the surcharge in foundation material
β (deg)	embankment slope
q (kPa)	surcharge
α_f (kN/m)	peak tensile strength of geogrid
ϕ'^* (deg)	reduced angle of internal friction of fill
α_a (kN/m)	allowable tensile strength of geogrid
k_s (N/cm^3)	modulus of subgrade reaction
P_g (-)	factor which takes into account the base geogrid
q* (kPa)	maximum surcharge
E (kPa)	deformation modulus of fill soil
σ_g (kPa)	tensile stress in the base geogrid
M (kN·m/m)	moment in the "foundation beam"
h (m)	height of "foundation beam"
J (m^4)	moment of inertia of "foundation beam"
L (m)	length of "foundation beam"
B (m)	width of "foundation beam"
α_g (kN/m)	tensile force in the base geogrid
T_g (m)	average thickness of geogrid
z (m)	embankment elevation above base level
x (m)	distance of instruments from slope
N_{tot} (-)	total number of geogrids
u (kPa)	pore·pressure in fill soil
R_u (-)	pore pressure parameter
H* (m)	embankment fictitious height
k* (-)	soil pressure parameter of fill soil
T (kN/m)	required total tensile force in fill soil
α(kN/m)	average tensile force per unit width in geogrid
ε (%)	average strain in geogrid

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