Settlements of buildings in the gravel of Santiago, Chile

Tassements de bâtiments sur la grave de Santiago, Chile

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ABSTRACT: The construction of important civil works and tall buildings in the last 30 years,with five or more underground levels,in the urban area of Santiago (Chile),have forced geotechnical engineers to study in detail the properties of the Santiago gravel in order to stand up the requirements of contact pressures up to 1.0 and 1.8 MPa for static and dynamic loads, respectively. For the purpose of increasing the knowledge of the gravel behaviour, was performed field tests on undisturbed gravel samples such as giants triaxial tests, vertical-horizontal plate bearings tests and control of settlements measurements during the construction of buildings. The results obtained and the experience reached in field observations has permited to propose a general method to predict settlements and to use higher values of contact pressures,including excavation effects,no linear pressure-deformation behaviour of gravel and size-shape foundations, which is a very important contribution and advance for geotechnical and structural engineers.

RÉSUMÉ: La construction dans les dernières 30 années d'importants bâtiments de grande hauteur,avec 5 ou plus étages en sous-sol,situés dans la zone urbaine de Santiago (Chili),a obligé les ingenieurs géotechniciens a étudier en détail les propriétés du gravier du sous-sol de la ville.L'objectif étant de pouvoir affronter le défi d'accepter des tensions de contact de 1.0 et 1.8 MPa pour des conditions de charge statique et dynamique respectivement. Dans le propos d'augmenter les connaissances du comportement du gravier, on a réalisé des essais en place sur des échantillons non perturbes du gravier,tels que des triaxiales de grande dimensions, des essais de plaque de charge verticale et horizontale, et des contrôles de mesures de tassement pendant la construction. Les résultats obtenus et l'éxpérience acquise avec les observations sur terrain, ont permit de proposer une méthode general pour prédire les tassements et accepter des valeurs plus grandes de capacité portante de contact, inclus les effects de l'excavation, le comportement non linéaire de la presion-deformation du gravier, et l'influence de la forme et dimensions des fondations. Tout cela a représenté un important développement et une grande contribution aux ingénieurs géotechniciens et structuraux.

1 CHARACTERISTICS OF THE SANTIAGO GRAVEL

The gravel of Santiago is a coarse granular material, of high compactness, good gradation, large particle size, particles unweathered and sub rounded, and some amount of cementation, from fluvial origin deposited by the Mapocho river by north and the Maipo river by south of the city. In the Mapocho deposit it is possible to distinguish two deposits: the first deposit begin at 6m depth and is similar in gradation to the 2^{nd} deposit overlaying it, but with plastic fines and a greater compactness and mechanical interlocking. The Maipo deposit is also of fluvial origin and has mechanical and index properties similar to the 2^{nd} Mapocho deposit . Details of the Santiago gravel characteristics are presented by Kort,1978a ; Ortigosa, 1987 ; Kort, 1978b; Kort, 1979 ; Poblete et al, 1981 ; ; Ortigosa & Kort,1999.

By using the results of plate bearings vertical and horizontal tests, including cyclic loads, in situ triaxial tests performed on giants undisturbed samples trimmed by hand in the first deposit under 6.0 m depth and settlements measurements control during the construction of buildings, was possible to obtain the methodology to evaluate the foundation settlements introducing excavation unload effects, specially important in buildings with several underground levels.

2 SETTLEMENTS FOR VIRGIN LOAD

2.1 Linear method

The Figure 1 show the variation of deformation modulus with depth for static loads in the Santiago gravel. These values correspond to virgin load. Using elastic theory we obtain the settlement, ρ ,for square foundations and for different width, B , dividing them for reference settlement, ρ_o calculated for square plate width B_o = 0.32 m. To obtain settlement was defined deformation modulus in the Figure 1 with depth D_F + B or $D_F + B_o$ *representative element*, where D_F is depth of foundation. The results allow us to conclude that the relation ρ/ρ_o vs B/B_o reached with linear method it is not affected for depth of foundations and we can demonstrated that it is the same in practice for Maipo and Mapocho rivers deposits.

2.2 Equivalent linear method

This method consider the no linear pressure-deformation behaviour of soil The application it is based in circular rigid foundations sizes up to 2.0 m diameters from finite elements and from constitutive law pressure deformation of hyperbolic form (Caballero, 1986). The expressions formulated by Caballero for a rigid foundation with radius R under static loads are :

$$E = 5\pi\ ((1 - v^2)\ R\ \sigma_e)/\rho \quad (kN/m^2) \qquad (1)$$

where σ_e in kN/m² ; R, ρ in m

$$\gamma_s(\%) = 63(\rho/R) \qquad (2)$$

where ρ, R in m

$$\sigma_o = 0.42\ \sigma_e - 11.0 + (\gamma\ Z_{eq}\ (1+2K_o))/3 \quad (kN/m^2) \qquad (3)$$

where σ_e in kN/m², γ in kN/m³ , Z_{eq} in m

$$E = 140(1+\upsilon)K_2\sqrt{\sigma_o} \quad (kN/m^2) \qquad (4)$$

where σ_o in kN/m²

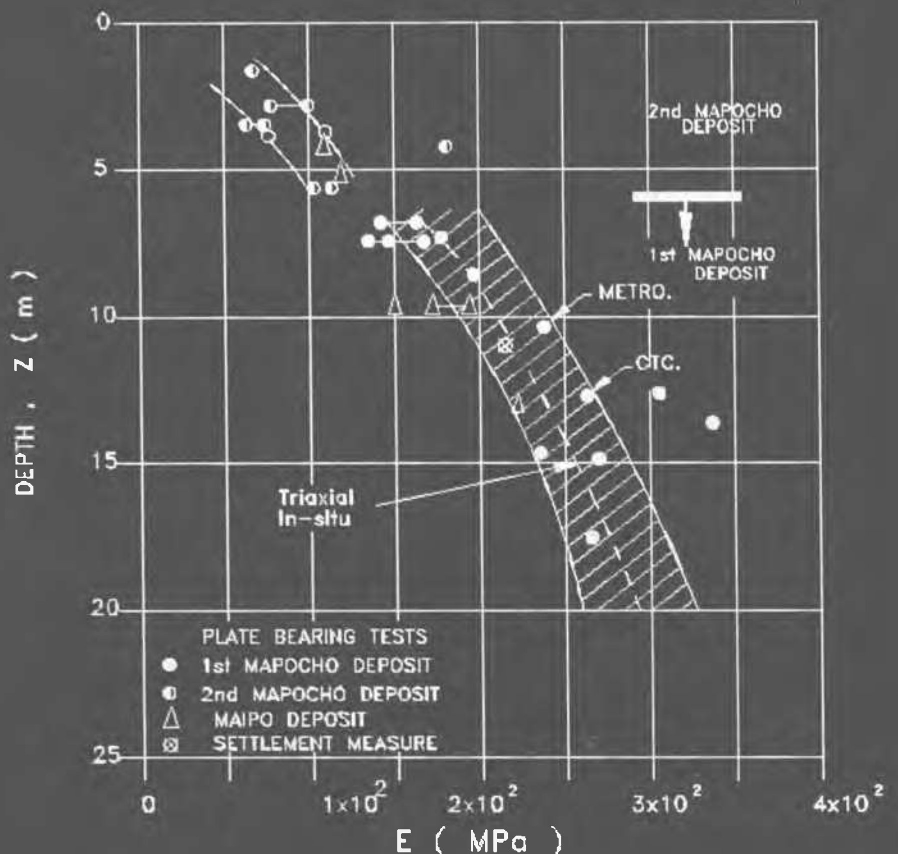

Figure 1. Deformation Modulus for Static Load in the Gravel of Santiago

where γ_s = maximum shear deformation for a *representative element* of soil below the center line of the foundation at depth Z_{eq} = 1.5 R under soil foundation; σ_o = average effective confining stress in the *representative element* ; γ = unit weight of soil below the foundation (use the effective or the submerged unit weight of soil if there is ground water level) ; K_o = coefficient of earth pressure at rest; K_2 = shear coefficient depending of rigidity characteristics of soil defined by the compactness, cementation, grain- size distribution, etc., and of the maximum shear deformation, γ_s, induced for the foundation in the *representative element;* and E = secant or linear equivalent modulus of deformation of the soil.

The key of the preceding relationship is based in the equation (1), originated in the theory of elasticity, gives an equivalent linear modulus of deformation similar with the modulus obtained by equation (4) for the *representative element.* If we have the graphic σ_e vs ρ , obtained with plate tests of radius R, then with the equations (1) to (4) we can evaluate the constitutive relationship K_2 vs γ_s of the soil where was performed the test. For the particular case of the Santiago gravel we used in the calculation ν= 0.30, K_o = 0.25 and γ = 23 kN/ m^3 , although these parameters have not important effects in the results. The constitutive relationship K_2 vs γ_s also was deduced using the results of in situ triaxial tests performed at 9.0 m depth in the first Mapocho deposit and the results are similar with those obtained by plate tests.

By using the relationship K_2 vs γ_s and the equations (1) to (4) have been derived curves σ_e vs ρ for circle rigid foundations with diameter up to 2.0 m. In order to changer later the circle foundation to the square foundation we used the equivalent area, which permitted to obtain the normalized settlements.

We conclude that equivalent linear method predict normalized settlements which are some dependant of contact pressure soil-foundation, explained by influence that have in the rigidity of a soil the confining pressure, and that the differences between the relationship K_2 vs γ_s obtained with the triaxial tests and the obtained with plate bearing tests are not affected mainly the generation of the normalized settlements.

2.3 Settlements measured in the buildings.

With the purpose to extend the normalized relationship ρ / ρ_o vs B / B_o for virgin charge to square foundation with width B> 1.8 m (width associated with maximum diameter of 2.0 m used in the deduction of the equations) we turned to the settlement records of two tall buildings with foundation level on the first Mapocho deposit.

2.4 *Summary of normalized settlements*

The results obtained with width foundations between 6.0 to 24.0 m using settlements records measurements of buildings have demonstrated that for the first Mapocho deposit it is not applicable the graphic normalized settlements proposed by Terzaghi, because underestimate several times the settlement of a foundation , specially for foundations or plates with large size. In opposite, but less marked are the results obtained with linear method. For the second Mapocho deposit and Maipo deposit, with similar values of the rigidity, we propose use the relationship ρ / ρ_o vs B / B_o obtained for the first Mapocho deposit. This extrapolation is necessary because we have not settlement records in these deposits that valid this type of relationship. However, the similarity of the characteristics of the gravel in these deposits and considering that we have a relation of settlement, the proposition is considered sufficient for engineer's effects.

3 UNLOAD EFFECT

On account of the soil have not an elastic behaviour , the process of unload during the excavation permit that with the posterior load originated for the foundations their response in reload is associated with deformation modulus, E_r, whose values range is between 2 and 3 times the modulus for virgin load modulus, E. As a result of this , if the excavation are depth, the effect load-unload must be included in the settlement calculus.

4 CONCLUSIONS

The efforts realized by geotechnical engineers in the last 30 years to model stability and soil structure interaction problems in the coarse granular soils of the city of Santiago, in response to the construction of important civil works, with five or more underground levels , has led to the performance of field tests on undisturbed gravel samples such as giants triaxial tests, vertical-horizontal plate bearing tests and control of settlements measurements during the construction of buildings. The performance of plate bearing tests in the different deposits of the Gravel of Santiago has permitted to propose constitutive relationship between the shear coefficient, K_2, and the maximum shear deformation, γ_s, for to predict static settlements with virgin load.

Using the equivalent linear method proposed in this paper, that use the constitutive relationship, K_2 vs γ_s, it was possible to obtain settlement curves , ρ_o, in function of applied load in a reference square plate with a width of $B_o = 0.32$ m. Also it has permitted to obtain normalized graphics of the type ρ / ρ_o vs B / B_o , where ρ and B are the settlement and B the width of a square rigid foundation , respectively. The construction of this graphic was extended to the large foundations with the help of settlement records measurements in buildings founded in the first Mapocho deposit , named commonly Gravel of Santiago. The methodology proposed was applied for to predict the settlements measured in tall buildings with excellent results.

5 REFERENCES

- Caballero, J.C. (1986) , "Estudio Analítico del comportamiento del suelo en Ensayos de Placa", Memoria para optar al título de Ingeniero Civil, Universidad de Chile.
- Kort, I. (1978a) , "Resultados de la Prueba de Carga en calle Suecia con Las Bellotas, Providencia, Santiago", Informe de Mecánica de Suelos para la Línea 1 del Metro de Santiago
- Kort, I. (1978b) , "Resultados Ensayes Triaxiales in situ en la Grava de Santiago", Informe de Mecánica de Suelos para la Línea 1 del Metro de Santiago.
- Kort, I. et al (1979), "Mediciones en sitio de propiedades mecánicas de la grava para modelo de interacción y cimentación del Metro de Santiago", VI Panamerican Conference on Soil Mechanics and Foundation Engineering, Vol. II, Lima , Perú
- Ortigosa, P. (1987), "Plate Tests on Gravels", VIII Panamerican Conference on Soil Mechanics and Foundation Engineering, Cartagena, Colombia.
- Ortigosa, P. & Kort, I. (1997), "Predicción de asentamientos en la Grava de Santiago", IV Congreso Chileno de Ingeniería Geotécnica, Valparaíso, Chile
- Poblete, M. et al (1981), "Características elásticas de la Grava Fluvial de Santiago determinadas por mediciones de asentamientos en edificios altos", Revista del IDIEM, Vol. 20 N° 2, Universidad de Chile