Limit stiffness in soil structure interaction of buildings

Rigidité limité dans l'interaction sol structure des bâtiments

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ABSTRACT: A model of the behavior of column load in framed building is used to analyse parametrically the growth of the soil-structure stiffness as a function of the construction sequence. The model was also tested using settlement readings of one multi-story building. The results show that this stiffness does not grow continuously but there is a limit stiffness after which the interaction is completed.

RESUME : Un modele du comportement des charges dans les colonnes des batiments est utilizé pour annaliser le augmente de la rigidité sol-structure dans la construction. Le modele a été testé avec les lectures de tassement d'un ouvrage de plusieurs étages. Les resultats montrent que la rigidité n'augmente pas de manière continue mais qu'il y a une rigidité limite aprés l'aquele l'interaction est terminée.

1. INTRODUCTION

The mechanism of soil-structure interaction (SSI) in buildings considers the upper-structure, infra-structure and foundation ground as an only system. When loads are applied on the ground, the soil is compressed causing settlements taken by the building, which will redistribute the loads among the columns until equilibrium is reached. Previous works have analysed the SSI effects such as load redistribution with columns and trend for settlement uniformity (Chamecky, 1956; Goshy, 1978; Lopes & Gusmão, 1991). Most of them make use of parametrical analysis and assume that the structural system is complete before any loading occurs. The effects of the construction sequence on the settlements were show by the first time by Gusmão and Gusmão Filho (1994) using settlement readings taken continuosly of several buildings.

The mechanism of SSI is influenced strongly by both the stiffness of soil and structure. Soil stiffness is a function of soil compressibility and structure stiffness depends on structural elements and building size. This paper analyzes the growing of the whole soil-structure stiffness, during building construction, in order to check if it grows continuosly or otherwise there is a limit stiffness.

2 EFFECT OF SSI IN THE LOADS

One important effect of the SSI is the redistribution of column load in the super-structure. It occurs with the construction of the building, since the increase of the number of floors means an increase of the structure stiffness as well as the loads at the foundation. A new condition of equilibrium is reached in the soil-structure system at each stage of loading, producing a deflection surface of settlement and change in the column load. In the case of a concave deflection, this loading change occurs with increase in load in the outsider columns and reduction of load in the insider columns. That means, as building construction goes on, soil-structure stiffness also increases and column loads change. So these loads include a part due to SSI.

The question to investigate is whether this increase of stiffness during construction reaches one limit or not, from which on the construction can continue but the stiffness does not change any more. In this case, once the limit stiffness is reached, the remainder growing of the building does not alter that part of column load due to SSI. Settlement will also continue but now at the same proportion as the load's increase.

3 METHODOLOGY

A theoretical model was set to describe this variation of the column loads. The behavior of column load was analysed through the growth of the soil-structure stiffness as a function of the construction sequence. In a given phase of construction column load has two parts. One is the conventionally determined column load $Q^t conv$ without settlement. The other part is the load ΔQ^t brought up to the columns or withdrawn from them by the mechanism of SSI, meaning the variation in column load due to SSI. Be $Q^t ssi$ the column load taking into account SSI, meaning that the supports can have displacement. So we have at a certain time t of construction, the normalized expression:

$$n_t = \frac{Q^t ssi - Q^t conv}{Q^t conv} = \pm \frac{\Delta Q^t}{Q^t conv} \qquad [1]$$

The variation of the parameter n_t is addmitted to be a function of the building construction as it is shown in Figure 1.

Three phases can be identified in this function, each one having different characteristics. In phase I, both the structure and its loading begin to grow. There is not yet the necessary stiffness to resist to differential settlements. As these setllements occur, the part of loading $\pm \Delta Q$ coming from these settlements also varies and so the n value. The beginning of phase II is that moment when the system reaches a limit stiffness and it corresponds to n_{lim}. From then on, the raise of the number of floors increases the total column loads but the portion $\pm \Delta Q$ remains the same.

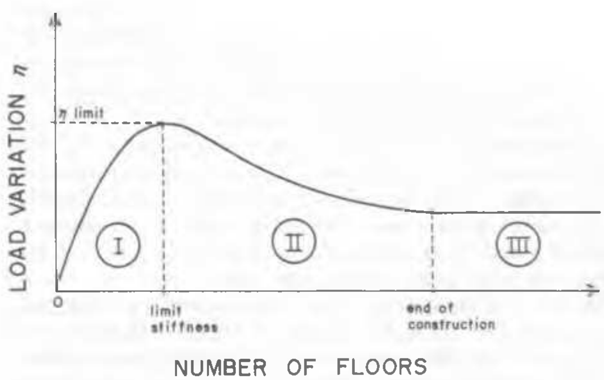

Figure 1. Variation of n during the construction

It means that the influence of the structure on the settlements comes to an end. The deflection surface of settlements gets a constant pattern and the settlement distribution is only a function of the load. The total settlements continue to increase.

At the end of the construction the increase of load quits and phase III starts. The system stiffness having reached its limit value since phase II remains with the same n value in each column equal to the value that it had at the end of phase II.

In case of the soil-structure system does not reach the limit stiffness given by n_{lim} before the end of construction, the system will not go beyond phase I. This happens when the soil stiffness is too large in relation to the structure stiffness.

In order to demonstrate the adequacy of this model to the actual mechanism of SSI, the model was tested using a parametrical study initially and then the experimental results of settlement lectures. Column loads can be predicted analitically assuming non-movable supports. As load measurement in-situ is an unusual and difficult task, then the model was tested using settlement measurements of one building during its construction.

3.1 The parametrical analysis

The structural analysis program SAP-90 was applied to a symmetrical bidimension frame with six columns equally spaced and 15 floors. The structure is supported by an infinite beam on an elastic basis representing the soil. This beam was chosen to model the soil instead of isolated strings for each column because strings do not transfer settlement to the other columns by foundation. So the model of soil as an infinite elastic beam is closer to reality.

The following parameters were used in the analysis: stiffness of columns and beams of the structure, stiffness I_s of the beam on elastic basis and string constant k. The frame was then calculated for each stage of floors to simulate the construction sequence. Figure 2 shows the variation of n in the outside columns of the frame. It can be seen an increase of 50 % in their loads conventionally calculated without settlement, once the third floor is concluded. From that on, phase II begins and the SSI does not transfer load to the columns. Thus there is a limit stiffness when a certain height of the building is reached. The frame was also calculated using different values of k and Is for the same structure and found that the less the soil stiffness the faster the soil-structure system reaches the limit stiffness.

3.2 The experimental analysis

The experimental data used to test the theoretical model are the settlements readings in one reinforced concrete framed building of 17 stories which column settlements were measured every 15 days during their construction time of 18 months. The structure was modelled by program SAP90 as a tridimentional frame and the columns loads were found for the conventional case of non-desplaced foundation at each time of settlement reading. Having the settlement readings and the loads, the settlements were imposed to the frame that actually existed at that stage of construction. Thus the results permitted to obtain the conventional Q^tconv and the load variation ΔQ^t for each stage of construction, as well the load Q^tssi that takes into account SSI and the percentage n_t of load variation given by equation [1].

The curves of percentage n_t of load variation against the time or the height of the construction deliver results as are shown in Figures 3 and 4, in which we can see the adequacy of the theoretical model as it is proposed in Figure 1.

The observed dispersion is due to the origin of the settlements and imprecision in their lectures. Although measured with precision 1 mm, the settlements of the building had multiple causes and so they have not to be proportional to the loads. However it is evident the general trend of load transfer even with such a restriction.

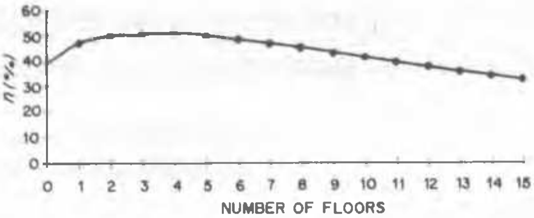

Figure 2 Load increase by parametrical analysis (Outer column)

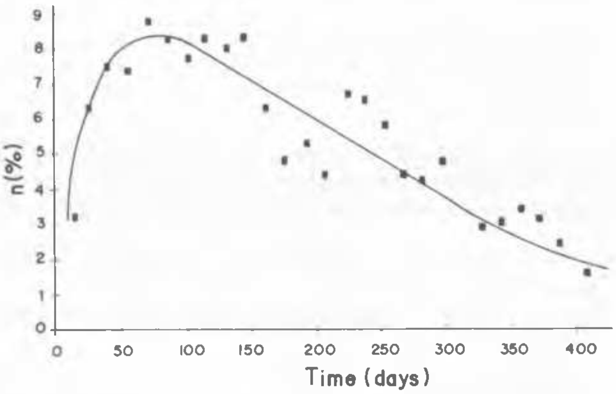

Figure 3 Load increase by settlement readings (Outer column)

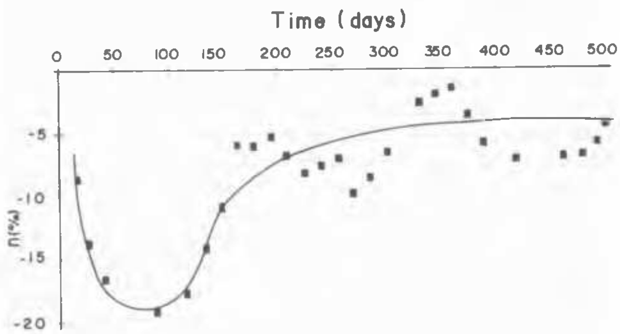

Figure 4 Load reduction by settlement readings (Inner column)

4 CONCLUSION

A theoretical model is presented that shows the variation of column load in a framed building due to soil-structure interaction as a function of the sequence of construction. The proposed model was tested initially through a parametrical analysis and then using settlement readings of one building. Curves of variation of column load are similar in both tests, placing in evidence that there is a limit stiffness to the system during the construction. The mechanism of SSI transfer load between the columns in this phase, having load increase or reduction depending on the column position in the structure. However, from a certain height on, the deflection surface of settlements maintains pratically the same pattern and the remainders floors do not contribute to load transfer.

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