08 May 1984, 8:00 am - 10:00 am

Load Measurements of an Anchored Retaining Wall

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SYNOPSIS Thirty six anchors, corresponding approximately to five per cent of the total anchors of a retaining wall, were instrumented using electrical load cells, aiming to study the variation of the applied load with time associated with the sequencing of construction. It was observed that the average total loss was 25% of the average applied load, which consisted of three major component: rapid loss; long term loss and loss due to adjacent anchors loading.

INTRODUCTION

In the thirties a major railway was built connecting São Paulo to Santos, crossing the "Serra do Mar", which is caracterized by abrupts scarps and irregulars slopes. Along its length included into the "Serra do Mar", the railway runs predominantly in tunnels, viaducts and man-made fills . At the 74th km a huge man-made fill was built with a length of 250 m using materials from a near borrow area.

Due to a heavy rainfall combined with the local topography, which imposes serious difficulties for designing an efficient superficial drainage system, the man-made fill has been subjected during this period to a very severe erosion , narrowing the railway support basis and endangering its stability condition. In view of this problem and the planning for duplication of the railway line, the need of a new project was considered. Among several alternatives it was decided to build an anchored retaining wall.

GEOLOGICAL AND GEOTECHNICAL ASPECT

Typical subsoil profiles based on standard penetration tests and rotary drillings are presented in Figure 1. The man-made fill, built with materials from a near borrow area, consists of micaceous silty-sand with fragments of rocks . Standard penetration tests showed values between 2 to 5 blows for the last 0.3 m penetration, indicating an average loose state of denseness. The designers, based also in laboratory testing, have adopted values of 33º for the effective friction angle; 0.5T/m² for the cohesion and 1.65/m³ for the unit weight.

Beneath the fill there is an intermixed heterogeneous mass consisting basically of a gravelly sandy silt. The upper part of this layer consists of colluvial deposits and the lower part consists predominantly of residual soils. Average values for the effective friction angle; cohesion and unit weight, have respectively been adopted by the designers, as : 35º; 2.0T/m² and 1.75T/m².

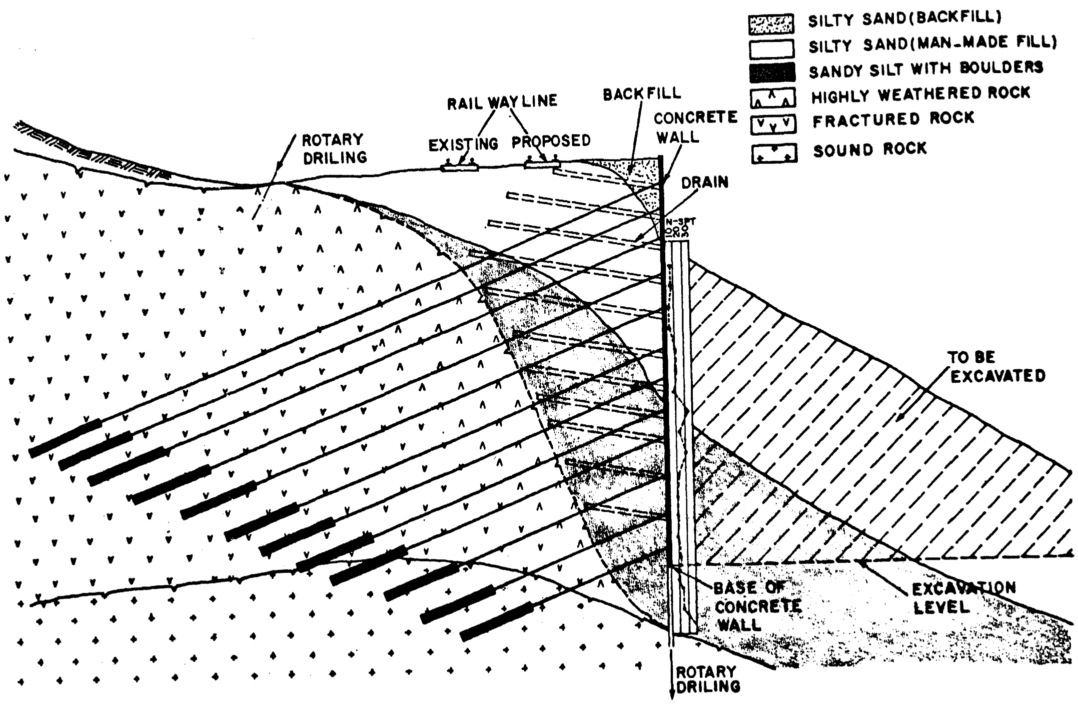
The rock mass consists of a Pre-Cambian gneiss which presents a high degree of weathering and a complex pattern of discontinuities filled with residual or transported materials. For the first 9 to 10 m the R.Q.D. (rock quality designation) indicated values between 0 to 25%. The degree of weathering decreases with depth, values of 90 to 100% for the R.Q.D. were found for depths bellow 30 m from the rock surface.

The static water table was not found at the site.

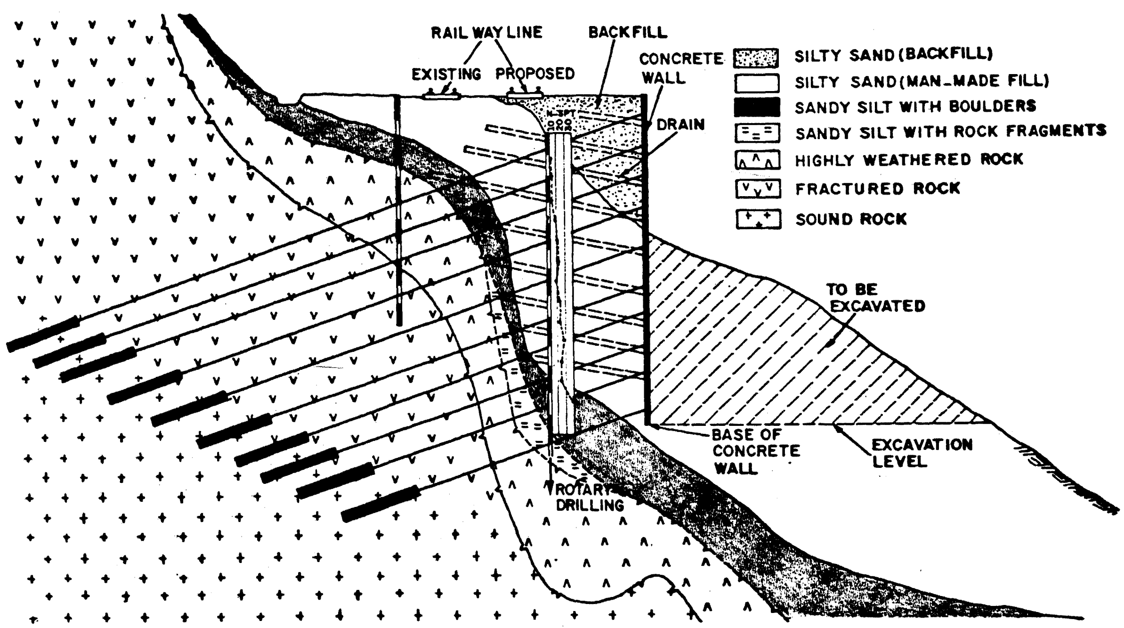
STRUCTURAL GEOMETRY AND CONSTRUCTION SEQUENCE

The anchored retaining concrete wall has a thickness of 0.35 m; a total length of approximately 205.0 m and a depth in relation to the railway line level of 19.0 m at the centre part,reducing in a discontinuous stepped fashion towards the extremities to 1.0 m at the right corner and 2.75 m at the left corner, see Figure 2. It has six vertical expansion joints and one continuous horizontal expansion joint (between F and G horizontal rows) along its entire length separating the top and botton panels. To support the retaining wall a total of 786 anchors were used, corresponding to 89 columns, 12 rows of anchors (centre) and 1 and 2 rows of anchors (right and left corners, respectively). The location of the anchors can be identified by a number,indicating the column (1 to 89) followed by a letter representing the row level (A to L), see Figure 3.

The anchors are inclined 20º in relation to the horizontal, have a fixed anchor length of 6.0 to 5.0 m and a free anchor length varying from 7.0 m (lower row) to 25.0 m (upper row). In many cases, the specified anchor free length has been shortened due to a presence of a better quality rock mass detected during the anchor hole drilling. The drilling system consisted predominantly of a rotary-percussive machine, using both normal water circulation and compressed air method to remove the drilling spoil materials.It was local practice to use, in proportion of aproximately 10 to 1 boreholes, a rotary drill system with sampling, to provide a qualitative assessment of the ground condition. In both systems the anchor hole diameter was 76,2 mm(3"). Along the soil strata and the highly weathered rock mass, it was necessary to case the borehole to avoid collapsing. The casing was withdrawn



1.A- SECTION M-M (SEE FIG.2)



1.B- SECTION N-N (SEE FIG.2)

FIGURE 1 - GEOLOGICAL-GEOTECHNICAL ASPECT AND STRUCTURAL GEOMETRY OF WALL

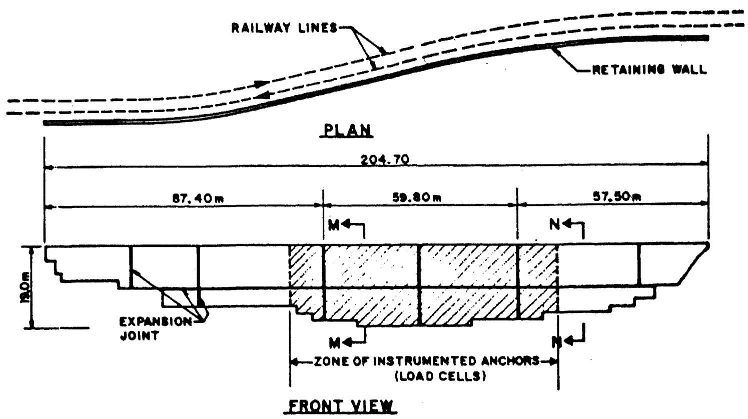


FIGURE 2 - LAYOUT OF THE ANCHORED RETAINING WALL

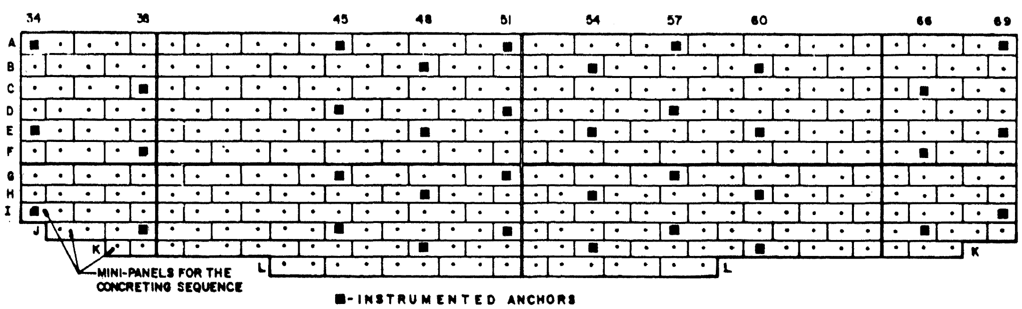


FIGURE 3 - LOCATIONS OF LOAD CELLS

immediately before the anchor tendon installation. The anchor tendon was formed of wires with 8.0 mm in diameter and having a specified ultimate tensile strength of approximately 150.0 kgf/mm² and an yeld stress of 135,0 kgf/mm², with protective polypropylene sheath over the free anchor length. Tendons composed of 10 and 8 wires were used corresponding respectively to anchors with 35 T and 25 T design load, see Figure 6.

The primary grouting of the fixed anchor length was carried out using the "tube à manchete" technique. After loading the anchor, a secondary grouting, using a neat ciment grout, was applied in the free length for protecting the tendon against corrosion. Two types of multi-wire anchorage head assembly, bearing against load distribution plates, were used: head with a supporting ring screwed over it and head with gripping wedges.

Figure 4 shows the construction sequence used for the excavation (1: cut; 2: anchor hole drilling, tendon installation and primary grouting; 3: mini-panel concreting and 4: anchor loading and secondary grouting) and backfill (1: anchor hole drilling, tendon installation and primary grouting; 2: mini-panel concreting; 3: backfilling and compaction and 4: anchor loading and secondary grouting). In both systems the mini-panels were 1.5 m or 2.0 m high and 4.5 m long, including two anchors per unity and connected together forming large panels separated by the expansion joints, see Figure 3.

INSTRUMENTATION AND RESULTS

The instrumentation consisted of electrical strain gauge load cells mounted at the head of selected anchors aiming to study the variation of the applied load with time. Thirty six anchors were instrumented, corresponding approximately to five per cent of the total anchors of the retaining structure.

The load cells used were developed at Civil Engineering Department of the Catholic University - Rio de Janeiro (Rocha Filho, 1979) consisting basically of a hollow cylinder element with tappered enlarged top and botton bases. Resistance strain gauges mounted in T-shaped pairs diametrically spaced and connected in a

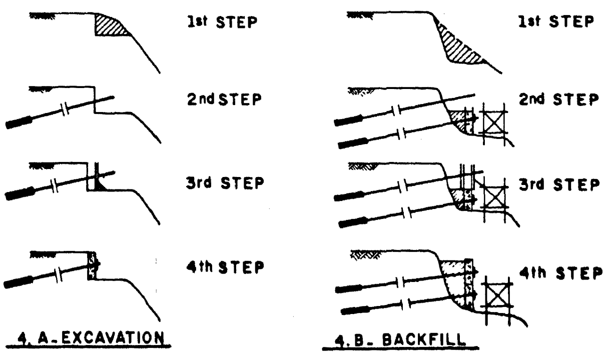


FIGURE 4 - CONSTRUCTION SEQUENCE

temperature-compensated Wheatstone Bridge circuit, were bounded to the aluminium columnar element. A protective outer casing with water-proof outlet socket and pressing against "O" rings at the top and bottom base of the cells, encloses the engauged core. Each load cell was carefully calibrated in the laboratory, with particular attention to long term stability and to effects caused by eccentric loads and shear strains and checked at the time of installation against the jacking load. Figure 3 presents the location of the load cells, which were indicated by the contractors and Figures 5.A to 5.K show the results of the applied load variation with time.

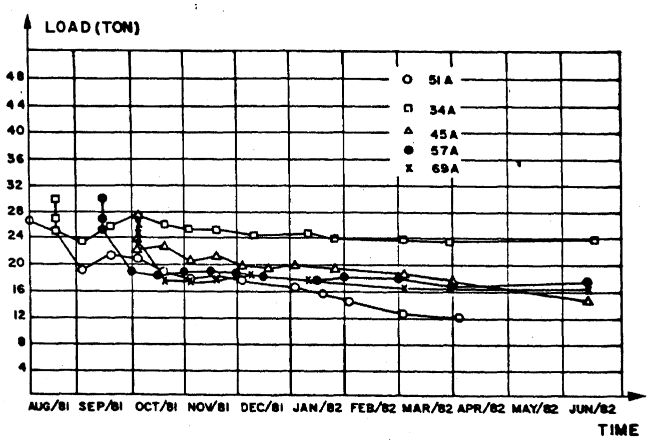


FIGURE 5.A - ANCHOR LOAD VERSUS TIME - LEVEL A

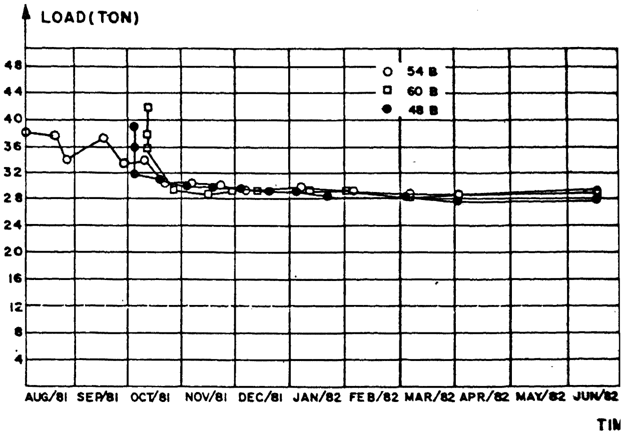


FIGURE 5.B - ANCHOR LOAD VERSUS TIME - LEVEL

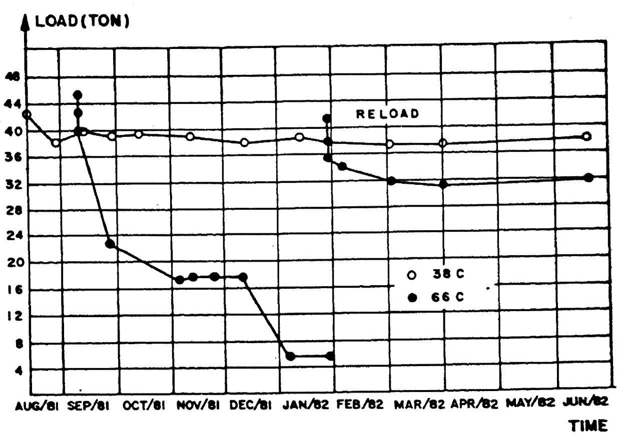


FIGURE 5.C - ANCHOR LOAD VERSUS TIME - LEVEL

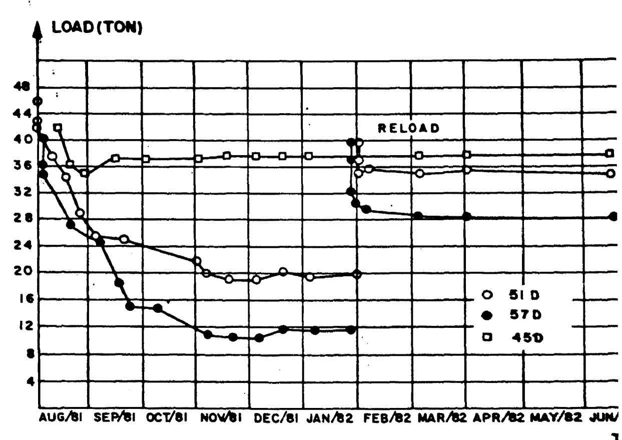
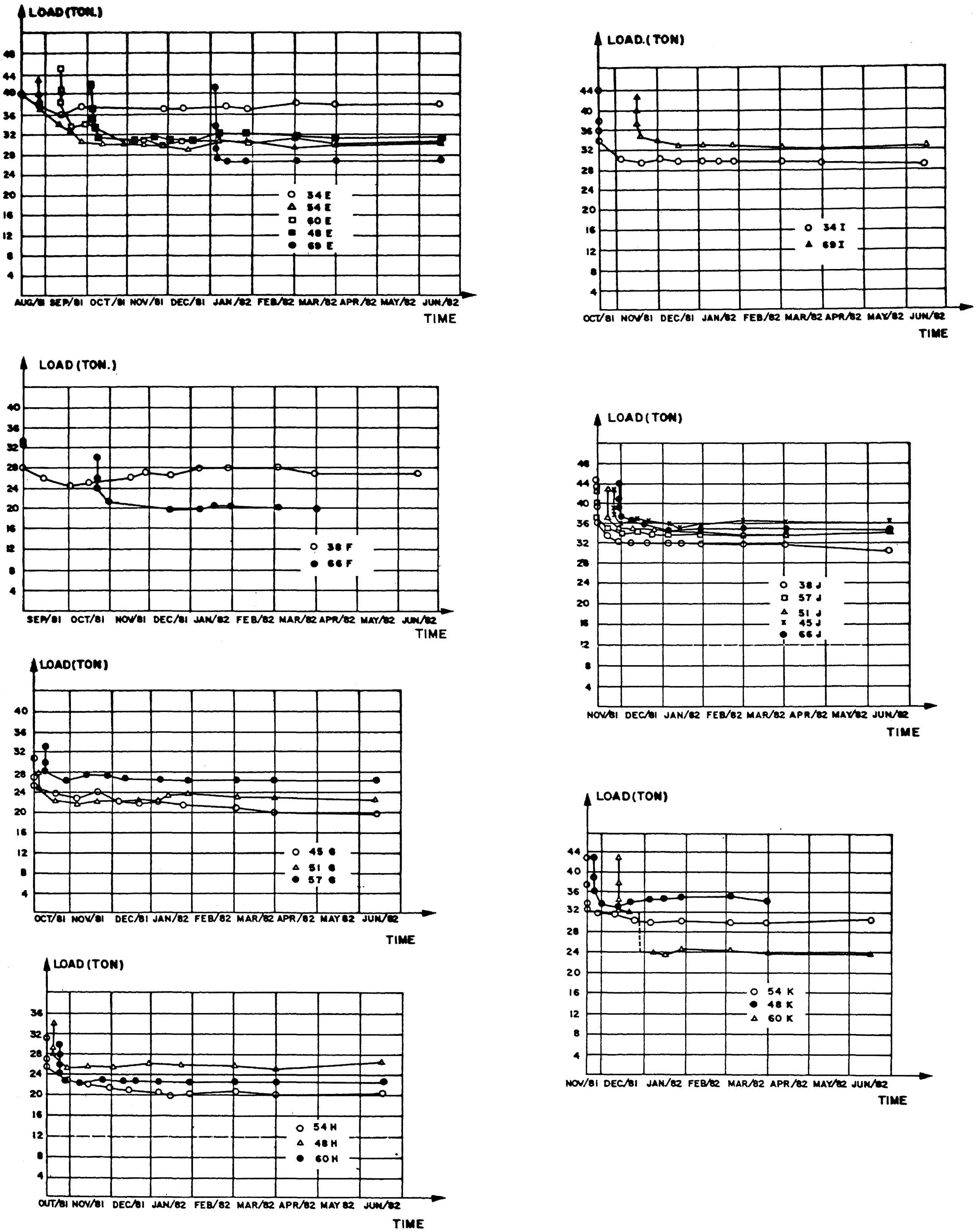


FIGURE 5.D - ANCHOR LOAD VERSUS TIME - LEVEI



FIGURES 5.E TO 5.K - ANCHOR LOAD VERSUS TIME - LEVEL E TO K

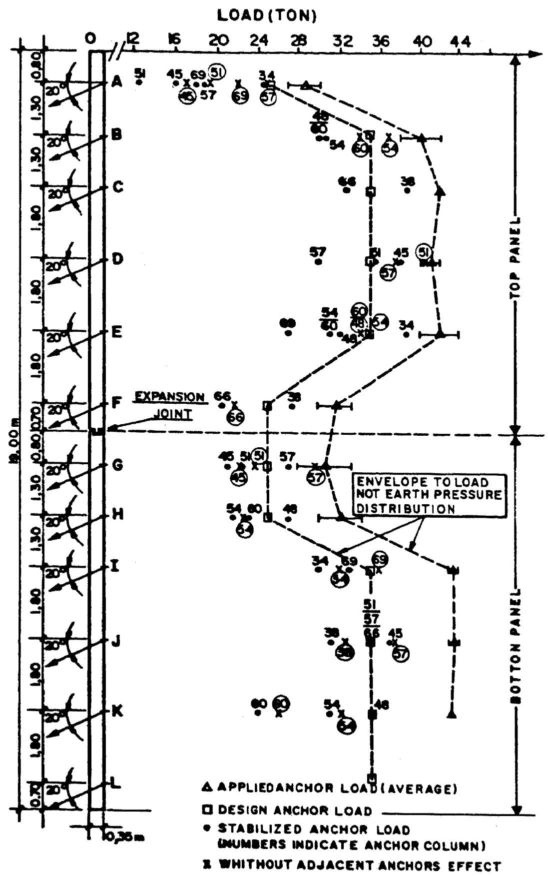


FIGURE 6 - APPLIED AND STABILIZED ANCHOR LOAD

ANALYSIS OF RESULTS

Load cells readings were taken at short period of time after lock off; at regular intervals and before and after each major step of the construction sequence.

It was observed that the average total loss was 25% of the average applied load; highest value corresponding to anchor 51A - 53% and lowest value corresponding to anchor 34E - 6.0%, see Figure 6. Three major components contributed for the total loss of the applied load: a) rapid loss = 55%; b) long term loss = 28% and c) loss due to loading of adjacent anchors = 17%. Influences of other technical occurrences associated to the sequencing of construction such as excavation, backfilling, panel concreting, etc, were difficult to be quantified, however, it is believed that components b and c may be increased, respectively to a small and great extent, by such effects.

The component b which could be associated to creep effect may also be predicted using values of creep coeficient determined from anchors load testing, as follows:

$$\Delta F = E_T \times A_T \quad (K_s \times \log \frac{T_2}{T_1} + \delta w)/l_f$$

where ΔF is the loss of load due to creep effect; E_T is the Young's Modulus of the tendon (21.000.00 kgf/cm^2); A is the tendon cross sectional area (402.4 mm^2 and 503.0 mm^2, respectively 8 and 10 wires of 8.0 mm diameter); l_f is the free tendon length; T_1 is a reference time (adopted as 30 mim); T_2 is the necessary time for the anchor load stabilization; K_s is the creep coeficient and δw is the wall movement. Average values determined from two anchor load testing, corresponding respectively to 25T and 35T (design loads) were 0.68 mm; 1.16 mm (K_s) and 0.1 mm; 0.12 mm (δw). Using this formulation it was found that the predicted long term component was 41% of the total loss of load and approximately 40% of the total anchors agreed reasonably with the measured values.

The design anchor loads indicated in Figure 6 were based upon the active earth pressure assumption due to the weight of soil plus a surcharge related to live load, which indicated a final lateral resultant consisting of 56% and 44% of the soil and train components, respectively.

The consideration of this surcharge component could have imposed a total acting pressure higher than the soil reaction corresponding to the at rest condition. Hence, even considering the absence of measurements of the lateral wall movements it is believed that the adopted design anchor loads imposed backward movements of the retaining structure establishing a new equilibrium by reducing the anchor loads and increasing the soil reaction due to partial mobilization of the passive earth pressure.

Load cells readings were also taken with a "full load" train purposely stopped at the site with no indication of any anchor load increase. This fact could also be an indicator of the conservativeness of the design assumptions. It should be emphasised that the average total loss was approximately 10% of the average design load. This fact raises a question about the considerations of live load regarding the design of anchored retaining wall.

REFERENCES

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ACKNOWLEDGEMENTS

The authors are grateful to the Railway Company of São Paulo (FEPASA) for giving permission to use the date to prepare this paper. They also wish to express their appreciation for the critical review of the original draft and valuables contributions by their collegues Dr. L.V. Medeiros and Dr. E.A. Vargas Jr.