Evolution of the "Displacement Method" Applied to Soil Reinforced Structures

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ABSTRACT: The use of geosynthetic extensible inclusions in reinforced soil structures like retaining walls is now common. This paper presents comparative results between the "displacement Method" (program CARTAGE) systematically used in France, its evolution independently produced in Australia (program MDISMET) and a Finite Difference Method (program FLAC). We focus on the design and on the modelisation of the progressive construction, step by step, of such earth structure.

1 INTRODUCTION

The "method of displacements" is used in France and in several other countries for the design of geotextile reinforced retaining structures (Gourc et al, 1986). The method is distinguished by the fact that the distribution of reinforcement tensions is calculated as a function of the extensibility of the reinforcement (computer program CARTAGE developed at the LCPC). While the use of the method to estimate the rupture limit state of such structures can now be considered to give satisfactory results (Delmas et al, 1992), its ability to calculate service state conditions could be improved by taking into account the effects of construction technique. Such an improvement has been proposed by Fidler (1992). This article is the result of a collaboration between the first author and the IRIGM at the University of Grenoble, in which the conventional "method of displacements" was compared with the modified method.

To validate the "modified method of displacements" (computer program MDISMET), in the absence of results for instrumented reinforced walls built using different construction techniques, the results of a general finite difference numerical model have been used (computer program FLAC, distributed by Itasca Inc.).

2 CASE ANALYSED

The retaining structure considered in the present study is illustrated in Figure 1 ; height H = 6m, length of the geotextiles, Lg = 4.5m, geotextile modulus J=300 kN/m. The facing is vertical, and the geotextile is wrapped around at the facing towards the top of the wall. A surcharge of 10kPa, is applied on the horizontal ground surface behind the facing. The variation in construction technique which is considered in the present study relates to the support provided to the facing during construction. The "propped" condition corresponds to a case in which horizontal support is provided to the facing until the final wall height is reached, at which time it is removed, allowing the simultaneous mobilisation of tension in all reinforcing layers. The "unpropped" condition corresponds to a case in which support is only provided to each lift of soil (0.5m) as it is placed, thus causing reinforcement tensions to be developed successively as construction proceeds.

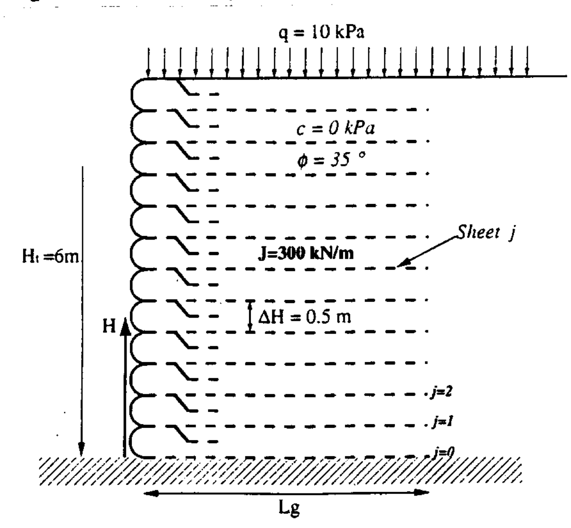

Fig. 1: Case analysed

3 FINITE DIFFERENCE NUMERICAL MODELLING (Program FLAC)

The method of analysis of the program FLAC is based on solving the differential equations governing the motion of a system of interconnected deforming bodies using the explicit finite difference technique. A Mohr-Coulomb constitutive relationship is provided for the two dimensional finite difference zones used to represent soil, and was used in the current analysis with a failure criteria defined by $\varphi = 35°$. Soil stiffness is defined in terms of shear and bulk modulus, and values of 15000 kPa and 25000 kPa were used respectively, corresponding to a medium dense sand. Cable elements which are numerically connected to the soil through interface shear force were used to represent the reinforcements (including the wrap around which forms the facing). Limiting interfacial shear force was specified to develop at a displacement of 15mm, and to correspond to an interfacial friction angle of 0.7 φ.

The locations of development of soil plasticity, as determined by FLAC for the propped case, are illustrated in Figure 2. It can be seen that soil plasticity is localised in a relatively narrow zone which passes through the toe of the wall. Displacements determined by FLAC for the same case show that the zone of soil plasticity corresponds well to the locations where the gradient of displacement is the greatest.

In Figures 3-a and 3-b we have the displacements at the free boundaries of the reinforced zone and we can see that smaller displacements are seen to develop for the unpropped case. The propped construction technique leads to an overturning of the wall at the same time as the simultaneous mobilisation of all the reinforcements.

4 METHOD OF DISPLACEMENTS

4.1 Standard "Method of Displacements"

This method is based on the limit equilibrium principle: reinforcement tensions are calculated to provide equilibrium for a chosen value of F_S: Factor of Safety with respect to soil shearing. Global equilibrium of the mobilised mass of soil is considered using a method of slices. The geotextile layers are considered to behave as anchored membranes, and local equilibrium calculations determine the developed tensions in the layers as a function of the displacement along the shear surface, which can be characterised by the vertical projection of the displacement at the horizontal ground surface (Gourc et al, 1989, Δ_{zc} in Figure 4). The program CARTAGE considers the limit equilibrium condition for the final height of the wall, and thus corresponds in principle to a case similar to the propped condition.

In the present case, shear surfaces are circles passing through the toe of the wall and are defined in terms of the distance Xc, the location of the intersection of the shear surface and the horizontal ground surface. It is also assumed that the soil strength is fully mobilised ($F_S = 1$), as was indicated by both FLAC and MDISMET. For each value of Xc, the circle which gives an overall maximum value of reinforcement tension is determined (that is, the circle which gives the maximum value of Tj max, where Tj is the reinforcement tension in layer j).

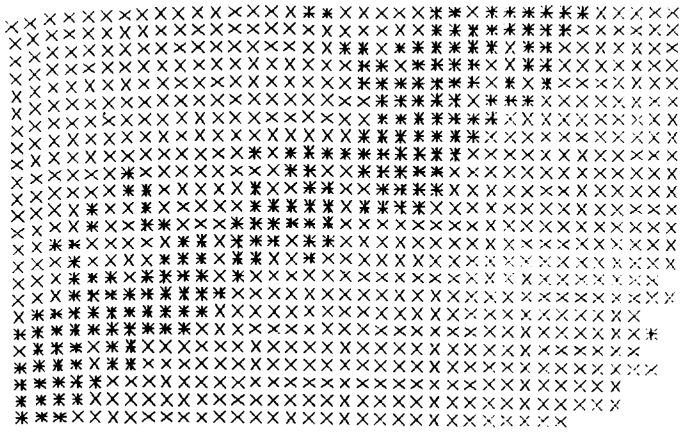

Fig. 2: (FLAC version 3.22) platicity zone (* indicator) J = 300 kN/m, Cables, Wall Propped

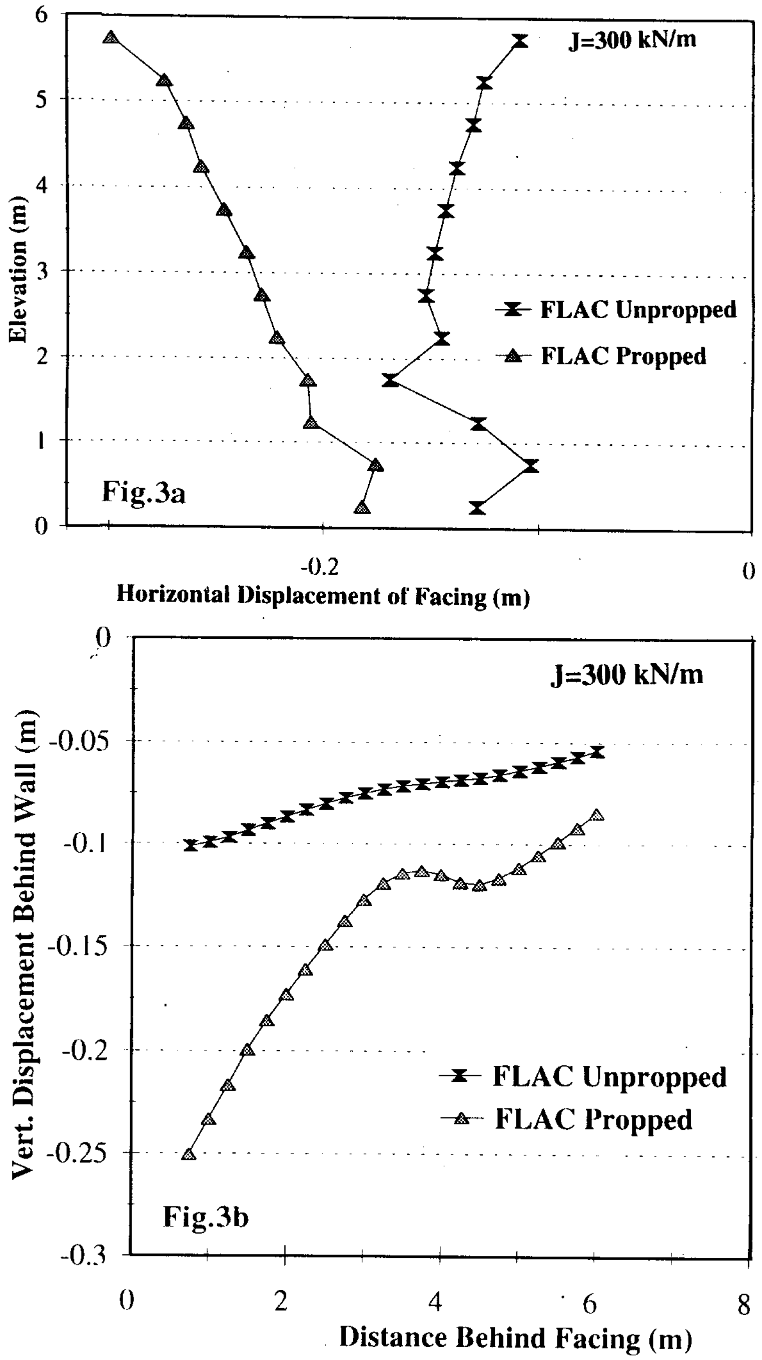

Fig. 3: FLAC results (version 3.22)
3a) Horizontal displacements of the wall facing
3b) Vertical displacements behind wall

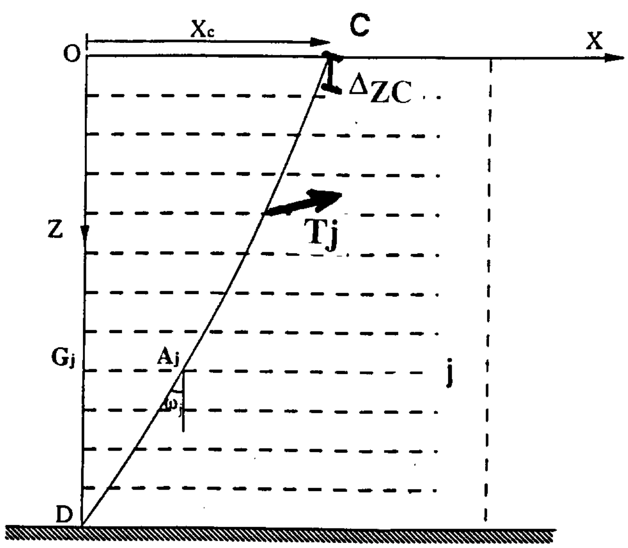

Fig. 4: Cinematic of the limit equilibrium method ; Parameters

4.2 Modified Method of Displacements -

Based on the same fundamental hypotheses as the standard method of displacements, this method is distinguished by several developments (program MDISMET). In the unpropped case, the displacement required to establish global equilibrium is calculated for each stage of construction, considering the stabilising contribution of the reinforcement layers that have been installed at that stage. The local reinforcement strains for each layer at the start of a construction step are equal to the sum of displacements from all previous stages. Similarly, shear displacement at each level in the soil develops progressively as construction proceeds, and the developed local soil shear resistance is calculated based on a simple elastic-plastic constitutive relationship and the definition of a shear displacement at which shear resistance is fully developed. A local soil Factor of Safety can be defined.

The method is described more fully in Fidler (1992) and Fidler and Wallace (1992), and the importance of local soil and reinforcement Factors of Safety is also discussed. For unpropped cases, the shear surface is considered to be a log-spiral, defined as above by the parameter Xc, which is close to the corresponding circle from CARTAGE. Maximum reinforcement tension (Tmax), and maximum Δ_{zc} are determine as above for CARTAGE, and are plotted as a function of Xc in Figures 5-a and 5-b respectively.

5 COMPARISON OF RESULTS

Figure 5 confirms that the critical shear surface for CARTAGE corresponds to both the maximum calculated value of Tmax, and the maximum calculated value of Δ_{zc}. The comparison of the results from CARTAGE and from MDISMET (propped case) indicate a relatively close correspondence between the maximum values of reinforcement tension (Figure 5-a), despite the fact that the critical shear surfaces are different. This minor influence of the different principles of calculation on the determination of Tmax is not however reflected in the calculated values of Δ_{zc} (Figure 5-b). It is worthwhile recalling at this point that the displacements calculated by MDISMET or CARTAGE are not real, but are simply to be used as criteria for design, by comparing the calculated "displacements" to those obtained with many types of reinforcement for the same structure (Gotteland, 1991). Notwithstanding, the same trends can be noted for the "displacements" determined by MDISMET (Figure 5-b), and those determined by FLAC (Figure 3-b), although the magnitudes of the displacements are very different.

In Figure 6a, the distribution of tensions Tj for the critical shear surface, as determined by MDISMET, is compared to the distribution of tensions at the same points as determined by FLAC (Figure 7), for the propped case. The values determined using CARTAGE are also plotted, for the critical shear circle given by CARTAGE. In Figure 6b, the same comparison is made between MDISMET and FLAC for the unpropped case, along with a comparison of the envelopes of maximum tension from both programs (for MDISMET the envelope represents the maximum values of Tj for each j, for all of the shear surfaces considered). Although MDISMET has over-estimated the tensions for the critical shear surface in comparison to FLAC, the overall maximums in each reinforecement for all potential shear surfaces correspons well to the maximums given by FLAC.

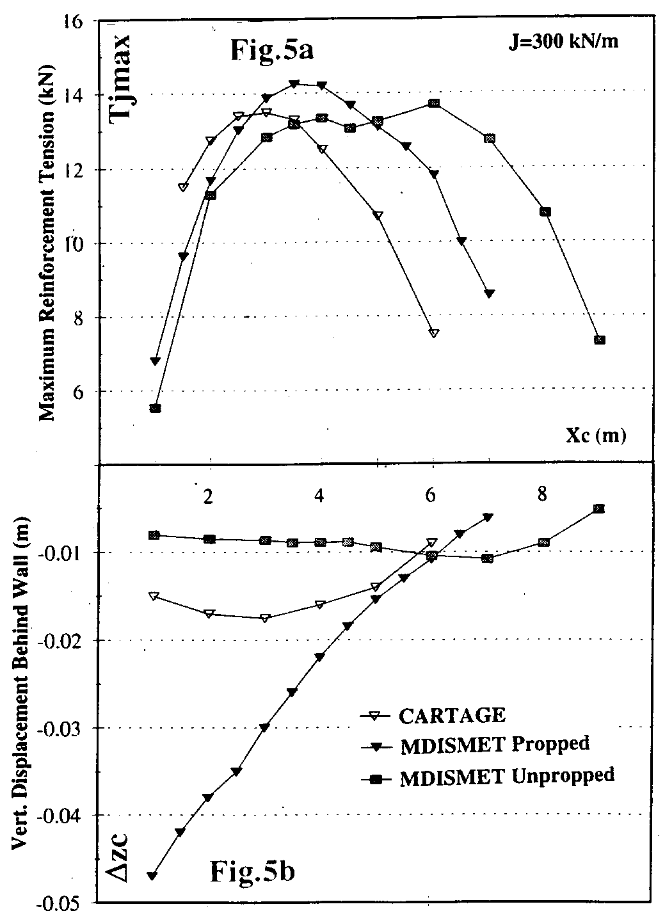

Fig. 5: 5a) Maximum tension T_j max versus X_c
5b) Vertical displacement Δ_{zc} versus X_c

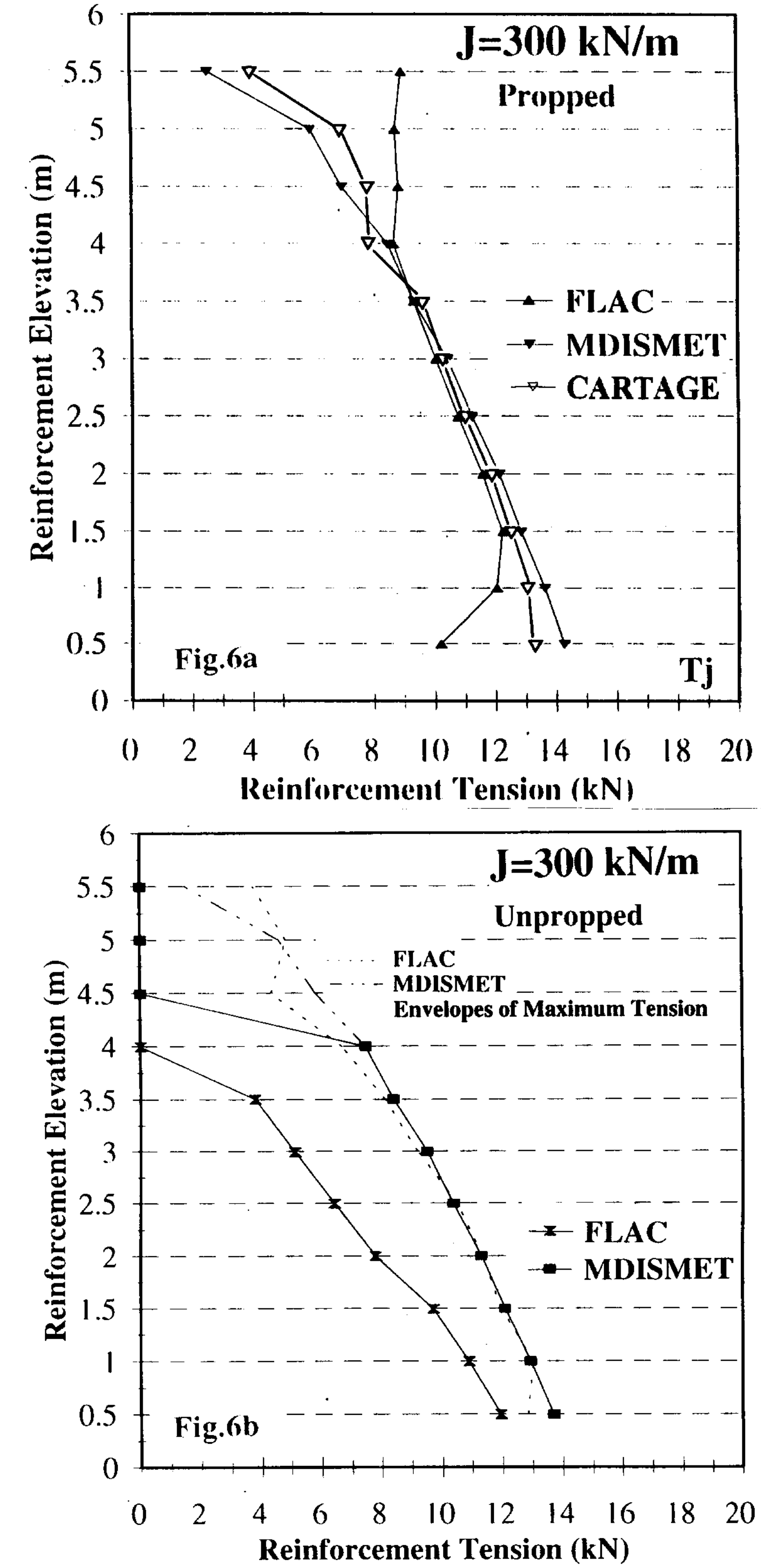

Fig. 6: Comparison of the reinforcement tensions Tj
6a) For critical shear surfaces (wall propped)
6b) For critical shear surfaces compared with envelopes (wall unpropped)

6 CONCLUSION

The estimation of the importance of construction technique for the design of reinforced retaining structures, such as has been proposed here and validated on the basis of the program FLAC, must still be validated for real structures. Notwithstanding, the evolution of the "method of displacements" that has been discussed here has already given promising results.

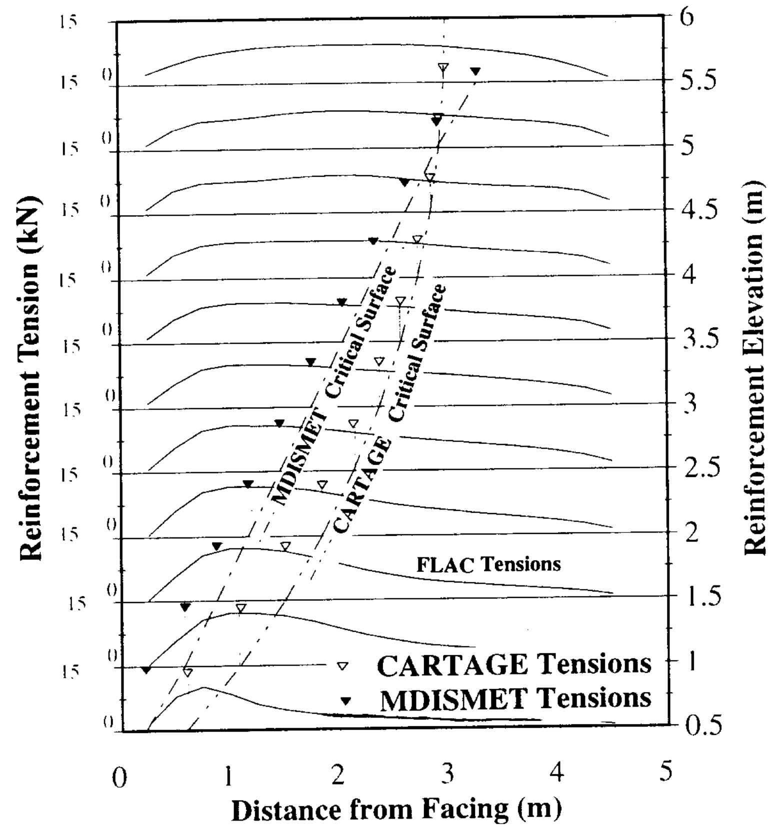

Fig. 7: Comparison of the tensions (CARTAGE, MDISMET) and distribution obtained with FLAC (J= 300 kN/m, wall proposed)

REFERENCES

Delmas Ph., Gotteland Ph., Gourc J.P., Haidar S. (1992) "Two Full Structures Reinforced by Geotextiles", *Grouting Soil Improvement and Geosynthetics, A.S.C.E. Geotechnical Special Publication* n°30 vol. 2, pp. 1201-1213.

Fidler, S.R. (1992) "Working load design methods for reinforced soil systems - The Importance of Strain Compatibility". *Master of Engineering Thesis, Queensland University of Technology, Brisbane*, Australia, 278pp.

Fidler, S.R and Wallace, K.B. (1992) "Strain compatibility and design criteria for reinforced earth". *Proc., Sixth Australia-New Zealand Geomechanics Conference*, Christchurch, pp.67-73.

Gotteland, Ph. (1991). "Renforcement des sols par géosynthétiques : dimensionnement et validation". *Thesis of Grenoble University*, France, 370 pp.

Gourc, J.P., Ratel, A, Delmas, Ph. (1986) "Design of fabric retaining walls : the Displacements Methods", *Proceeding of Third International Conference on Geotextiles and Geomembranes*, Vienne, Austria.

Gourc, J.P., Gotteland, Ph., Delmas Ph. (1989) "Parametric study of geosynthetic reinforced retaining walls using the "displacements method", *North American Regional Conference "Geosynthetics' 89*, 12 p, San Diego, U.S.A.