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Estimation of the bearing capacity of the Lahar in San Jose city, Costa Rica, using PMT testing, for the foundation of buildings over 50 m in height.

Estimation de la capacité de support du lahar dans la ville de San José, Costa Rica, par des tests PMT, afin de construire des bâtiments de plus de 50 mètres de hauteur.

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ABSTRACT: The population growth in the metropolitan area of San José, capital of Costa Rica, has fueled the development of medium rise residential buildings (over 50 m high). From the geological point of view in this area there are superficially sandy silt and clayey silt soils are typical found in thicknesses ranging from 10 m to 20 m. These upper soils have an allowable bearing capacities ranging from 50 kPa to 300 kPa. Below these upper soils, the lahar is detected, which is a mixture of soil and fragmented rock (boulders), tipically ranging from centimetric to decimetric in size, but boulders sizers of more than one meter in diameter has been found, which made the geomechanical characterization was very tricky with traditional methods of exploration (DMT, CPT and SPT inclusive). This lahar is also known as debris flow, and it is suitable for the foundation of these structures of more than 50 m in height.

In the past there no geotechnical tools proper exploration to able to characterize this lahar. Never the less with the use of the pressuremeter (PMT), the allowable bearing capacity of the Lahar can be estimated properly, which varies between 400 kPa and greater than 1000 kPa. The latter has provided to structural engineers accurate information for foundation design.

RÉSUMÉ: La croissance de la population dans le centre de la ville de San José, capitale du Costa Rica, a provoqué le développement des bâtiments en copropriété de plus de 50 mètres de hauteur. Dans cette région, il existe en superficie des sols limoneux sableux et limoneux argileux de 10 mètres à 20 mètres d'épaisseur. Selon les essais DMT et CPT déjà réalisés, cette strate a une capacité de support admissible comprise entre 50 kPa et 300 kPa. En dessous de cette strate, il se trouve le lahar qui s'agit d'un mélange du sol et des blocs des roches de tailles centimétriques à décimétriques, et dans certains secteurs de blocs de plus d'un mètre de diamètre. Ce lahar est apte pour la création de ce type de structure de plus de 50 mètres de hauteur.

Avec l'utilisation du pressiomètre (PMT), on a fait une estimation de la capacité de support acceptable du lahar qui varie entre 400 kPa et plus de 1000 kPa, ainsi que d'autres paramètres géomécaniques. Ce dernier a fourni aux ingénieurs en structure des informations précises sur la conception des fondations.

Keywords: Bearing capacity; Lahar; Pressuremeter; Soils; In situ test.

1 INTRODUCTION

At least 15 or 20 years ago, a traditional soil study in Costa Rica with DMT, CPT or SPT was sufficient to design the buildings required in the country, since the structures in general were relatively low (less than 55 meters high), with shallow foundations practically, and in some cases deep foundations such as piles or micropiles were required. However, at present this condition changes, due to the type of structures required at this time.

In order to take advantage of the reduced spaces in the capital, the development of condominium buildings of more than 50 m in height (60 m to 100 m), has been fundamental to supply the great housing demand in the central and eastern sector of San José province (Metropolitan area). That structures require several stories of basements, which can be used as parking spaces, and as a space for the placement of the electromechanical systems of these buildings. Because of the above, these buildings require foundations displaced at greater depth.

However, local geology offers very heterogeneous soils in small areas, which is why an adequate exploration is essential to determine the bearing capacity of the soil and subsoil layers, for the development of any construction project.

2 AREA OF INTEREST

The projects reviewed are located in the cantons of San José Central, Montes de Oca, Curridabat, Goicoechea and Tibás, as shown in figure 1. These projects are mainly made up of residential buildings, as well as commercial and government buildings, which, due to their design, were planned to be found on the lahar, or in a layer of soil close to the contact with this geological formation.

In the figure 1, the red dots indicate the location of the sites where the tests were made.

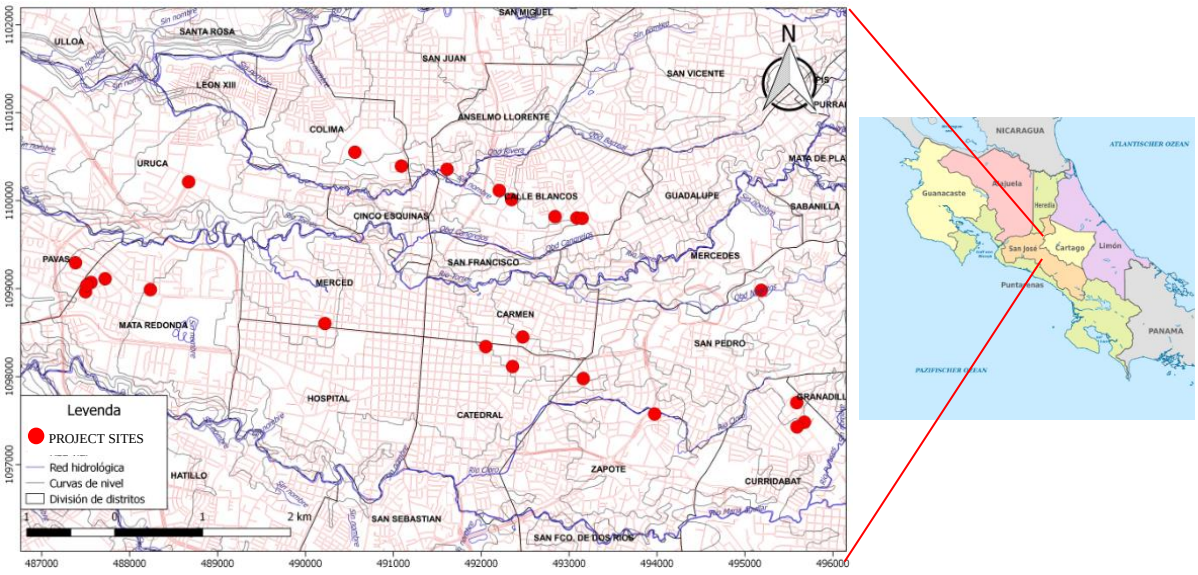


Figure 1. Map with the location of the projects in the study area.

3 LOCAL GEOLOGY

The formation of the Central Volcanic Mountain Range during the Pleistocene-Holocene caused depressions, where, due to the erosion, removal and transport of recent volcanic products, materials such as mud and ash avalanches accumulated, generating a "filling" of large areas in what is now known as the Central Valley of Costa Rica.

In the Cenozoic period, lahars were formed in the Central Valley, underlies the superficial layer conformed by very fine weathered pyroclastic deposits (ashes), of variable thickness between 10 m and 20 m. The lahars are constituted by a matrix of clays, silts and sands, which include lithic fragments of all sizes, type and shape, badly cemented and chaotic, with an approximate thickness of 60 m (Madrigal, R, 1966).

The figure 2 shows a profile of the study area with the soil layers detected.

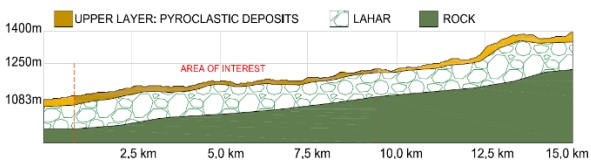


Figure 2. Soil profile of the interest area.

In figure 3, the recovery of soil and lahar samples is appreciated by means of the rotary drilling system in one of the study sites.

Figure 3. Recovery of lahar samples by means of the rotary drilling test.

In addition, this geological formation is very clearly detected with MASW geophysical tests, which shows an increase in the shear wave velocity (vs) from upper layers between 200 m/s and 350 m/s, to shear wave velocities (vs) greater than 450 m s in the lahar. In figure 4 it is clearly observed in dotted line, the contact with the lahar in two of the analyzed projects.

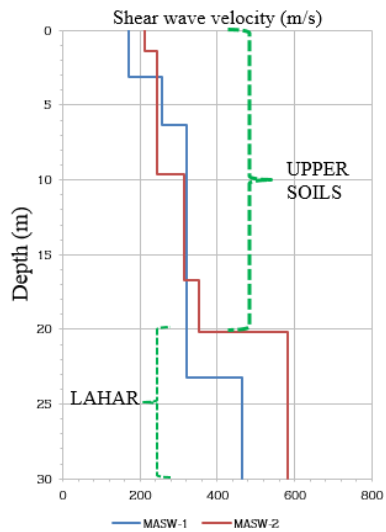


Figure 4. Results of MASW geophysical tests.

4 GEOTHECNICAL EXPLORATION STRATEGIES

4.1 Geotechnical characterization on upper soils

In all the study points, dilatometer tests (DMT) were carried out to characterize the superficial soils up to the depth of contact with the lahar. It was determined that sandy silts and clayey silts predominate, typical of volcanic deposits (very fine weathered pyroclastic deposits) in the area. Figure 5a shows some examples of Material Indexes (ID) obtained from DMT tests, from different project sites in the East of the study area, while Figure 5b shows Material Indexes (ID) of the West zone analyzed.

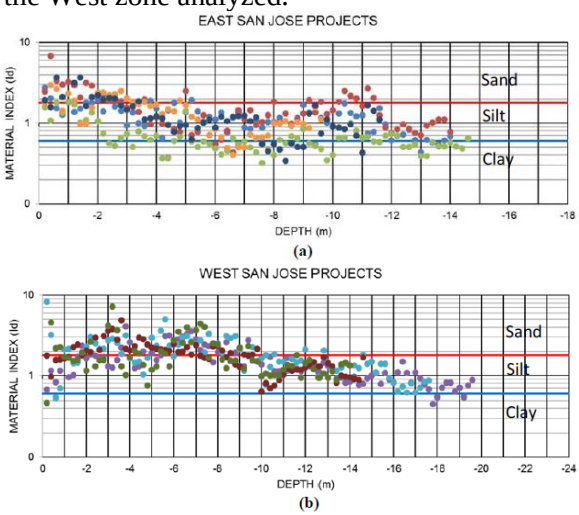


Figure 5. Description of the upper soils according to the DMT Material Index.

As can be seen in figure 5a, at the eastern sector clayey silts predominate from 3,0 meters up to the depth of contact with the Lahar. At the west sector (figure 5b) sandy silts predominate up to 10-13 m deep, followed by clayey silts until contact with the lahar.

4.2 Characterization of Lahar

Once the depth of contact with the lahar was determined, rotary drilling were carried out to insert the pressuremeter probe and perform the PMT tests.

In figure 6, are appreciated the different components of the pressuremeter equipment (TEXAM) used in the tests.

Figure 6. Detail of the PMT equipment used in the tests.

The PMT probe is inserted into a pre-excavated hole, the probe is inflated in series of equal volume increments (Method B), it exerts a uniform radial pressure on the soil by contact with the walls of the perforation, thus obtaining pressure - deformation curves. The pressuremeter test is essentially an in situ load test carried out inside a borehole.

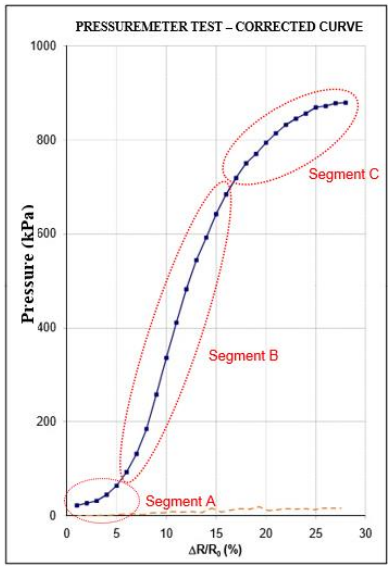
The preparation of a quality borehole is a very important step in obtaining a satisfactory pressuremeter test (Briaud, J.L., 1992). The tolerances on the borehole diameter are:

$$1{,}03D_p \leq D_i \leq 1{,}20D_p \quad (1)$$

Where D_p is the diameter of the deflated PMT probe, and D_i is the initial diameter of the borehole.

From the pressure and volume data, a tension strain graph is constructed, from which the necessary parameters for the calculation of bearing capacity presented in this study are extracted, in addition to other important parameters for the design of any structure.

Next, graph 1 shows an optimal curve resulting from one of the PMT tests.



Graph 1. Corrected curve obtained from the PMT test.

As shown in the previous graph, three well-defined curve segments are drawn:

• Segment A: It allows defining the horizontal stress at rest (P_O).

• Segment B: The straight line identifies the range of elastic behavior of the soil. This segment defines the modulus of deformation of the tested material.

• Segment C: Indicates the range of plastic behavior of the soil. The charged mass enters a plastic state during which the deformation accelerates towards a complete point of failure, that is to say, the limit pressure (PL).

Once the initial pressure (P_O) and the limit pressure (PL) are obtained, the allowable bearing capacity (qa) is calculated, which is expressed as follows:

$$qa = \left(\frac{K*(PL-Po)}{FS}\right) \quad (2)$$

Where q_a is the allowable bearing capacity (kPa), K is the bearing capacity factor, PL is the limit pressure (kPa), Po is the horizontal stress at rest (kPa), and FS is the Safety factor (FS=3).

5 BEARING CAPACITY RESULTS IN THE LAHAR

We obtained representative data of the bearing capacity of the lahar in different sectors of the province of San José, where pressuremeter tests were carried out. Results of the geothecnical exploration in 18 different projects of varying size, were gathered. As part of the scope of verification of the capacity and deformability of the lahar, were carried out approximately 200 pressuremeter tests (PMT).

The graph 2 shows the results of these pressuremeter tests, in which the depth is compared with the allowable bearing capacity.
From this graph, several important data are interpreted:

The largest number of tests performed presented results higher than 400 kPa and up to 1400 kPa, and mainly between 14 and 30 meters deep, however, there are many additional results at depths below and above the prevailing range.

The high dispersion of the results, observed in the graph 2, confirms the heterogeneity of the lahar in terms of bearing capacity, due to the geological formation process (chaotic).

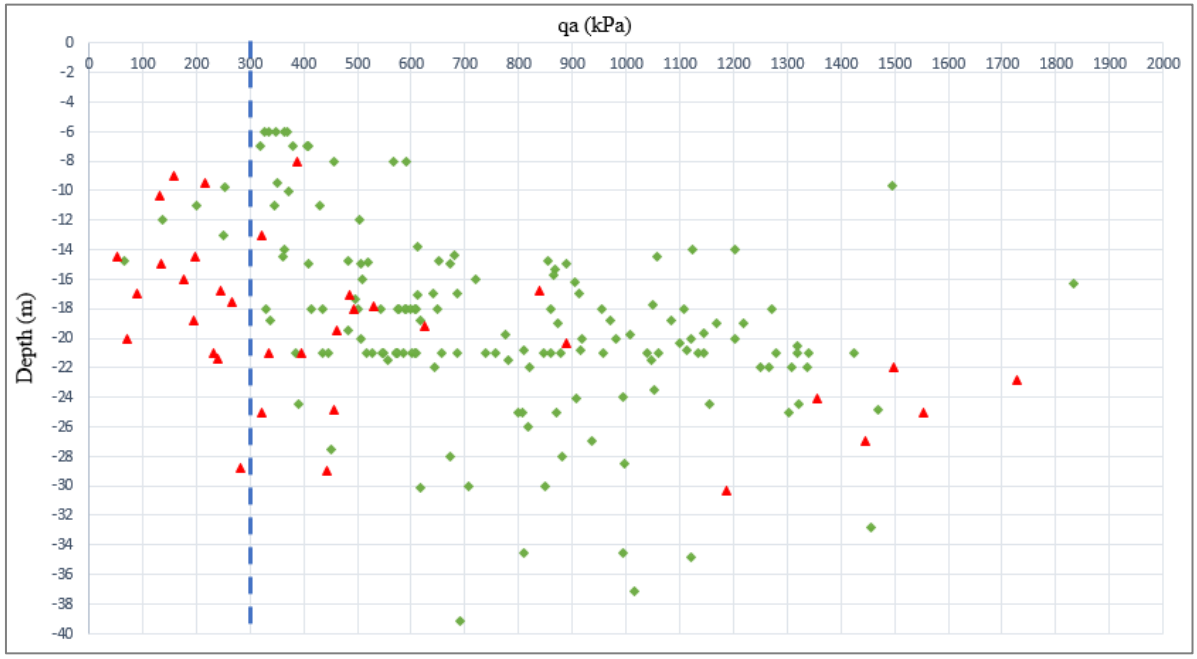
The triangles in red represent results where soil plasticization was not achieved due to:

• The presence of angular blocks and sharp edges resulting from the rotary drilling method, often cause membrane failure during any of the stages of the test. This is reflected as a pressure loss in the PMT curve.

• The loosening of the blocks and matrix of the walls of the well, which cause its diameter to expand considerably, so that the diameter of the

borehole (Di) was greater than 1,2 times the diameter of the deflated probe (Dp). This caused a lot of initial readings that did not allow the plasticizing zone to be reached.

In addition, in some cases the test reached the maximum capacity of the equipment (10 000 kPa) very quickly, indicating that the PMT probe was trapped in a block of rock. In these cases, the test was discarded and the depth of the test was changed, because the values obtained were not representative of the lahar.



Graph 2. Results of allowable bearing capacity of the Lahar according to PMT tests.

It is important to mention that, when presenting cases in which the plasticization of the soil cannot be achieved, we must estimate its limit pressure (PL) with the last value of the curve, so that the bearing capacity calculations can be very conservative, being much lower than those that really characterizes the tested material.

The results lower than 300 kPa, is due to the fact that the pressuremeter tests were carried out in the transition zone between the soil and the lahar, and/or did not reach the limit pressure (PL), due to some soil condition such as which are indicated above.

6 CONCLUSIONS

The DMT, CPT and SPT tests (traditional methods in Costa Rica to estimate the bearing capacity in the upper layers of soil), cannot penetrate the lahar. However, the PMT is very useful in this geological formation, as long as the respective care is taken.

The PMT is an excellent tool to study bearing capacities in soils with blocks of rock (boulders). Because the PMT probe is radial and large area, and allows testing heterogeneous soils, where there are different combinations of rock blocks and matrix (silt, sand, clay, etc.), such as lahars.

The values obtained from the PMT are very reliable, since it is the closest thing to an in situ load test.

The bearing capacities of the lahar oscillate between 400 kPa and 1400 kPa. This is very important for the design of foundations of buildings or some other structures that need to be based on this geological formation.

Due the heterogeneity of the lahar in terms of bearing capacity in small areas, it becomes extremely important to carry out tests in each of the construction projects, and not to estimate the bearing capacity using data from nearby projects.

The use of the pressuremeter has been important for the design of medium rise buildings, because it provides reliable and accurate information for its design, providing a balance between cost and safety.

Rotary drilling should be carried out with sample recovery, to visualize the material that forms the lahar, as well as to determine the depth at which it is detected. In addition, these probes are necessary to insert the PMT probe and determine the depth of the test.

It is recommended to perform pressuremeter tests before designing the structure, and during the execution of the work to confirm and guarantee the estimated allowable bearing capacity, both in the soil layers where the foundations are laid, as well as in greater depth.

7 ACKNOWLEDGEMENTS

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