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Reinforced earth ramps over flexible inclusions in Beirut

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ABSTRACT: This paper describes the execution of relatively high reinforced earth retaining walls founded on very compressible soil, the safety factor at the punching being very close to 1. The installation of sand drain columns beneath the walls has considerably ameliorated the foundation soil and has secured in few months the total settlement of 0.5m.

1 INTRODUCTION

At the beginning of the years 70s', well before the war, the Executive Council of the Great Projects of the city of Beirut has foreseen a network of highways cutting out the capital and leaving for road users easy approaches on the South and the North exits.

One of them, subject of our study, is the one allowing to connect the two zones surrounding the Beirut River being essentially BOURJ HAMMOUD and its outskirts on one part and ACHRAFIEH on the other.

The two branches of the Y are the extensions of the two principal axes connecting the East and the West of Beirut notably the Ring leading out to Charles MALEK Avenue and the SODECO passage leading to President Elias SARKIS Avenue. As Figure 1 shows, this way is composed of roads of variable elevations including a series of bridges.

The very compressible nature of the foundation soil of the plain part has led to the replacement of the sections of the bridges whose foundations were proving very onerous by Reinforced Earth access ramps.

In fact to have an idea of the cost of the foundations of the bridges' supports used on the Y branch thriving from the President SARKIS Avenue, it is appropriate to specify that for each pier 18 piles of 80cm diameter and of a depth varying between 25 and 30m were foreseen; the cost, per support, is about 150,000$.

Needless to say that in these conditions a retaining wall solution where applicable was much less expensive. In view of the difficulties presented by the foundation soil, only the reinforced earth by order of its flexibility could afford an economic and elegant solution.

2 GEOTECHNICAL DESCRIPTION OF THE SITE

Figure 2 points to the position of the first boreholes realized on the site in 1994 (B1 to B9). These soundings gave a qualitative description of the soil and

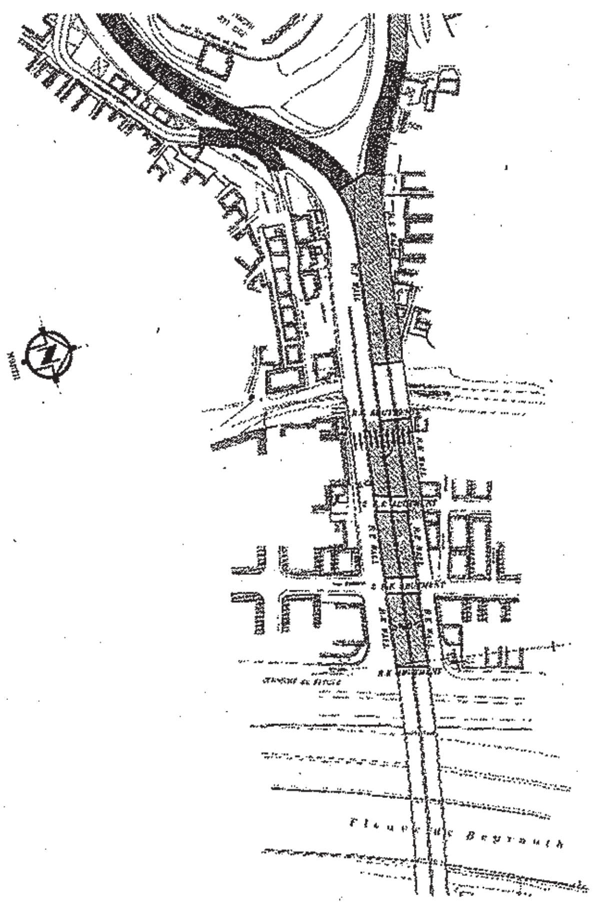

Figure 1. General view of project.

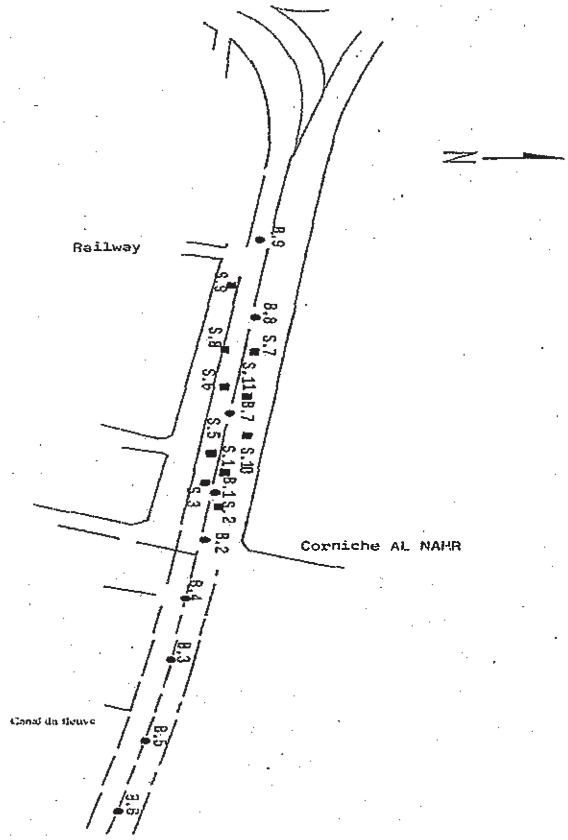

Figure 2. : Boreholes set-up of 1994 (● B1–B9)
: Boreholes set-up of 1996 (■ S1-S11)

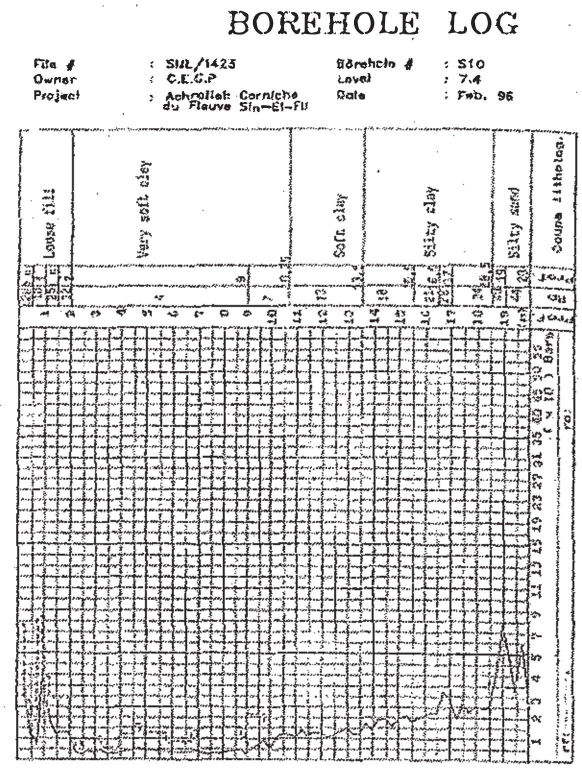

Figure 3. Typical borehole log.

showed that, roughly, over the lower platform, 1.5m to 3.0m of fill material existed, overtopping an argillaceous creamish deposit, possibly including sand, of a thickness at least equal to 17m. Below, a clayey marl was found.

The tests on the found soil were rare: some pressuremeters, more or less successfully done due to the enlargement of the hole during drilling, about ten identification tests showing a liquid limit varying between 23 and 52, a plastic limit ranging respectively between 11 and 28, and a natural water content very close to the plastic limit.

Two consolidation tests give the following results:

- at 5m depth, $C_c = 0.078$ $C_v \approx 10^{-3}\ cm^2/s$
  $e_o = 0.5$
  $\sigma'_c = 70KPa$
  $\gamma_d = 18.2KN/m^3$

- at 16m depth, $C_c = 0.056$ $C_v \approx 10^{-3}\ cm^2/s$
  $e_o = 0.685$
  $\sigma'_c = 150KPa$
  $\gamma_d = 16.2KN/m^3$

This leads to overconsolidation ratios OCR very close to 1, hence indicating that the clay in presence is normaly consolidated.

In these conditions and in view of recognizing the mechanical characteristics of this slightly resistant clay, SOIL MECHANICS has conducted a broader survey including 10 boreholes concentrated in the compressible zone and noted S.1 to S.11 as shown on Figure 2. The level of the top of these boreholes varies between +6 and +7.7. This survey was done by means of the static dynamic penetrometer ANDINA (No similar engine exists in the world after the economic crisis at the beginning of the years 90s' in Europe).

We hereafter, give one typical section of registered end resistance and lateral friction. Figure 3.

The exploitation of these results together with the layers classification based on a normal consolidated clay and applying the relation given in *"The Application of Pressuremeter Test Results to Foundation Desing in Europe"* edited by the International Society for Soil Mechanics and Foundation Engineering, leads to distinguish well differenciated types of soil section where,

- The first one, between the Corniche du Fleuve and the BADAOUI road, is characterized by following layers :

0m - 6m	96KPa <Cu< 165KPa	
6m - 11m	43KPa <Cu< 67KPa	
11m - 22m	175KPa <Cu< 270KPa	
22m - 26m	Cu> 500KPa	

- The second one, between the BADAOUI road and VARTAN road is characterized by the following layers :

0m - 11m	35KPa	<Cu<	42KPa
11m - 16m	136KPa	<Cu<	191KPa
16m - 19m		Cu>	350KPa

- The third, between the VARTAN road and the railroad is characterized by the presence of a relatively stiff clay, Cu being comprised between 141 and 243KPa.

Finally, the water table existed at level +3.5.

3 THE PROJECT

The road project includes four tracks, two of which (the extrems of each side) are being very close to natural ground, and the remaining inner two, cross over a fill and are staggered one with respect to the other.

Figure 4 shows an average section where it appeared that the total width of the fill is equal to 17.6m.

This fill is held by two extremity walls and by an inner wall, all of them being reinforced earth walls. Elsewhere, at the abutment of the Corniche du Fleuve, the bridge lays over piers leaning against slabs transmitting their load through piles, the reinforced earth serving solely as retainement to the fill. Figure 5.

The maximum height of the reinforced earth wall is equal to 11.5m, of which at least 1m is for embedding, and the corresponding length of the high adherence galvanized steel strips is equal to 8m.

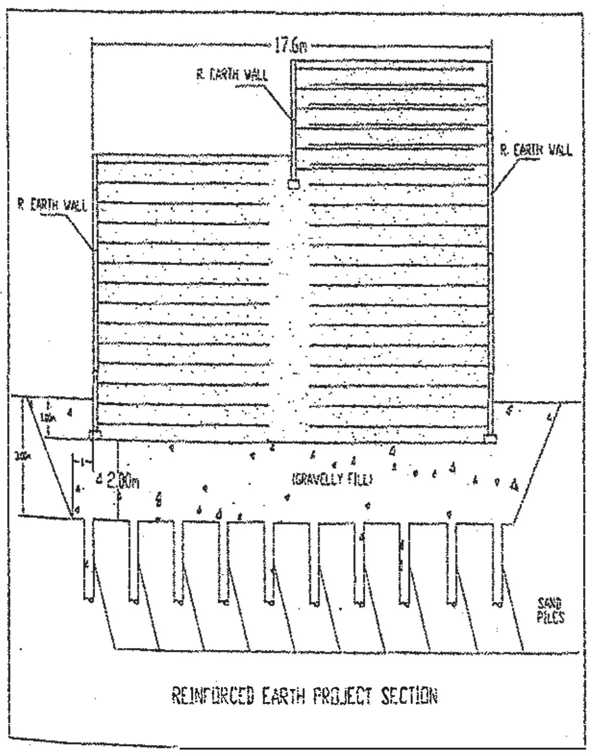

Figure 4. Reinforced earth project section.

4 GEOTECHNICAL STUDY

4.1 *Punching (Ultimate bearing capacity)*

The ultimate bearing capacity q_{ult} has been studied by means of the MENARD Pressuremeter method, the Menard limit pressures being calculated from :

$$Cu = Pl/10 \qquad (1)$$

The calculations show that the safety factor at punching is comprised between :

1.08 and 1.57 for section I.
0.60 and 0.92 for section II.
3.35 and 4.68 for section III.

This showed in a clear manner that it was necessary to improve the foundation soil below the reinforced earth walls,
- on one hand as to increase the previous factors
- on the other hand as to avoid the service settlements which are more important and as to accelerate the speed of these settlements.

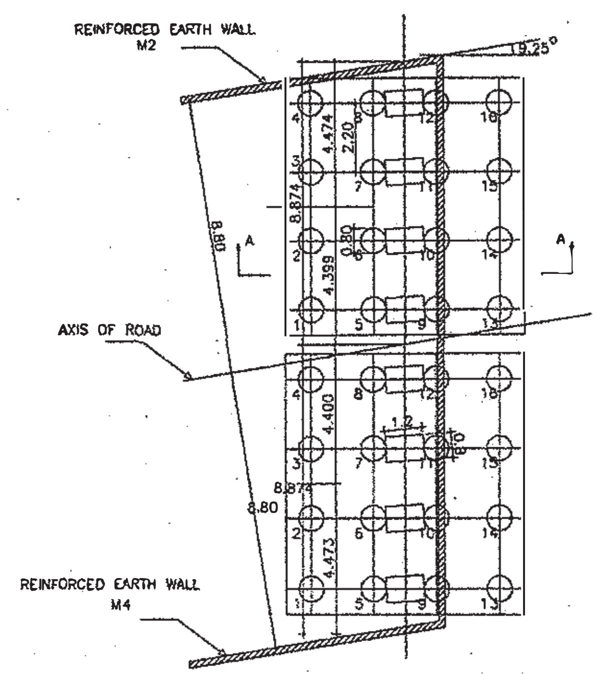

Figure 5. Abutment P1 foundation drawing.

As we will see hereafter the most suitable technique will consist of realizing sand drains and of substituting the superficial soil, till the water table level, by a well compacted, 2m thick, draining gravelly fill.

4.2 *Total settlement*

The total settlement has been computed by the method indicated by Menard.

This method has been preferred to that unidimensional consolidation of Terzaghi for the thickness of compressible layer is in the magnitude of the width of the width of the fill, which is very far from Terzaghi's hypothesis.

The carried out calculations have shown that:
- on one hand the settlement's preponderant values were those of spherical term; i.e, those induced by the exerted loads between the surface and 12m depth.
- on the other hand the total settlement in the Corniche du Fleuve-VARTAN road zone varied between 15 and 40cm according to where we stand respectively near to Vartan road or close to the Corniche du Fleuve.

4.3 *Consolidation period*

The settlement rate is defined from the time factor Tv given by the relation :

$$Tv = Cv\, t/H^2 \qquad (2)$$

Where H is the drainage distance.

H is being taken equal to 10m.

For a consolidation degree Uv of 70%, the time factor Tv given by TERZAGHI'S unidimensional consolidation chart is equal to 0.4.

From which $$0.4 = \frac{10^{-3} \times t}{(1000)^2} \qquad (3)$$

We derive t = 12 years.

4.4 *Acceleration of consolidation*

To accelerate consolidation it was thus necessary to provide a radial drainage by means of sand drains.

Supposing that the radial consolidation factor Cr is equal to Cv and choosing a 4 months consolidation period, the radial consolidation chart of BARRON shows that the radial consolidation degree Ur is equal to 70%, which can be obtained with 35cm diameter drains whose diameter of influence is of 2.5m corresponding to a 2m x 2m square lattice.

In these conditions the time factor Tv is equal to 0.01 which corresponds to a vertical consolidation degree Uv equal to 15%.

The global consolidation degree U is given by the relation (1-U) = (1-Uv) (1-Ur) from which U = 75%.

4.5 *Stability of great sliding*

We have verified the stability of sliding along a circle crossing the superficial layers and the reinforced earth fill.

The calculations have been conducted by TALREN with the characteristics and safety factors indicated on Figure 6. The minimum found Γ_{max} is 1.06 for short term characteristics of section II.

4.6 *Conclusions*

The analysis of the previous results shows that it was necessary :
- to foresee sand drains as to insure a radial drainage and to accelerate the consolidation.

For a four months period of consolidation, these 35cm diameter drains will be in the center of a 2m x 2m square lattice and will be at least 12m deep ; the plan of these drains is given on Figure 7.
- to substitute the surficial existing soil down to the water table level by another with better mechanical characteristics and which will be additionally draining. In principal, this excavation was of 3m depth, the substitution gravelly fill being of 2m thickness. See Figure 5.

5 SETTLEMENTS OBSERVATION

The settlements have been followed on eight benchmarks of which four between the VARTAN road and the BADAOUI passage.

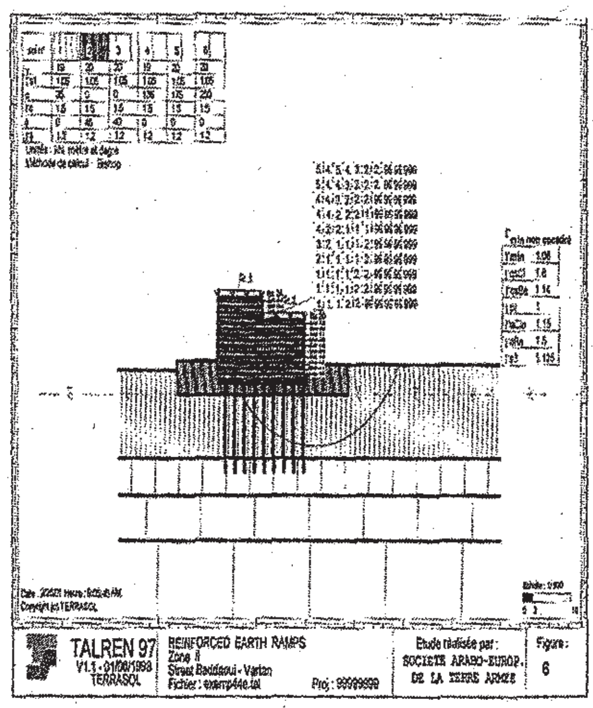

Figure 6. Stability verification by TALREN.

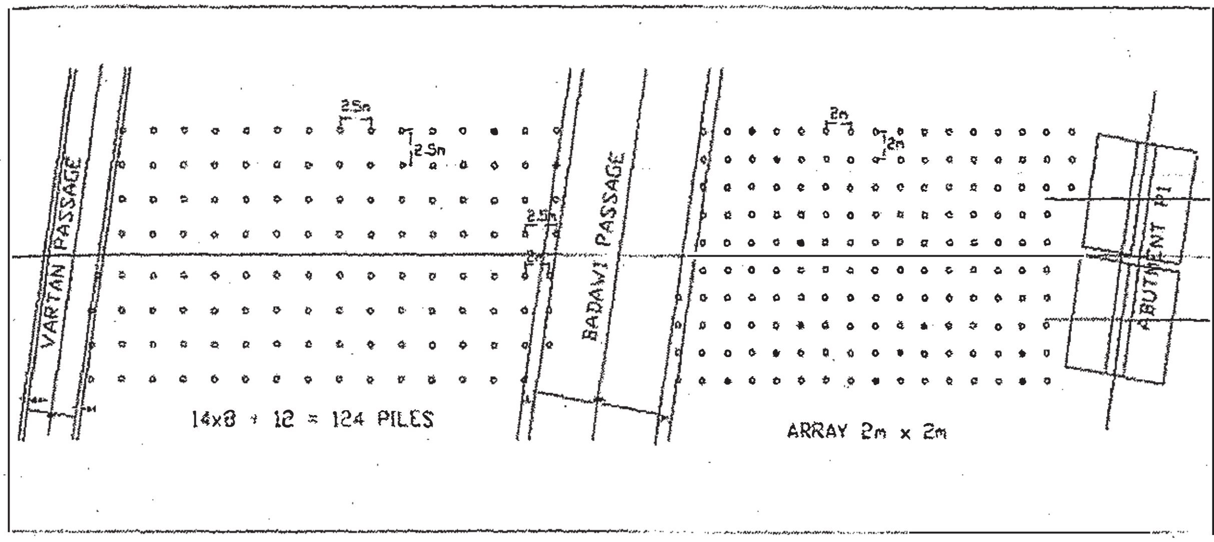

Figure 7. Drawing of the 281 piles of sand.

In this last zone the total settlements having been limited to about ten centimeters at the end of construction, we have stopped their readings and we were interested to follow those obtained in the zone between the BADAOUI passage and the Corniche du Fleuve where the amplitude was by far greater.

On Figure 8 we give an elevation of the wall in this zone and we indicate the position of benchmarks C and E over walls 2 and 4.

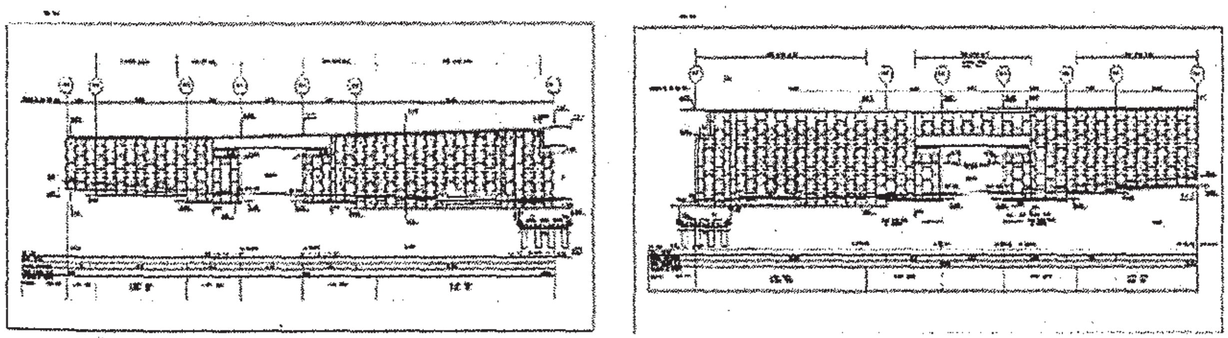

Figure 8. Elevation of the wall.

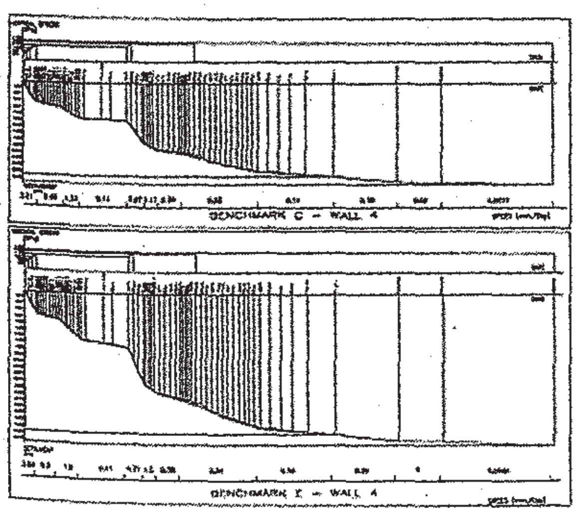

Figure 9. Settlements observation on wall 4.

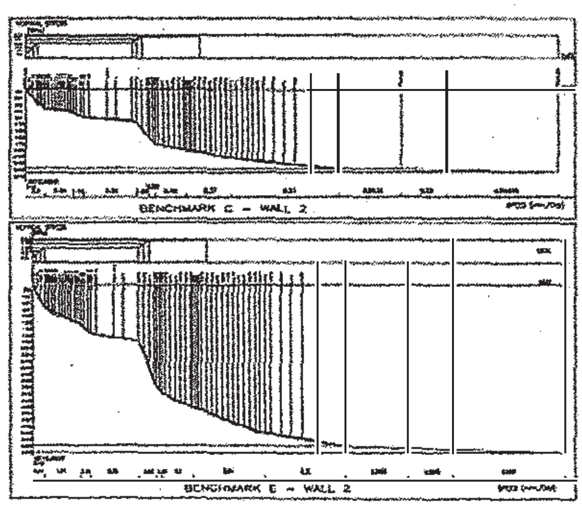

Figure 10. Settlement observation on wall 2.

Table 1. Total settlement and consolidation degree four months after load application.

Designation	Bench-mark	Settlement End of loading	Settlement four months after	Settlement 1,5 year after	U %
Wall 4	C	21.5	27.5	31.0	87
Wall 4	E	33.5	41.5	46.0	88
Wall 2	C	19.0	23.0	25.5	88

The settlements observation started on September 30 th, 1996 that is as early as the application of the first load and continued as indicated on Figures 9 and 10 during the construction of the structure, and over a one and a half year period after its completion.

These curves have shown the following:

- During the loading phase the settlement speed is comprised between 4.5 and 5.5mm/day at bench-marks presenting an important total settlement (E2 and E4) and is close to 3mm/day elsewhere.

However, once the load applied the settlement speed at benck-marks E2 and E4 is in the order of 1.5 to 2mm/day during two months and it drops by at least 0.5mm/day thenafter.

- The total loading of the soil is completed on May 20th, 1997, and the total settlement noted on that date was equal to 38.5cm (Bench-mark E, Wall 2); four months later it equaled 47cm and on September 1998 a final reading gave the value of 51.5cm.

The scrutiny of the settlement curve aspect on this mark E shows that we are practically at proximity of an asymptote that would be close to 52 cm for which the consolidation would be in practice terminated.

In these conditions, four months after the end of works, the degree of consolidation could be calculated as being equal to 47/52 = 90%, much better than the value foreseen by computation.

It is worth to note that at the level of the four bench-marks the total settlement four months after load application as well as the consolidation degree as calculated previously were as shown on Table 1.

It becomes evident that the calculated settlements in the most sensitive zone of the structure have values in the same order of that maximum obtained by computation; i.e. 40 cm, but on average the measured settlements are appreciably weaker than the calculated settlements.

This could not be otherwise for the calculated value has been obtained by means of correlations which, even standardized, cannot reproduce reality.

- The differential settlement obtained is in the order of 2 to 3%, a value ten times greater than accepted for reinforced concrete walls.
- The settlement having not led to any tilting of the wall nor to any spectacular fracture of the panels it has been held at wall top by a reinforced concrete beam.

6 CONCLUSION

The use of the reinforced earth has allowed in this project to solve a complex technical problem and to realize substantial savings by substituting foreseen deep foundations.

Once more if it were still needed to be proven the flexibility of this material and of the concrete panels of the dressed facing wall has permitted to bear important global and differential settlements and this without distinction between retaining walls and bridges' abutments.