35m-high Geogrid-Reinforced Slope: New Heights and Innovative Construction

N. N. S. Chao
Plato Engineering Consultant Co. Ltd, Taipei, Taiwan

J. H. C. Hew
Jack & Vicky Co. Ltd, Taipei, Taiwan

P. Rimoldi
Tenax SpA, Vigano, Italy

ABSTRACT: The paper describes the design and construction of a 35m high geogrid reinforced soil wall in Taiwan. All the features of this special project, which achieves new "heights" in geosynthetics technology, are described, including design considerations, drainage systems, innovative construction techniques and geocomposite aided face vegetation.

1 THE PROJECT

In the central part of Taiwan, a housing estate scheme was meant to extend its construction on top of a mountaineous area. Several design and construction options were considered and a cost effective decision resulted in a 35 m high, 2:1 (V:H) geogrid reinforced slope (Huang et Al., 1993). Besides cost, other considered aspects were: aesthetics; maximisation of usable space; full utilisation of available on-site weathered shale for backfill. The designated site was situated 10 km away from a residential area, where any noise and air pollution was undesirable.

HDPE mono-oriented geogrids were introduced as the reinforcing elements in the slope design. The 35 m high wall consists of a stepped slope with 5 m high partial slopes at 2:1 (V:H) and 2.5 m wide berms. To the knowledge of the authors this should be at present the world's tallest geogrid reinforced wall. The main design considerations included seismic factors, existing backfill, adequate sub-surface and backfill drainage, vegetation of slope face and increase of development space.

Construction techniques were strongly emphasized in this particular project. The site was in a sub-tropical rain forest area, therefore torrential rainstorms were frequent. Good compaction and rapid installation were mandatory.

This fact required appropriate wooden formworks to support the face during compaction. The formwork itself was supported in the soil temporarily with fixing wire - a cost and time saving method.

The paper describes all the features of this special project, including design considerations, drainage system, innovative construction techniques, and geocomposite aided face vegetation. The paper can be considered a perfect example of new "heights" achieved with geosynthetic technology.

2 CHOICE OF A REINFORCED SOIL WALL

The project was located on a privately owned housing estate property near Taichung city in Taiwan. The property owner planned to maximise the usable land space to fit in luxury villas and townhouses. In order to create more space for new housing, the engineers had to consider building a 35 m high wall with 250,000 m^3 of excavated backfill soils on a V-shaped valley. The soils were excavated from a near hill slope. Various design options, including a traditional concrete wall, were taken into consideration: a geogrid reinforced wall was chosen as the most favorable solution for the project. The main factors of consideration were the followings.

1) A 35 m high reinforced concrete wall would be subject to a concentrated three dimensional distribution of soil pressure on the wall face, whereas the flexible geogrid reinforced soil wall sustains less pressure on the face, since most of the stresses are absorbed by the geogrid (Chou, 1992).

2) The flexible geogrid reinforced soil wall exhibits no cracks under lateral movements and uneven settlements. Soil pressure is reduced or rediverted to areas of less concentration of loads if there is any deformation of the soil structure.

3) The geogrid reinforced soil wall literally provides a large foundation surface footing, therefore it increases the factor of safety for bearing capacity. As far as the slope stability is

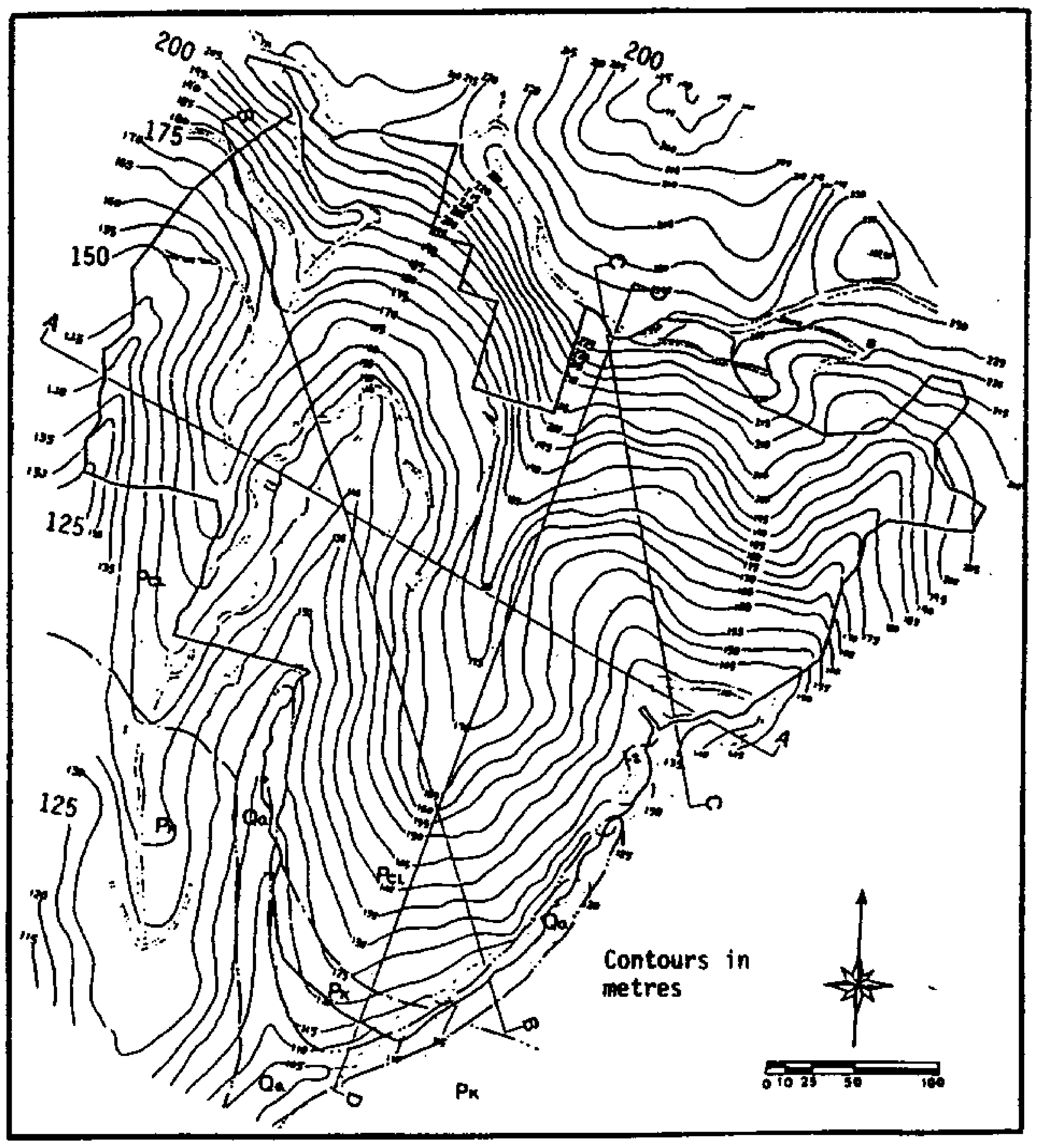

Fig. 1 Topography of the Site

concerned, the geogrid reinforced wall extends the radius of the circular failure.

4) Cost effectiveness: the fill soil materials were excavated from a on-site slope and the total construction costs 30-50% less of the conventional reinforced concrete wall.

5) The geogrid reinforced soil wall is easier and quicker in construction, since there are no excavations of foundation footing, no steel formworks, no alignement of reinforcing steel, no waiting time for concrete curing, etc. Therefore, it saves tremendous construction time. Also, it does not require very sophisticated equipments: the installation steps are very much repeatable, therefore the construction labor can easily familiarise with their flow of work. In fact the whole section of the 35 m high wall was completed in 3 months, whereas the conventional RC wall would have needed at least 6 months.

6) Aesthetics versus environment: the geogrids are wrapped around the face, with the inclusion of a special geocomposite which maintains the moisture content and greatly helps to vegetate the face of the wall. It creates an aesthetic scenary and preserves the natural environment. The vegetation provides a natural camouflage, hence it reduces the phychological effects of the giant steep wall.

7) Resistance to earthquake damages: since there is no concentration of stresses on the wall, as a result the geogrid reinforced slope would not be subject to tension failure during earthquakes.

8) Air and noise pollution to the surrounding residences had to be reduced to a minimum: the geogrid reinforced wall is a perfect answer to this concern, since the passage of trucks and materials through the surrounding residential areas is almost avoided, while a conventional wall would require the transport of huge quantities of concrete.

3 GEOLOGICAL SURVEY

The plan view of the project is shown in Fig. 1. The heart-shaped area for geological survey covers about 13 ha. The elevation of the northern portion is 115 m higher than the southern. The western side forms a valley by itself whereas the eastern area and the slope outside this area form another valley. The river system is divided into two branches by the central ridge. Mao-Loo stream collects the two branches at the southern part of this area.

The environmental geological map indicated the sequences of the formations of this site. The formations from new to old are: alluvium, Cholan formation, and Chinshui shale formation respectively. Seven rock-core samples at the depth of 10 to 35 m showed that the grey Cholan formation is covered by surfacial yellow to brown soil. The Chinshui shale formation is located at the southern valley.

STP laboratory tests were performed to characterize the mechanical behaviour of the soil formations. The N-Values were around 10 to 20 for the alluvium. The area of the rock formation shows higher N-values, in the range 20-100 for both the Cholan and the Chinsui formations.

4 CHARACTERISTICS OF SOILS AND GEOGRID

The reinforced soil wall was filled with the locally available wheatered shale, whose geotechnical characteristics are summarized in Tab. 1. The same table reports also the properties of the foundation soil.

Tab. 1 characteristics of the fill soil and the foundation soil

PROPERTY	FILL SOIL	FOUNDATION SOIL
Type of soil	wheatered shale	wheatered shale
ϕ'	29°	30°
c'	80 kPa	10 kPa
γ	19.6 kN/m^3	20.0 kN/m^3

The HDPE mono-oriented geogrids selected for the reinforcement of the weathered shale were TENAX TT601 SAMP, produced by Tenax SpA in Italy. The properties taken into account for design are summarized in Table 2. It shall be noted that the Factor of Safety for damage during installation, equal to 1.0, based on tests performed by the producer, attests the very high resistance of this type of geogrids to damages, as confirmed later by indipendent controlled field tests (Wright and Greenwood, 1994).

The face was lined, internally to the geogrids wrapping, with a special geocomposite purposely produced in Taiwan: it consists of a light staple fibers nonwoven geotextile, with grass seeds incorporated in the nonwoven web; dry straw fibers are fixed to the geotextile by longitudinal stitching.

Table 2 - Properties of TENAX TT601 SAMP geogrids

PROPERTY	VALUE	UNIT	TEST METHOD
Peak tensile strength	100.0	kN/m	GRI-GG1
Yeld point elongation	13.0	%	GRI-GG1
Tensile strength at 2% strain	31.0	kN/m	GRI-GG1
Tensile strength at 5% strain	56.0	kN/m	GRI-GG1
Long term design strength	40.0	kN/m	GRI-GG3
Factor of Safety for damage during installation	1.00	--	controlled field tests

5 DESIGN OF THE GEOGRID REINFORCED WALL

The wall was designed as a unitary steep slope, by using the TNXSLOPE computer code developed by Tenax. This software is based on the method presented by Jewell (1991). This fast code yielded a geogrid spacing of 0.50 m, a geogrid length of 18.5 m and wrapping length of 2.5 m at the face (see Fig. 2). A bi-oriented geogrid, 3.5 m wide, was inserted at the face for avoiding bulging and face deformations.

This design was then checked against the following criteria.

A) The global stability was checked by using the TNXSTAB computer code, developed by Tenax, which implements the modified Bishop method, as described by Rimoldi and Ricciuti (1992). Only drained conditions were considered due to the drainage measures that were included in the design.

B) The analysis of the bearing capacity of the foundation soil showed, for a large area, the inadequacy of the subgrade to support the surcharge provided by the 35 m high wall. Hence low pressure injection grouting columns were designed at 2 m centres, with a depth of 12 m (see Fig. 2). They extended for a width of 20 m from the wall toe, covering an area that is 30 m long.

C) The infiltration of seepage water, coming from the upstream hills, into the reinforced soil block was considered very dangerous, hence an appropriate drainage system was designed: it consists of an incremental cast-in-place concrete well surrounded by a layer of coarse gravel, 1.0 m thick, at the back of the reinforced block, which was raised while the reinforced block itself was built (see Fig. 2). This drainage blanket collects the water and carries it to the base, where a large concrete tube culvert diverts the water into a small stream flowing in front of the wall.

D) The seepage of the torrential rain water on the face of the wall was considered dangerous for the local stability of the face: hence the seepage flow was collected by horizontal strips of geocomposite edge drains, 5.0 m long and 200 mm wide, placed at a horizontal interval of 1.5 m and a vertical spacing of 1.5 m.

E) The wall lies in a seismic region, therefore the design was checked for the seismic coefficients $S_h=S_v=0.15$ g. The analysis was performed using the same TNXSTAB code, with the reduction of the required Factor of Safety, as suggested by Bonaparte et Al (1986).

F) Vegetation of the face was achieved through the pre-seeded geocomposite, placed internally to the face wrapping of the geogrids. To avoid dessication due to summer draught at the steep face, a irrigation system was designed, consisting of flexible plastic pipes (ø 1/2") and water sprinklers, uniformly distributed on the wall face.

6 CONSTRUCTION METHOD

As already said, the site is in a sub-tropical rain forest area, where torrential rainstorms are frequent: therefore the contractor had to finish up the whole installation in less than 3 months time. Considering the fact that a cost and time saving method was required, an original wooden formwork system was developed to achieve the slope angle and to support the face during compaction (see Fig. 3). The wooden formworks were fixed to the soil temporarily with steel wire. The geogrids were fixed with #4 U-shaped steel bar along the reinforced block and along the formworks. Then the geocomposites were placed inside the geogrid. U-shaped bars were used to fix the overlap sections between two adjacent geogrid layers. All the geogrid wrappings were connected to the next geogrid layer through bodkin joints (see the detail in Fig. 3): in this way any movement or deformation of the face is almost avoided. The drainage strips were placed at 1.5 m interval then backfilling with the shale soil was accomplished. The compaction required for this project was minimum 95% of Standard Proctor and it was monitored and tested frequently. Heavy rollers were used, but, for about 0.50 m at the face, the compaction was achieved using small jumping jet compactors. Compaction was accomplished in two lifts for each geogrid layer: between the first and the second lift the secondary geogrid was placed. After the completion of the first layer, new formworks were added to increase the height. The formworks were supported

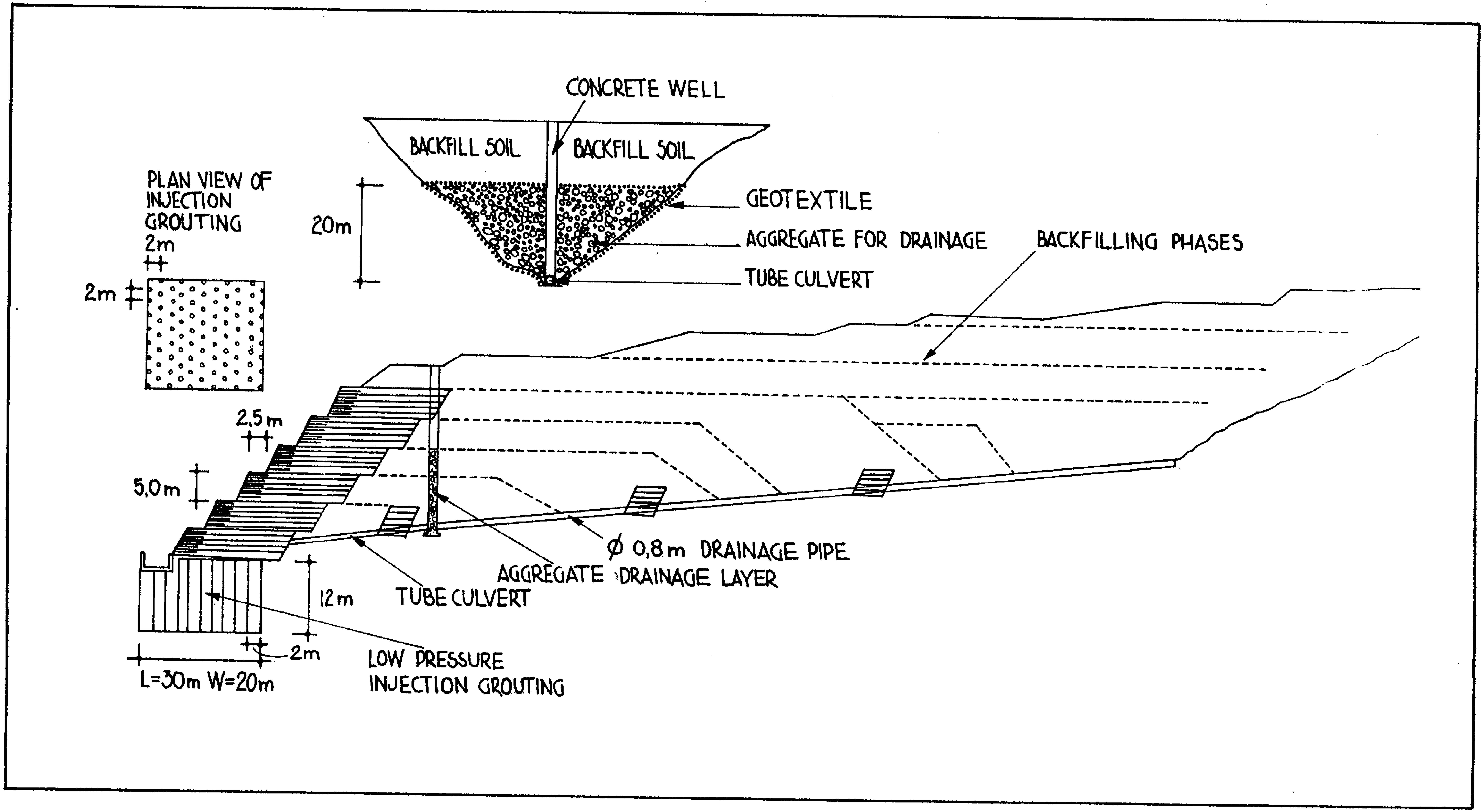

Fig. 2 - Cross section of the geogrid reinforced soil wall with details of the drainage system

and braced horizontally and vertically (see Fig. 3). The wooden tables could be withdrawn and detached from the main formwork structure, just simply by cutting the fixing wire at the outer part of the bracer. The whole formwork system performed as a flexible moving span, which resulted efficient, fast and very economic.

Fig. 4, 5, 6, 7 show different phases of the construction and the completed wall.

7 CONCLUSIONS

The successfull completion of the 35 m high geogrid reinforced soil wall has achieved the following objectives:

- low cost, fast construction and easyness to shape the slopes;
- fast and excellent vegetation of the face;
- minimization of air and noise pollution;
- excellent stability: after one year of continuous monitoring, only minimal base and face movements were recorded;
- positive drainage: no sensible pore pressure was noted in the reinforced block while the culvert discharges a continuous high flow.

Hence this project shows that good geosynthetics engineering can provide a solution even to extremely difficult problems.

REFERENCES

Bonaparte, R., Schmertmann, G.R., Williams, N.D. (1986), Seismic design of slopes reinforced with geogrids and geotextiles, *Proc. III Int. Conf. on Geotextiles*. Vienna, Austria.

Chou, N.S. (1992) Performances of geosynthetic reinforced soil walls, *PH.D Thesis*. U. of Colorado, USA.

Huang, S.W.S., Chou, N.S., Lai. C.T.C., Lee, S.Y. (1993), A 35 m high geogrid reinforced wall for housing development in Taiwan, *Proc. 5th Conf. on current researches in Geotechnical Engineering in Taiwan*. Taipei, Taiwan. (In Chinese).

Jewell, R.A. (1991), Application of revised design charts for steep reinforced embankments, *Geotextiles and Geomembranes, Vol. 10, No. 3, 1991, pag. 203-234*.

Rimoldi, P., Ricciuti, A. (1992), The role of geogrid reinforced embankments in landslide stabilization: theory and practice in Italy, *Proc. 6th Int. Symp. on Landslides*. Christchurch, New Zealand.

Wright, W.C.A., and Greenwood, J.H. (1994), Interlaboratory trial on installation damage in geotextiles and comparison with site trials, *ERA Report 93-0915, ERA Technology*. Leatherhead, UK.

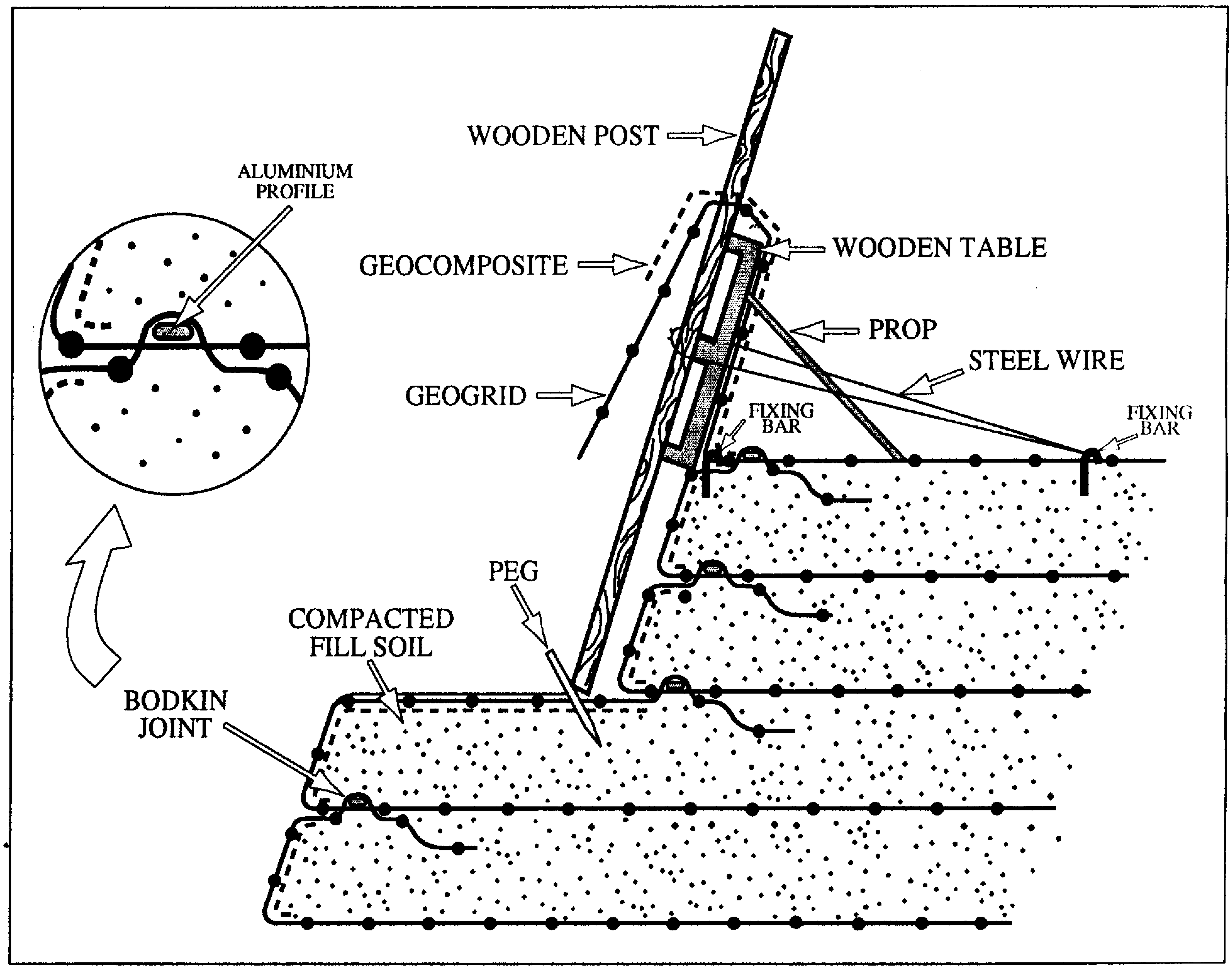

Fig. 3 - Detail of the formwork system developed for this project

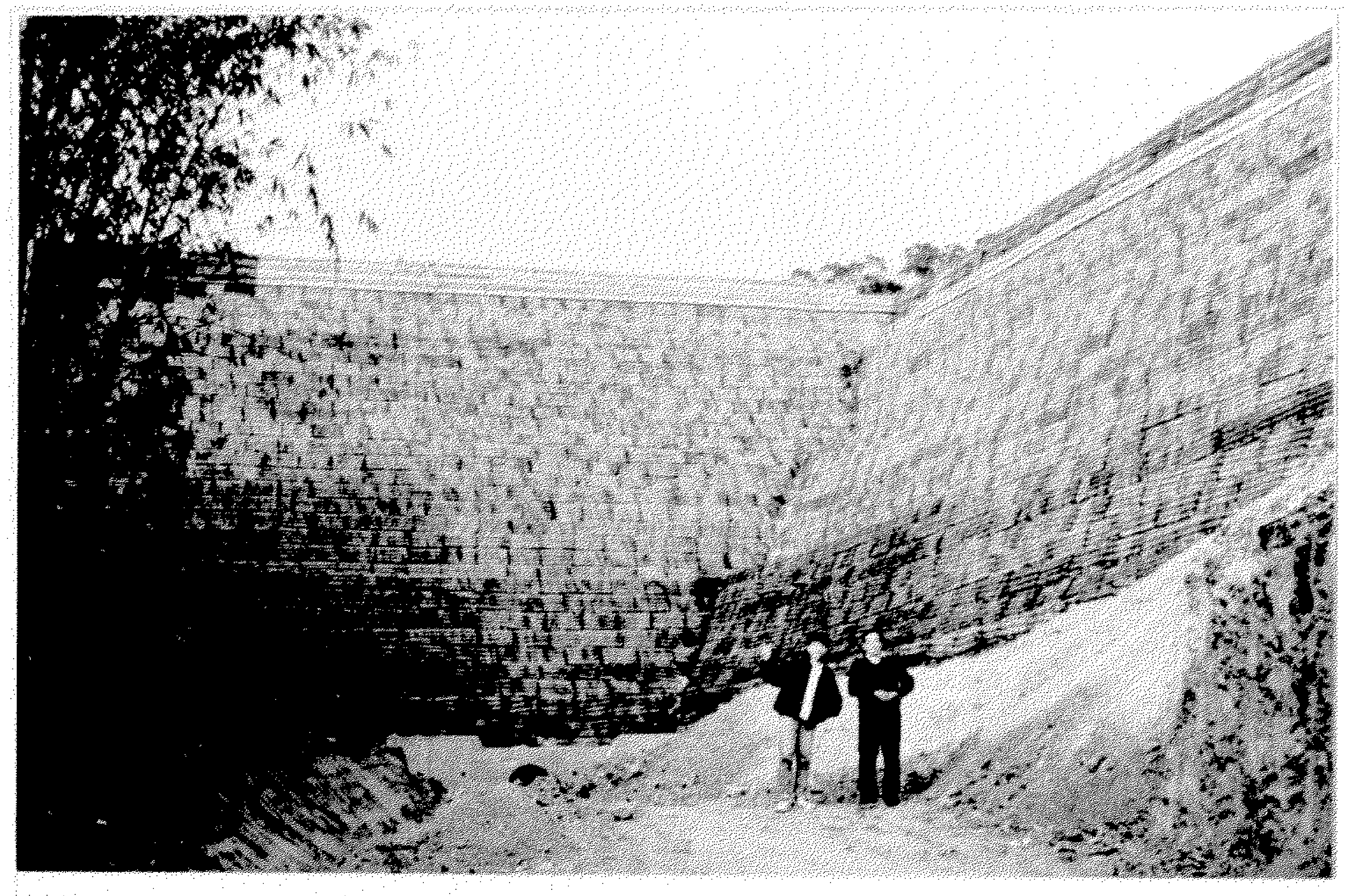

Fig. 4 - Front view of the wall during construction

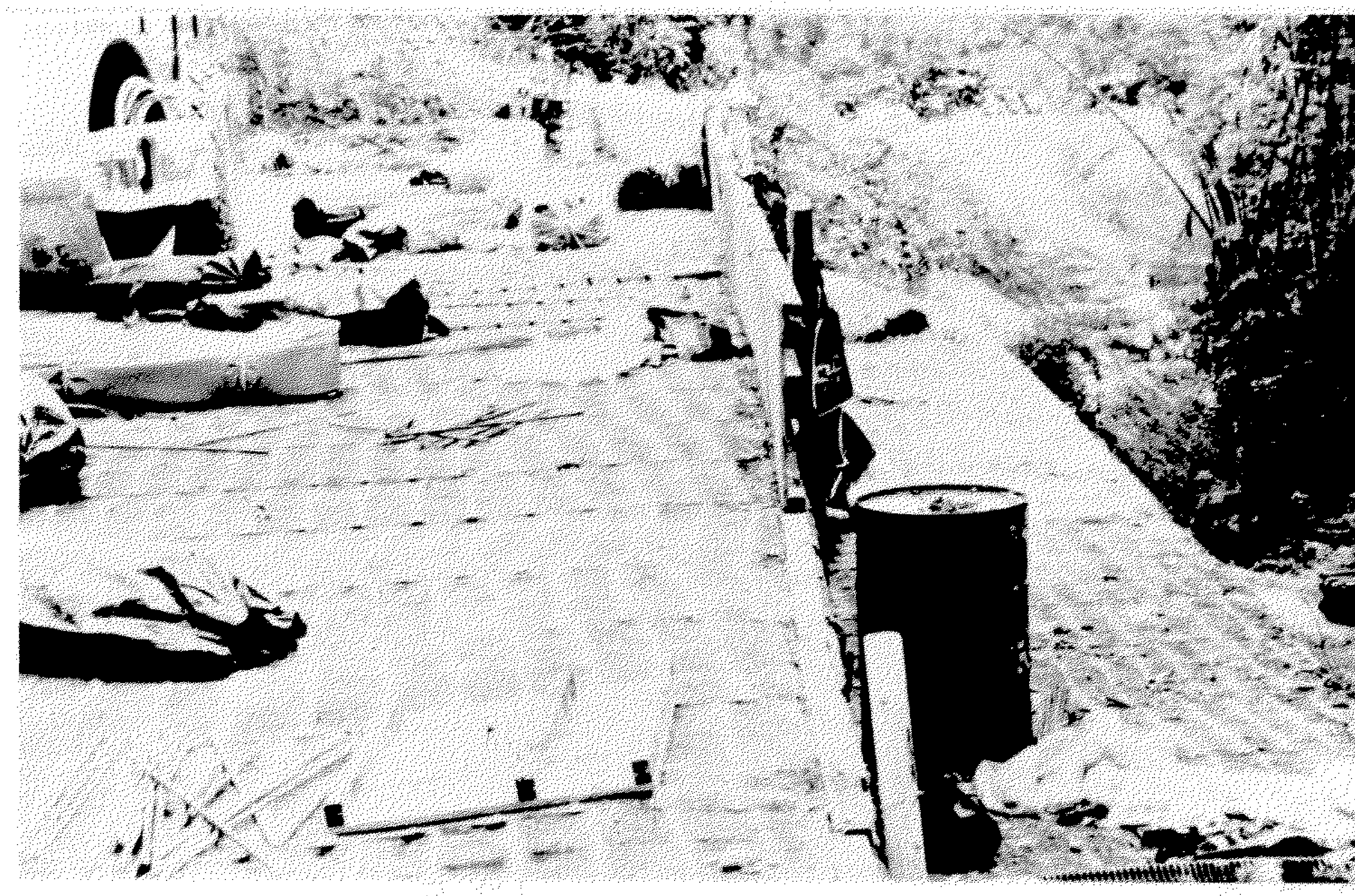

Fig. 5 - Detail of the formwork system, showing the wooden tables, the wooden posts, the prop sticks, the steel wire

Fig. 6 - View of the wall during construction, showing the geogrids and the edge drains for face drainage

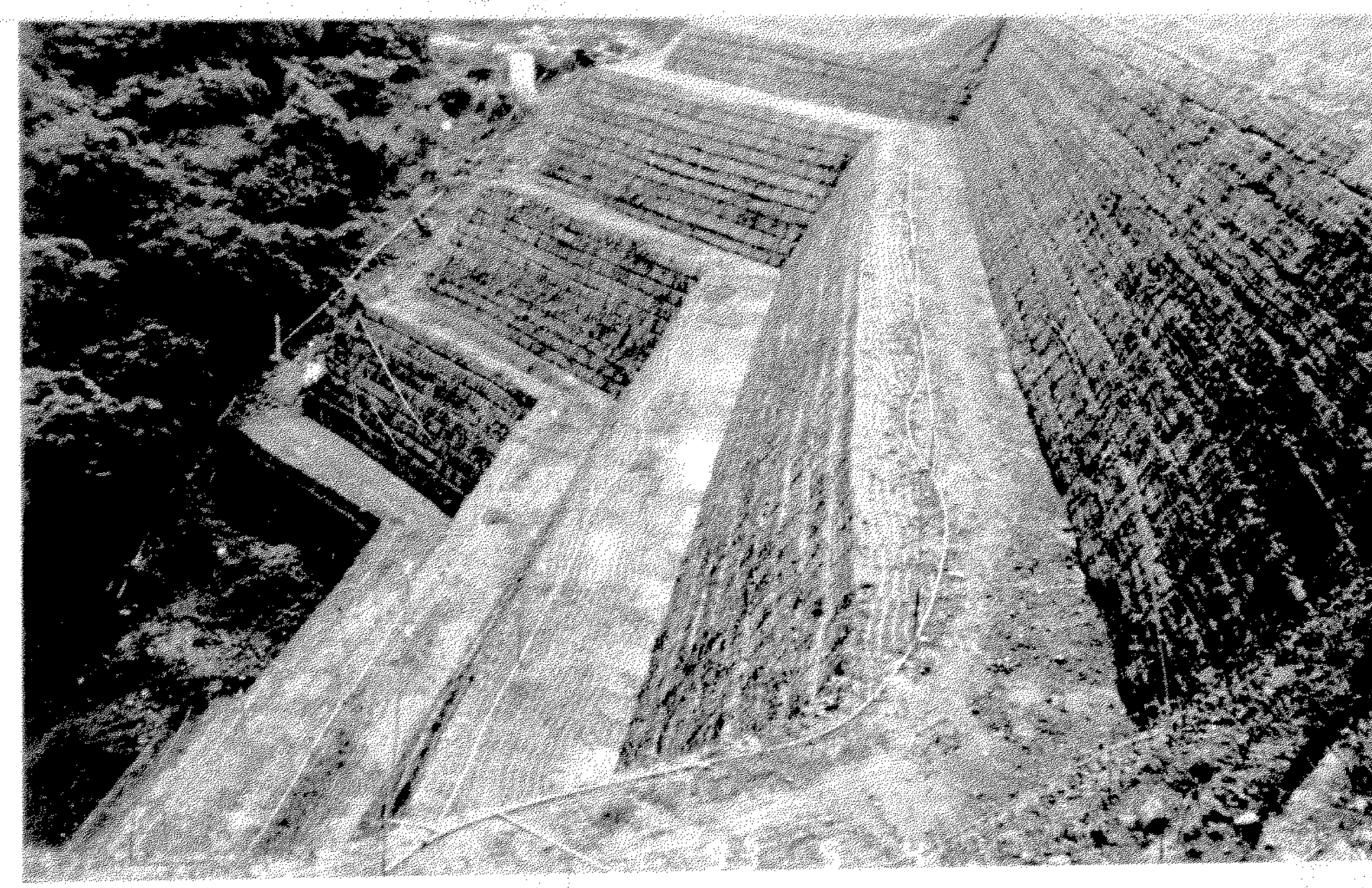

Fig. 7 - View of the wall at the end of construction, showing the irrigation system and the grass already growing