Experiences from High Reinforced-Soil Structures

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ABSTRACT: The paper discusses the typical behavior of the Geosynthetic-Reinforced-Soil-Structures (GRSS) observed and analyzed by the Writers during recent years and provide data of the performance of a high GRSS designed by them. Considerations and suggestions relevant to both analysis and various aspects of the design, such as fill material, reinforcing geosynthetic, type of facing, drainage and monitoring, are given.

1 INTRODUCTION

Reinforced soil applications to build steep, grassed slopes, are fast spreading. Materials, technologies and patents have multiplied in parallel with the booming number of the applications of Geosynthetic-Reinforced-Soil-Structures or GRSS. The appeal of structures considered to be of relatively low cost and 'easy' to construct, fuels a fast increase of their height and attracts non-specialist designers and contractors into what is actually a job for specialists. GRSS with average slopes steeper than 50° and exceeding 25 m in height are now on record and heights exceeding the 40 m mark have been reached with outer slopes in the 30 - 50° range.

Experience suggests that, as the height and steepness of a GRSS increase, their behavior becomes less and less a linear extrapolation of the behavior of lower and more conventional prototypes, say less than 6 to 8 m high. Important distresses and even failures may produce in form of inadequate stability, of excessive deformations or unsatisfactory final appearance and negative impact on environment.

2 OBSERVATIONS FROM HIGH GRSS

What follows, exclusively applies to retaining GRSS structures, subject or not to surcharge on the top, properly designed and accurately built. The main reference case will be the Champagne embankment, shown in Fig. 1, whose main section is 27 m high, with an average outer slope of 60°. The behavior of this structure was monitored for more than 1 year after completion.

Displacements provide the easiest way for checking the behavior of a GRSS, being obtained with conventional surveying techniques. To this end both horizontal and vertical displacements must be considered, though the horizontal ones are the most important by far, being in the direction of reinforcement.

Horizontal displacements of the outer slope start since the early construction steps, showing different trends according to the stiffness of the reinforcement, and asymptotically increase with time. Low modulus reinforcements, such non-woven geotextiles, allow outward movements of the face, though they suddenly start only after 0.5 to 1 m of fill are added and compacted on the reinforced layer. Stiffer reinforcements, like geogrids, initially tend to produce inward displacement of the face as shown in Fig. 2. After a substantial fill is added, the slope starts moving outward. Usually, displacements continue for a sizable time after vertical load stabilized.

Monitoring the behavior of an instrumented geogrid during compaction showed that within 1 to 2 m from the face the mobilized strength of the reinforcement under a 1.4 m fill was about 8 kN/m. Correspondingly the horizontal and the vertical pressures were 16 and 30 kPa, giving a hearth pressure coefficient of about $k = 0.5$. This coefficient was larger than that strictly required for the equilibrium and small inward movement could hence be justified. In some instances, the soil/geosynthetic combined material can therefore exhibit an 'overconsolidated' behavior, due to the locked-in compaction stresses. Only after placing a substantial height of superimposed fill, will the locked-in stresses reduce to negligible levels. A detailed understanding of these mechanisms is essential to a proper modeling of a GRSS.

Horizontal displacements of the GRSS face tend to be maximum near the lower third of the structure height,

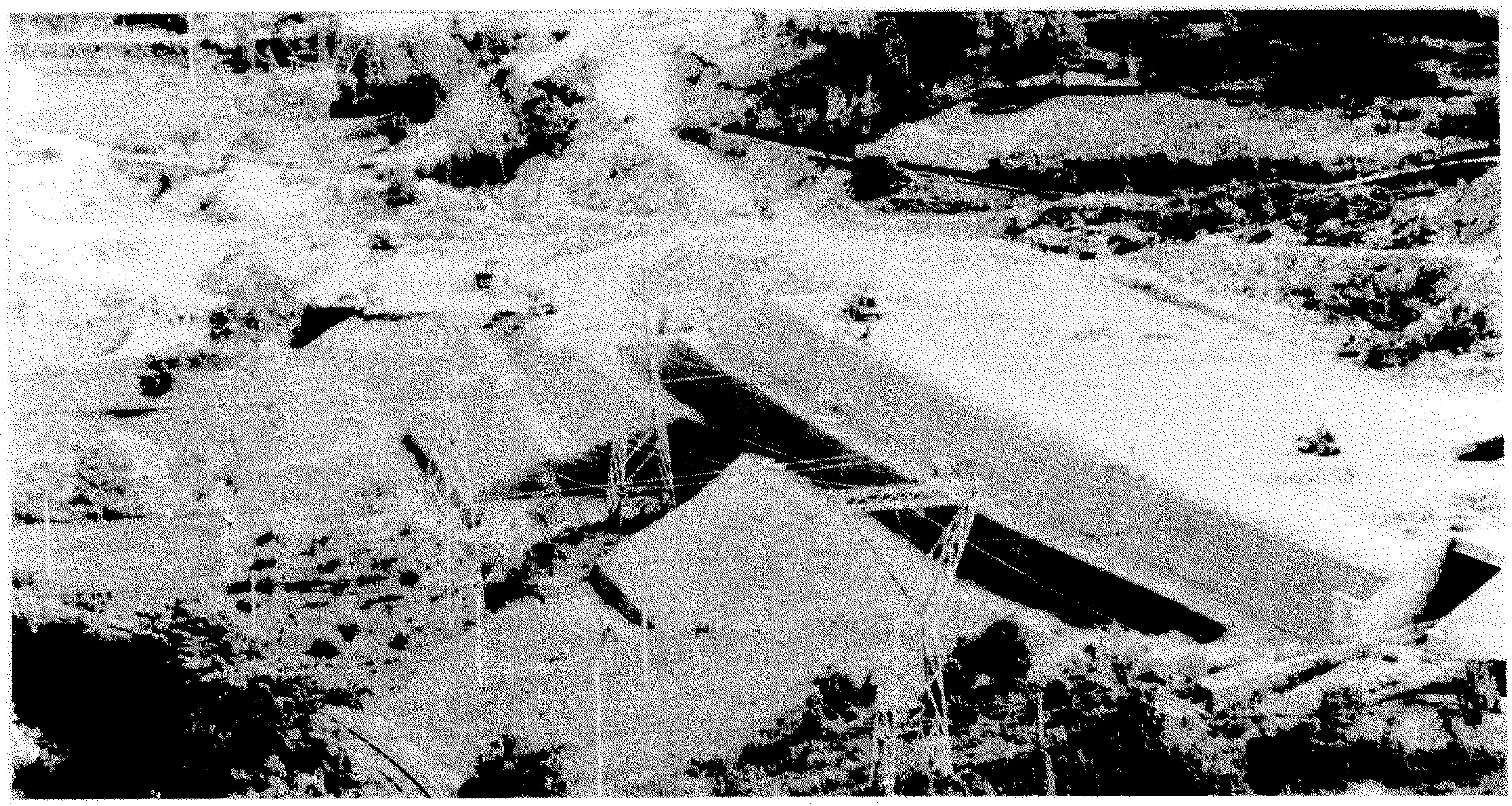

Fig. 1 Champagne Embankment on the Aosta - Monte Bianco motorway. View of the GRSS almost completed. The structure is 350 m long and 27 m high and will carry two staggered carriage ways.

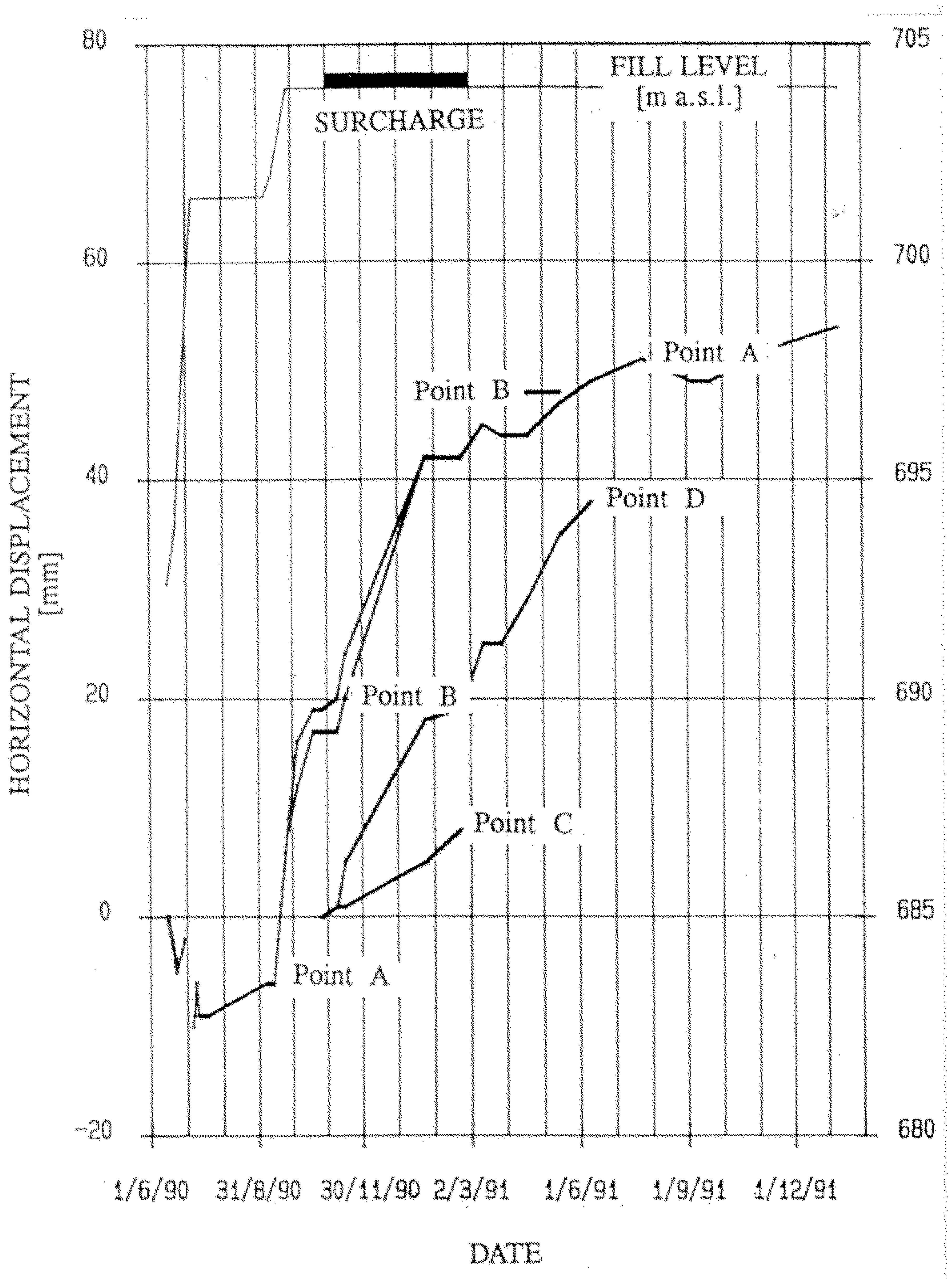

Fig. 2 Long term evolution of horizontal displacements of the face of a GRSS structure. Part of the recorded displacement is due to the presence of a 200 kPa surcharge, removed after February 91.

shown in Fig. 3. According to previous model developed for the stability of cuts in cohesive materials, the deformed face is compatible with development of shear strains in the lower portion of the structure and elastic tension strains at the top.

Strains continue to grow for an appreciable period of time after all fill has been placed. Fig. 4 shows the evolution of average strain levels in the fill, vs. distance from the face, at various construction stages. With time, strains propagate within the fill and the strain field becomes more uniform. While this occurs, the shear stresses in the soil mass are transferred to the reinforce-

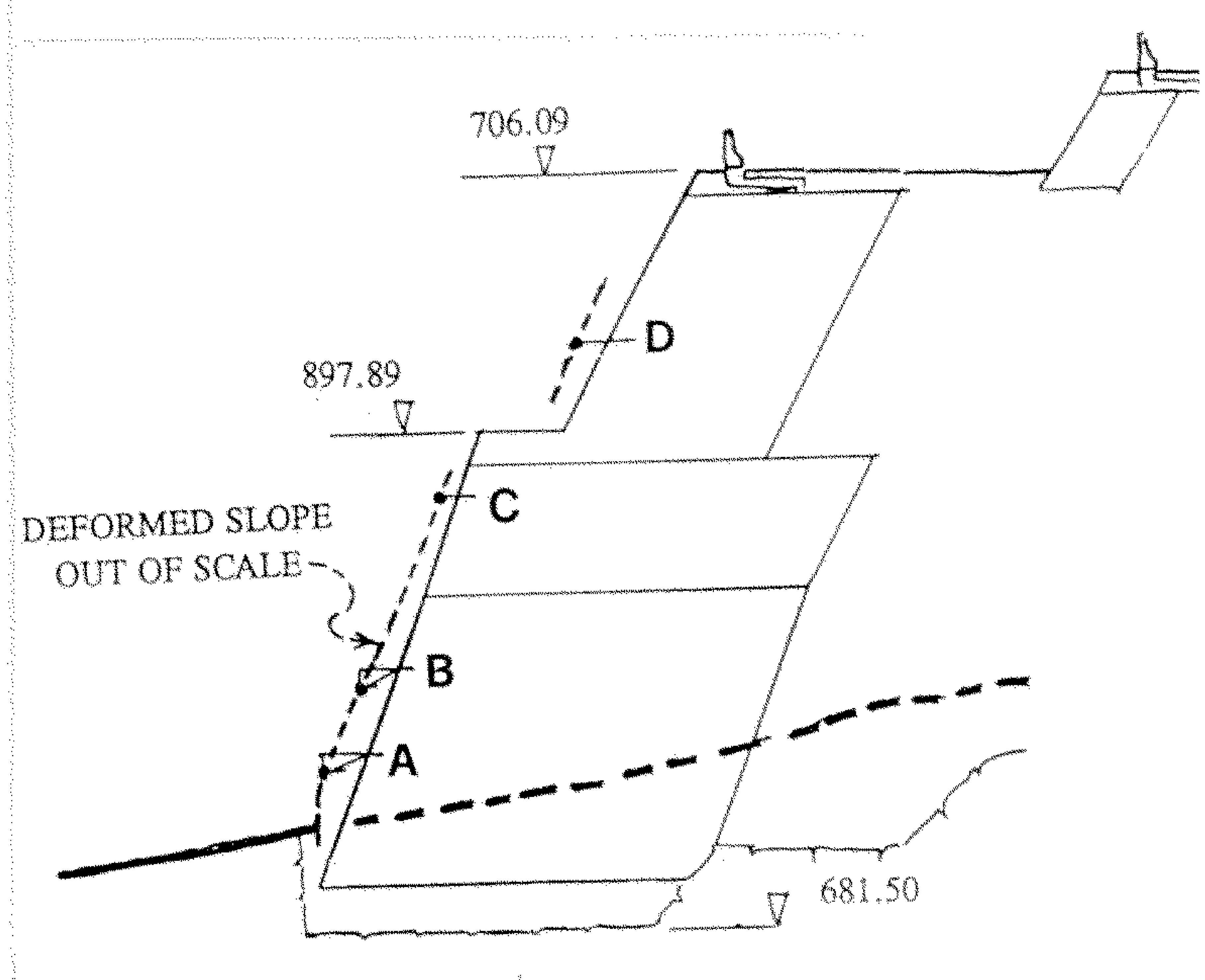

Fig. 3 Overall outward deformation of the face of a GRSS structure.

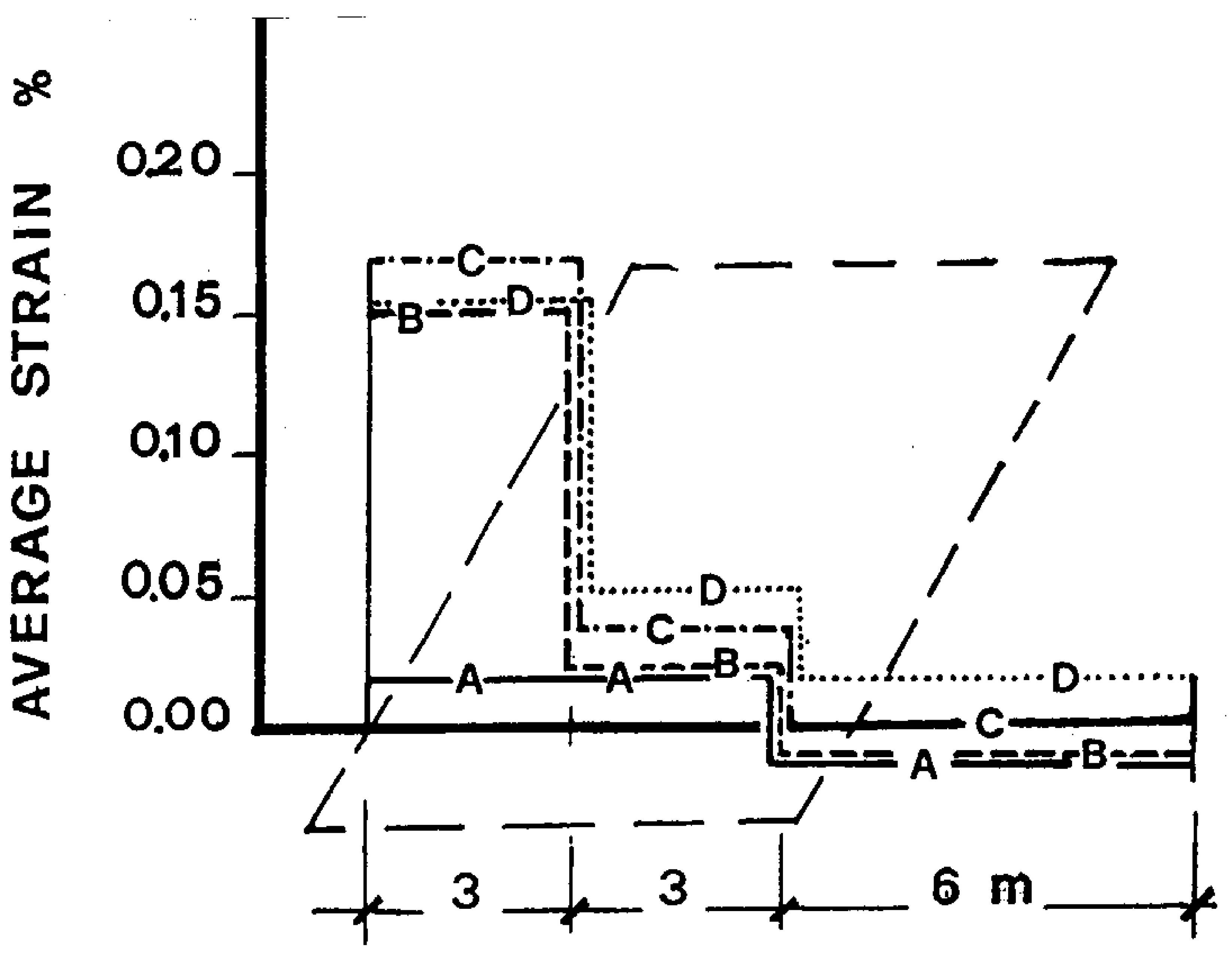

Fig. 4 Evolution of average strain levels in the fill of a GRSS structure vs. distance from the face, at various construction stages. A = compaction of first 0.75 m of fill, B = just after compaction of the 0.75 - 1.00 m lift, C = under 4.25 m of fill, D = under 5.25 m of fill.

ments until equilibrium is reached. The above suggests two main remarks, which require further confirmation: a) the peak strains, and the corresponding required strength, seem to occur during construction and closer to the face, b) the lack of the appropriate length of the reinforcement and corresponding discomforts may appear sometimes after construction completed.

The level of the measured strains, averaged over 3 m of the geotextile reinforcement, did not exceed 0,4%, even after 1 year from construction. Local strains in the geotextile, measured with special strain gages on 60 mm long bases during construction remain below 0,5%. Such levels of strain, confirmed by several Authors, inevitably force to reconsider the meaning and applicability of pull-out tests as well as of in-air extension tests.

All the above suggest that the final equilibrium configuration can be reached depending on the fill-geosynthetic interaction which, in turn, depends on the geosynthetic and fill characteristics, on design details and on construction methods. The problem has a high degree of static indeterminacy and to date is not yet completely solved even with the most sophisticate FEM Techniques.

Limit Equilibrium is probably adequate to analyze high rise GRSS where most of the overconsolidation effect has been lost at the level of the lower lifts. Clearly the mobilized strength in the reinforcements is strictly related to the interslice forces. It should be recalled that if the distribution of interslice forces is changed within a stability analysis method the overall factor of safety does not change but tensions in the reinforcement do. This problem could be overcome only modeling the stiffness of the reinforcements, along the potential sliding surface, and imposing the strain compatibility. However, to date the most suitable method for defining the strength requirement of the geosynthetics still seems evaluating the total required horizontal force by a conventional Simplified Stability Analysis Method and assuming a reasonable distribution of stresses over the height of the GRSS.

3 DESIGNING THE REINFORCED SOIL

The reinforced soil is a high tech composite material, built on site. A comprehensive design approach for reinforced soil, especially for high GRSS, requires, in the Writer's opinion, considering four main elements among others rather than simply evaluating the strength requirements. Such elements are the fill material, the reinforcing geosynthetic, the type of facing and the compaction procedure.

Fill materials should be easy to compact: a well graded sand and gravel with less than 10 % of #200 sieve (0.074 mm) fines is possibly the most suitable fill. The maximum particle size should be selected based upon the thickness of the lifts and survivability requirements of the reinforcement. An excellent material has been proved to be the muck from tunneling moles: the sandy fraction protected the geotextile reinforcement from excessive damage by the coarse angular particles, some 25 to 50 mm in diameter. In any case, a proper safety factor to account for reinforcement damage during installation should be considered whenever the fill contains coarse particles. Clean sands are not the best option as they compact only at some depth where a sufficient confinement exists. At relatively small depth, though, compaction is hindered by the presence of the geosynthetic. The compacted fill should be dilative in order to mobilize the reinforcement strength. This may be no longer true under high structures for which high confining stresses are involved, even if the proper fill materials and placement methods are used.

Reinforcements should be selected on the basis of their stiffness relative to the soil, drainage capability and survivability in presence of the placement injuries. Their spacing should never be smaller than 0.25 m. It seems reasonable using stiff reinforcements in the lower portions of high GRSS, for both strength and stiffness requirements. The non-woven geotextiles are better used in relatively low structures especially with impervious fills. Ageing, chemical compatibility and survivability are all vital item in the selection of the reinforcement.

Of paramount importance is selecting the proper facing. Facing should allow compacting right to the slope without appreciable deformation, as shown in Fig. 5, and should be strong enough to hold while horizontal stresses build up. This can better be obtained if the slope is not flatter than about 60°. Facings should also be rated for their adequacy to promote and support a fast vegetation growth. Several different technics have been developed and patented for facings. Welded steel wire-mesh, to be left in place, are used extensively.

Fig. 5 4 t drum vibratory roller compacting the fill of a GRSS right to the face of the structure.

A very important requirement of the facing which is often overlooked is that it must allow appreciable shortening of the face to accommodate settlements of the fill. Often the largest vertical displacements take place near the face due to poor compaction. However even small vertical displacement in a well compacted fill may cause bulging of the facing elements and, as a consequence, a reduction of lateral confinement on the adjacent fill.

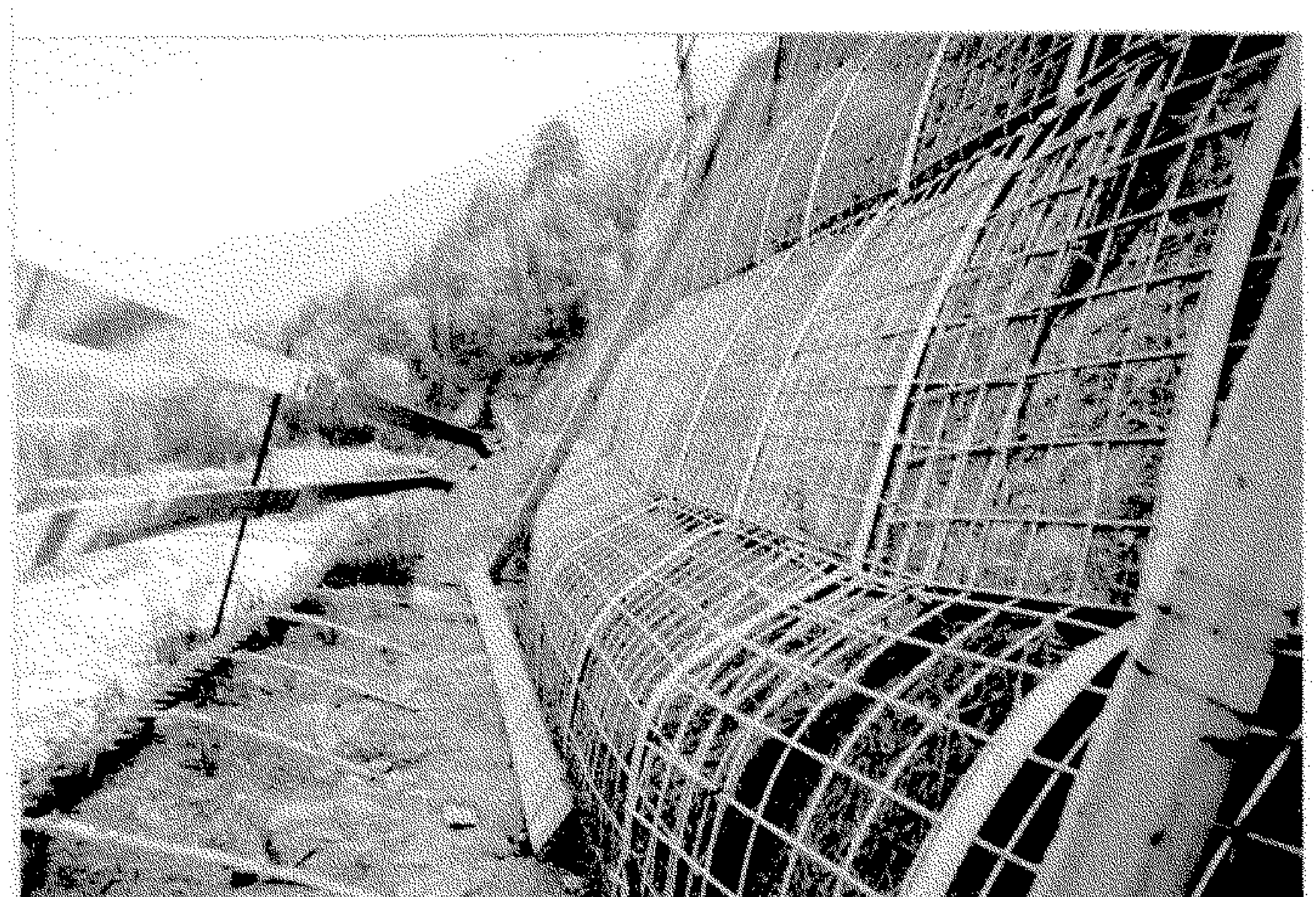

Fig. 6 View of a distressed face of a GRSS structure with bulging of the welded-wire form and loss of fill material.

Wash out and loss of the unconfined fill material usually are observed in concurrence with the above. Any loss of fill brings additional unnecessary deformations, stress changes and undermines a regular growth of vegetation on the face. Face shortening may reach upon 10% with disruptive effects as those testified by Fig. 6.

Compaction shall be heavy enough to produce a dilative fill, throughout the GRSS. The modern vibratory rollers are suitable for compacting the fill, even at a short distance from the slope (although small compactors are often used here). In order to obtain heavy compaction using relatively light rollers (4 t drums), lifts not more than 0.3 m thick should be preferably spread for compaction.

4 CONSIDERATIONS ON GRSS AS A WHOLE

GRSS are usually complex structures which require a high degree of detailing. Key elements for a good performance of the structure are the connections at boundary to adjacent structures and drainage provisions, for both surficial and ground water.

Monitoring is recommended for all structures exceeding the 8-10 m mark, though yet not at all easy. Surface movements can be monitored with conventional distometry. Overall strains are possibly best obtained installing clusters of long base extensometers. The use of strain gauges to measure local strains, especially on geotextiles, requires special techniques and is recommended for research rather than for conventional jobs. Piezometers, also quite important, can be conventional, porous tip, fine-bore stand-pipe. Monitoring of in-soil ageing of the reinforcements is of paramount importance and recoverable samples should be buried at appropriate locations. A full set of data for the virgin geosynthetic shall be put on record.

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