EXPERIMENTAL VERIFICATION OF ANCHORED CURTAIN WALL

Vérification expérimentale d'un rideau ancré

by

A.J. da COSTA NUNES

Prof. of the Federal University of Rio de Janeiro - President of Tecnosolo S.A.

P.H. VIEIRA DIAS

Engineer - Division Chief - Tecnosolo S.A.

SOMMAIRE

Cette communication décrit une méthode d'évaluation expérimentale des conditions de stabilité d'une grande enceinte de construction ancrée en béton armé de plus de 20 m de profondeur. A la fin des travaux, le « rideau » a montré des déplacements horizontaux atteignant plus de 25 cm. Les essais des ancrages avec cinq reprises de précontrainte permettent de déduire les diagrammes de poussées des terres sur les rideaux et la sécurité de la construction. Les caractéristiques du sol compatibles aves les charges imposées ont été déterminées indirectement et comparées avec les valeurs utilisées dans le calcul. Les facteurs de fluage des ancrages ont été inférieurs à 0.5 mm, se situant bien en dessous de la valeur de 1 mm considérée comme convenable pour un terrain sableux par les Normes Brésiliennes.

SUMMARY

The paper decribes a method to evaluate experimentally the stability conditions of anchored, reinforced-concrete, retaining walls. In the case presented the curtain walls were constructed to contain an excavation of more than 20 meters in depth. Prior to construction, the convenience of installing instrumentation to monitor the behaviour of the anchorages was not considered. In view of wall movements occuring, it became necessary to perform additional studies. Described here is a technique to determine experimentally the earth pressures exerted against a curtain wall that has not been instrumented. At the same time the limiting loads and the relaxations of the anchorages are determined. With these elements, applying the safety factors defined in Standards, it can be concluded that reinforcement of the structure is, or is not, required. The values of the parameters of the soils can also be determined indirectly, compatible with the pressures imposed, and compared with the values used for design.

INTRODUCTION

The project referred to here is an experimental verification of the stability of a large anchored excavation wall, more than 20 m high and with a perimeter of about 430 m. The excavation was made in residual soil, partially collapsible, for the new headquarters building of the Central Bank of Brazil, located in the Capital city of Brasilia.

The design of the wall was based on soil parameters obtained from laboratory tests made on undisturbed samples. Toward the end of the construction it was determined that the walls were moving and in particular one wall gave evidence of horizontal movement that reached 25 cm (more than 1% of the height), moving into the excavation (wall Nº 2).

Fig. 1. — **Photograph of the excavation and the anchored wall.**

Fig. 2. — **Photograph of the excavation and the anchored wall.**

To investigate the movement, the owner contracted with a consultant. As there was disagreement between the owner's consultant and the design engineer regarding the soil parameters used for design (cohesion *c* and friction angle ∅), the owner engaged the senior author to arbitrate the question. His suggestion to perform experimental verification of the anchorage loads was accepted by all parties concerned. The existing wall had not been instrumented.

METHODOLOGY

a) The residual loads in the anchorages were determined in two typical sections of each of the four walls by testing with a hydraulic jack and calibrated gage (Costa Nunes, 1966).

   Incorporation loads in the anchorages were then reduced to slightly less than the residual loads (about 5% less), and afterwards retested until the residual load increased between tests. The lower load, thus obtained was considered to correspond to the bearing pressures. The limiting load for each anchorage was also determined. This is the largest load applied for which the movements were still stabilized.

b) From the results obtained from testing 42 anchorages, and at least five re-post-tensioning tests each, diagrams of the existing pressures were obtained.

   As to the distribution of the earth pressures over the walls, these will closely approximate uniform distribution with the minimum pressures (always the highest anchorages) varying about 20% from the average pressures.

c) These diagrams were increased by the influence of the surcharge to be placed in the future behind the wall, and compared with the limiting loads of the anchorages that were also determined experimentally, considering also relaxation loads. The necessity of reinforcing the walls was determined. Using the safety factors of 1.75 fixed by Brazilian Standards (NB-565) for permanent anchorages. Consequently, three of the four walls were reinforced ; the maximum increase was 13% over the capacity of the anchorages for wall N° 2, which had suffered the undesirable movement (see table I).

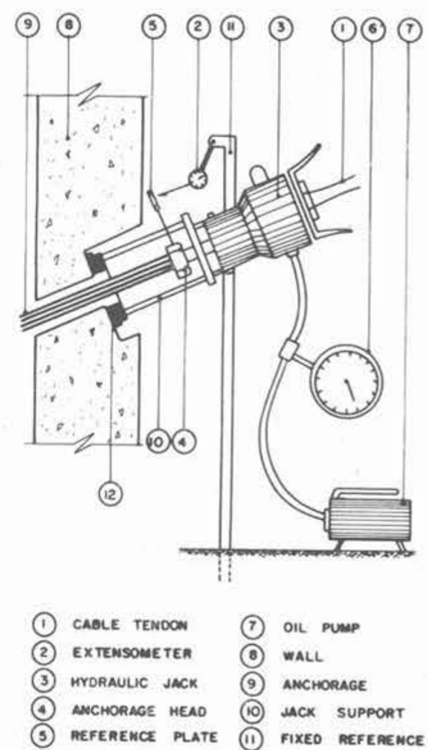

Fig. 3. — **Diagram of the test set-up.**

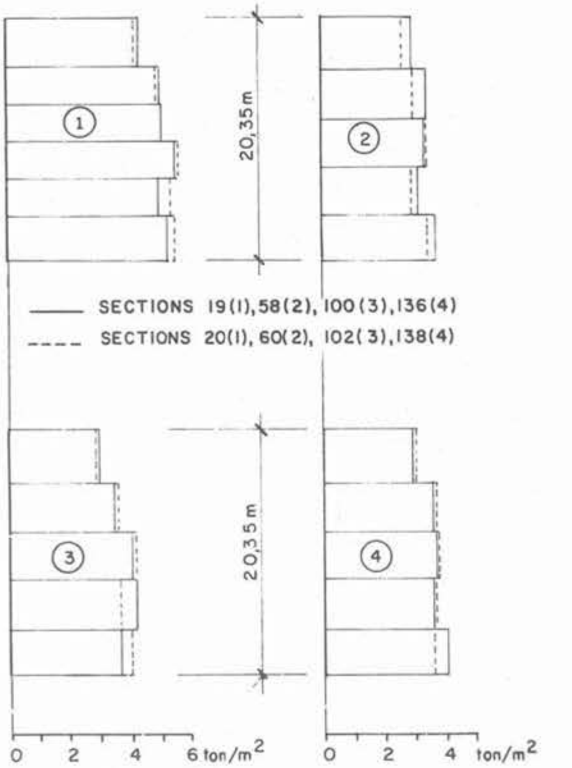

Fig. 4. — **Diagrams of acting pressures ; the numbers in the circle identify the walls.**

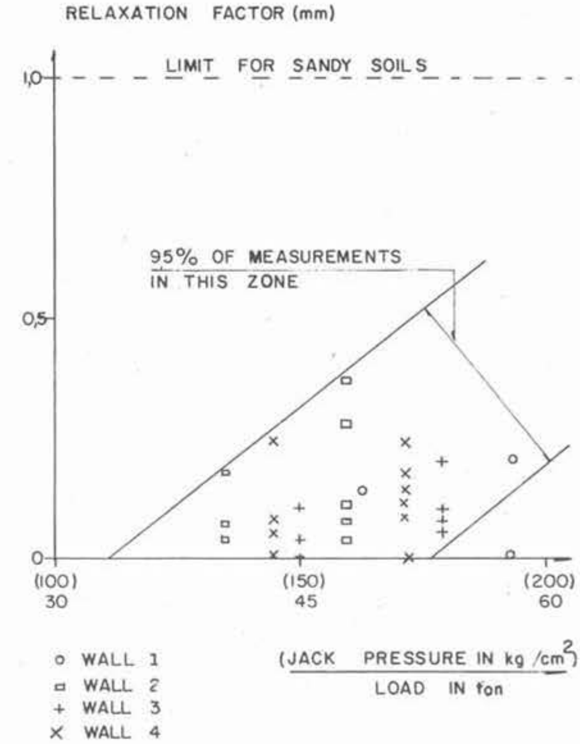

Fig. 5. — **Graph of load vs relaxation factor.**

d) The relaxation factors of the anchorages were always less than 0.5 mm, well below the value of 1.0 mm, considered as adequate for sandy soils by the Brazilian Standards. The German Standard, DIN 4125, allows values of 2 mm, for any soil. It is observed that the relaxation factors were determined for loads between 40 and 60 tons.

ANALYSIS OF REINFORCEMENT REQUIRED

The sequence of calculations used for each wall, considering the average loads in the anchorages, is the following:

a) Determination of C_a (minimum residual load, determined experimentally) ;

b) Determination of the increase of loads C_s, caused by the surcharge ;

c) Determination of the load $C_a + C_s$;

d) Determination of the limiting test load, 1.75 $(C_a + C_s)$, necessary ;

e) Determination of the limiting test load C_1, experimentally ;

f) Verification of the necessity, or not, of reinforcement, comparing the loads from items d) and e):
- if $1.75\ (C_a + C_s) \leqslant C_1$, reinforcement is not necessary ;
- if $1.75\ (C_a + C_s) > C_1$, we pass to the following step ;

g) Calculation of reinforcement necessary, in percentage:

$$\left[\frac{1.75\,(C_a + C_s)}{C_1} - 1\right] \times 100\ ;$$

The calculated values are presented on table I.

TABLE I

Summary of calculated anchorage loads and wall reinforcement necessary
(loads are in ton)

WALL	1	2	3	4
a) C_a	48.9	37.0	42.1	41.1
b) C_s	—	3.0	3.0	2.4
c) $C_a + C_s$	48.9	40.0	45.1	43.5
d) $1.75\ (C_a + C_s)$	85.6	70.0	79.0	76.1
e) C_1	82.7	62.2	72.5	70.8
f) compare *d* to *e*	>	>	>	>
g) reinforcement required (additional capacity)	3%	13%	9%	7%

INSTRUMENTATION

As the project schedule already had been substantially delayed it, was undesirable to interrupt the construction while performing the investigation or necessary reinforcement of the wall. It was resolved, therefore, to instrument the wall and to continue with construction, providing an alarm system for any eventuality. The instrumentation included mechanical cells of the «Interfels plates» type and extensometers, as well as the method of re-post-tensioning that already had been used extensively, all of which accompanied the changes in actual loads bearing on the anchorages before, during, and after execution of reinforcement.

The instrumentation confirmed as correct the reinforcement measures previously recognized, and indicated the necessity of the removal of the surcharge of construction materials that had been stored next to the walls.

RECALCULATION OF THE EARTH PARAMETERS

Although beyond the study objectives, the results permit the determination of values of the parameters *c* and ∅, once the unit weight is known, as well as the distribution of earth pressures over the walls. Table II summarizes the values of *c* and ∅ and the coefficient of active horizontal earth pressure K_{ah}.

TABLE II

Summary of values of *c*, ∅ and K_{ah} computed from load tests (cohesion in t/m^2)

∅	10°	15°	20°	25°
K_{ah}	0.97	0.65	0.51	0.40
wall 1	6.44	4.24	2.99	1.78
2	7.40	5.40	4.30	3.26
3	7.17	5.12	3.99	2.91
4	7.21	5.18	4.05	2.98
		c values		

It was verified that the induced values of *c* and ∅ were clearly less than some of those obtained from laboratory tests on undisturbed samples.

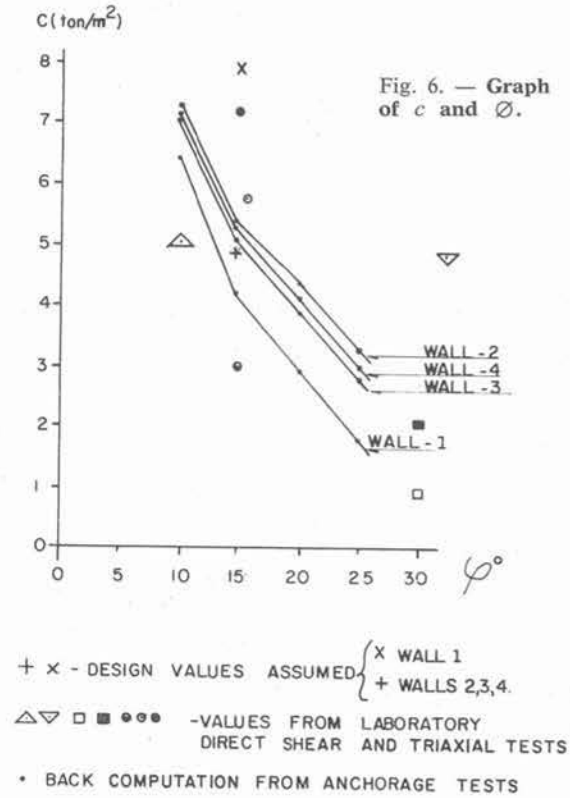

Fig. 6. — **Graph of *c* and ∅.**

CONCLUSIONS

In the opinion of the authors, the method of re-post-tensioning, in the absence of a representative number of instrumented anchorages, offers the possibility of determining the approximate distribution of earth pressures acting on anchorage curtain walls and the factor of safety of the construction.

REFERENCES

COSTA NUNES (A.J.). — «Slope Stabilization. Improvements in the techniques of prestressed anchorages in rocks and soils», Proceedings of the First Congress of the International Society of Rock Mechanics, Lisboa (LNEC), Portugal, Vol. 2, pp. 141-146 (1966).

COSTA NUNES (A.J. da) and VIEIRA DIAS (P.H.). — «Some Results from the Systematic Verification of the Load Capacity of Anchorages», 10th Brazilian Congress on Large Dams, Curitiba, Brasil (1975).

COSTA NUNES (A.J. da). — «Performance of Deep Excavations», Panel Discussion, 5th Pan-American Conference on Soil Mechanics and Foundation Engineering, Buenos-Aires, Argentina (1975).

DIN 4125. — Verpressanker für verübergehende Zwecke-Bemessung, Ausführung und Prüfung. Deutsche Normen. Der Tiefbau Ingenieur Strassenbau (11) : 973-980 (1969).

DIN 4125. — Erd, und Felsanker Verprebanker für dauernde Verankerungen (Daueranker) im Lockergestein. Bemessung, Ausfuhrung und Prüfung. Deutsche Normen. Teil 2 (1976).

HABIB (P.). — «Anchorages, especially in soft ground», Proceedings of the Seventh International Conference on Soil Mechanics and Foundation Engineering, Mexico, Vol. 3, pp. 513-516 (1969).

NB-565. — Brazilian Standard 565, «Anchored Structures», ABNT, Rio de Janeiro (1976).