v. 3, n. 4, 2023

Journal of
Engineering
Research

# THE INFLUENCE OF THE CONSTRUCTION SEQUENCE ON THE MECHANISM OF SOIL INTERACTION STRUCTURE FOR A LOW BUILDING OF REINFORCED CONCRETE

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 DOI 10.22533/at.ed.317342323016

**Abstract**: In the present article, initially, the loads on the pillars of a low building (3 floors) are evaluated for the elastic behavior with instantaneous loading and with gradual loading (construction in 3 stages). The commercial finite element program SAP2000 (version 15) is used with the phased construction module. Subsequently, an analysis is carried out over time, also considering instantaneous loading and built in 3 steps. The staged construction module makes it possible to consider concrete creep and shrinkage. With regard to the elastic analysis with instantaneous loading and in 3 stages, it was found that even for low values of normal efforts, there was a redistribution of requests in the columns. Thus, the importance of considering the influence of the constructive sequence on the redistribution of efforts in reinforced concrete structures is highlighted. It appears that future investigations are necessary, also considering the influence of masonry, coatings and occupancy overload, in addition to structures with elements (especially beams and pillars) of different stiffness, and also the study of the redistribution of efforts for the case of taller buildings. Regarding the analysis carried out over time (fluency and retraction), it was noticed that there was no redistribution of requests. This result may be linked to the simplicity of the studied model.
**Keywords**: Constructive Sequence, Soil Structure Interaction, Low Buildings, Reinforced Concrete.

## INTRODUCTION

Until recently, the design of structures and their foundations was always carried out assuming that these two elements had independent behavior, that is, the effects of soil structure interaction were neglected, as illustrated in Figure 1.

Lately, with the availability of increasingly sophisticated engineering calculation programs, some designs have been developed considering the interaction between the structure and foundations. However, this interaction is carried out assuming only the immediate portion of the deformations and displacements. For example, the creep of the structure material is not taken into account.

According to Barata (1986), the consideration of the soil structure interaction mechanism is quite complex and requires an intimate and intense collaboration between structural and geotechnical engineers.

The mechanism of soil structure interaction depends on a number of factors such as the number of floors in the building, the influence of the first floors, the shape of the building in plan, among others, and also associates mechanical effects. In general, there is a redistribution of stresses on the structural elements, especially on the pillars, with a transfer of stresses from the pillars that tend to settle more to those that tend to settle less and, as a result of this fact, there is a tendency to standardize the differential settlements.

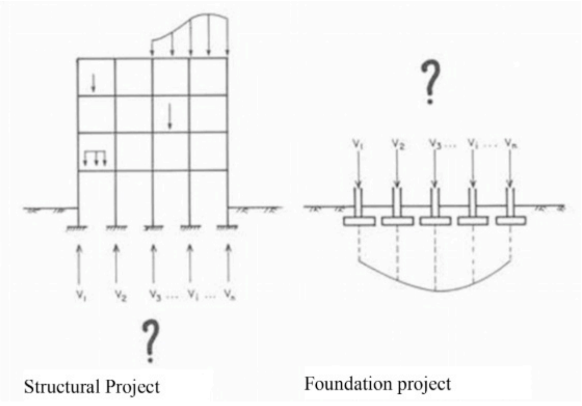



Figure 1. Conventional design carried out until recently: dimensioning of the structure and foundation elements carried out independently (Gusmão, 1990).

According to Gusmão (1990) and Gusmão and Gusmão Filho (1994a and 1994b), most studies on soil structure interaction assume the hypothesis that thereis no loading during the construction of the building. The authors point out that as the rigidity of the structure is greatly influenced by its height, the Construction sequence assumes an important influence on the soil structure interaction. The authors dealt with the subject from a practical point of view through the reading of settlements during the construction of some buildings in the city of Recife. They observed an increase in absolute settlements due to the increase in loads on the columns. As the constructionprogressed, the rigidity of the structure also increased with the tendency to standardize the settlements and redistribute the loads between the columns.

Considering the cases of instantaneous and gradual loading, Brown and Yu (1986) analyzed a flat structure using the methodology proposed by Poulos (1975, apud Gusmão, 1990) and a three-dimensional one according to the focal program described by Fraser and Wardle (1976). Analysis of these cases showed that, for interaction purposes, the effectivestiffness of a building that is progressively loaded during constructio nis approximately half that of a building with instantaneous loading.

Fonte et al. (1994) studied a fourteen-story building, taking into account the influence of the construction process through an automatic finite element program, the Building Computational System. Regarding the settlement predictions, they stated that the model adopted for instantaneous loading without considering the soil structure interaction overestimates the differential settlements. On the other hand, the model that considers the effect of the soil structure interaction and applies instantaneous loading underestimates the differential settlements due to the implicit consideration of a stiffness for the structure greater than the real one. The most accurate results were obtained by the models that consider the interaction effect and the gradual application of loads and, consequently, the increasing stiffening of the structure.

Moura (1995 and 1999) also considered the effect of the constructive sequence in his analysis with the Interaction Module program for a nineteen-story building in reinforced concrete and observed a great influence of the constructive effect in the redistribution of requests in the columns.

More recently, Silva et al. (2016) presented a study of the influence of the Construction method on the redistribution of efforts in reinforced concrete frames and found a significant relevance, depending on the size of the construction, and also the need for further studies to improve the analysis.

It is in this context that this articleis inserted. The influence of the Construction sequence on the soil structure interaction mechanism over time is studied for a low reinforced concrete building (3 floors). Structures with instantaneous and gradual loading are compared. This study aims to provide elements for the interpretation of the results of more sophisticated structures, such as, for example, multi-storey reinforced concrete buildings, taking into account the soil structure interaction over time.

## STRUCTURE MODELING

The SAP2000 program (version 15) is used, which enables elastic and over time analysis.

This version 15 of the SAP2000 program brings the possibility of considering the creep and shrinkage of materials such as, for example, concrete based on CEB-FIP (1990).

For the modeling of the 3-story building, the beams and columns were discretized using bar elements. For the slabs, plate elements were used.

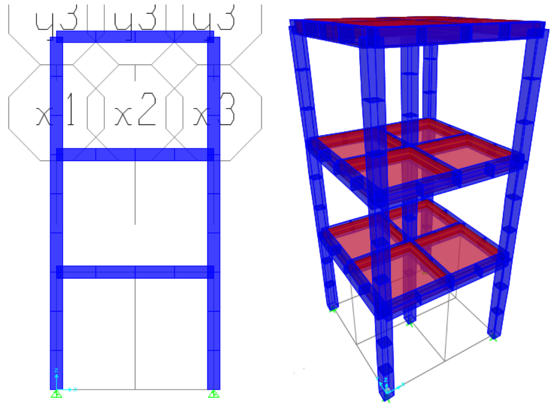
The structure is subject only to its own weight, that is, masonry, coatings and building occupancy overload were not considered.

The building has 5 pillars reaching to the foundations. The beams are 4 meters long. The right foot is 3 meters. The cross sections of the beams and columns have dimensions of 30 x 30 centimeters. The thickness of the slabs is 30 centimeters.

In the discretization of the structure, the specific weight of the concrete equal to 25 kN/$m^3$ was considered. An initial tangent modulus of elasticity, at 28 days, of 25 GPa was adopted. This value was assumed from Nunes (2005).

For the properties of the concrete over time, for the analysis that includes the creep of the concrete, values of 0.25 for the coefficient that depends on the type of cement (normal hardening), 50% for the relative humidity of the medium environment and 0.15 for h (h = 2Ach/u, where Ach = cross-sectional area of the plain concrete column and u = perimeter of the cross-section of the column in contact with the atmosphere). For the analysis of concrete shrinkage, values of 5 were adopted for the coefficient that depends on the type of cement (normal hardening) and zero for the age of the concrete at the beginning of shrinkage. Such concrete properties were adopted based on CEB-FIP (1990).

Figure 2(a) shows a front view (Y = 0) of the structure discretized in finite elements and Figure 2(b) the three-dimensional model with undisplaceable supports.




(a) (b)

Figure 2. (a) Front view (Y = 0) of the structure discretized in finite elements with non-displaceable supports and (b) Three-dimensional model of the building.

## NORMAL EFFORTS OBTAINED IN PILLARS - ELASTIC MODEL

Table 1 presents the values of normal efforts obtained in the peripheral (1, 3, 7 and 9) and central (5) pillars for the elastic model with instantaneous loading and with construction loading in stages (3 construction stages, namely: 1st floor, 2nd floor and 3rd floor). It is noteworthy that all columns and beams have the same stiffness.

| Pillar | 1 | 3 | 5 | 7 | 9 | Σ | |
|---|---|---|---|---|---|---|---|
| Normal Stress (kN) | 99 | 99 | 192 | 99 | 99 | 587 | Instantaneous Charging |
| | 94 | 94 | 213 | 94 | 94 | 587 | 3-Step Construction - Gradual Loading |

Table 1. Normal forces obtained in the columns – elastic model.

From Table 1, it is observed that the values of normal efforts are low. This happens due to the consideration made in the study (structure subjected only to its own weight). Even for low values of normal efforts, a redistribution of requests on the columns is observed when considering the construction in stages – a situation closer to reality. The central pillar (5) presents an increase in demand (approximately 11%), while the peripheral pillars present relief (approximately 5%). Thus, the importance of considering the influence of the constructive sequence on the redistribution of efforts in reinforced concrete structures is highlighted. It appears that future investigations are necessary, also considering the influence of masonry, coatings and occupancy overload, in addition to structures with elements (especially beams and pillars) of different stiffness, and also the study of the redistribution of efforts for the case of taller buildings.

## NORMAL EFFORTS OBTAINED IN PILLARS - ANALYSIS OVER TIME

Six situations are studied for the loads obtained from the structural modeling in finite elements of the two three-dimensional structures (instantaneous loading and loading in stages) over time (with consideration of creep and shrinkage of the concrete), namely:

(i) Structure with non-displaceable supports and structure material subject to creep;

(ii) Structure with non-displaceable supports and structure material subject to creep and shrinkage;

(iii) Structure with spring supports (k = 100 kN/m) and structure material subject to creep;

(iv) Structure with spring supports (k = 100 kN/m) and structure material subject to creep and shrinkage;

(v) Frame with spring supports (k = 1000 kN/m) and frame material subject to creep.

(vi) Structure with spring supports (k = 1000 kN/m) and structure material subject to creep and shrinkage.

Figures 3 and 4 show, respectively, the normal forces for the corner columns and the central column for the instantaneous loading situation.

The normal efforts were normalized in relation to the normal effort in time equal to zero for the situation of non-displaceable supports and elastic structure material through expression 1:

$$\nu = \frac{N(t)}{N_e(t)} \tag{1}$$

And with these features:

$\nu$ =Normalized normal effort.

$N(t)$ = Normal effort over time: $t$.

$N_e(t_0)$ = Elastic normal stress in time: $t_0$.

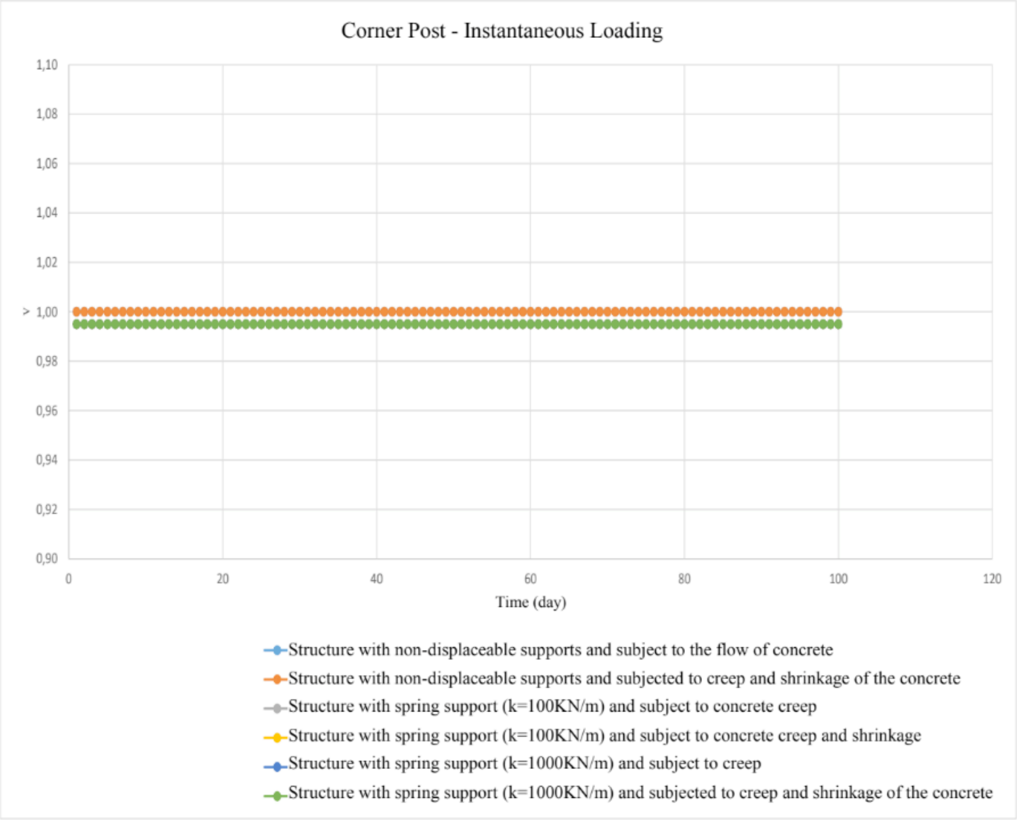



Figure 3. Normal stress on building corner pillars versus time for the instantaneous loading situation.

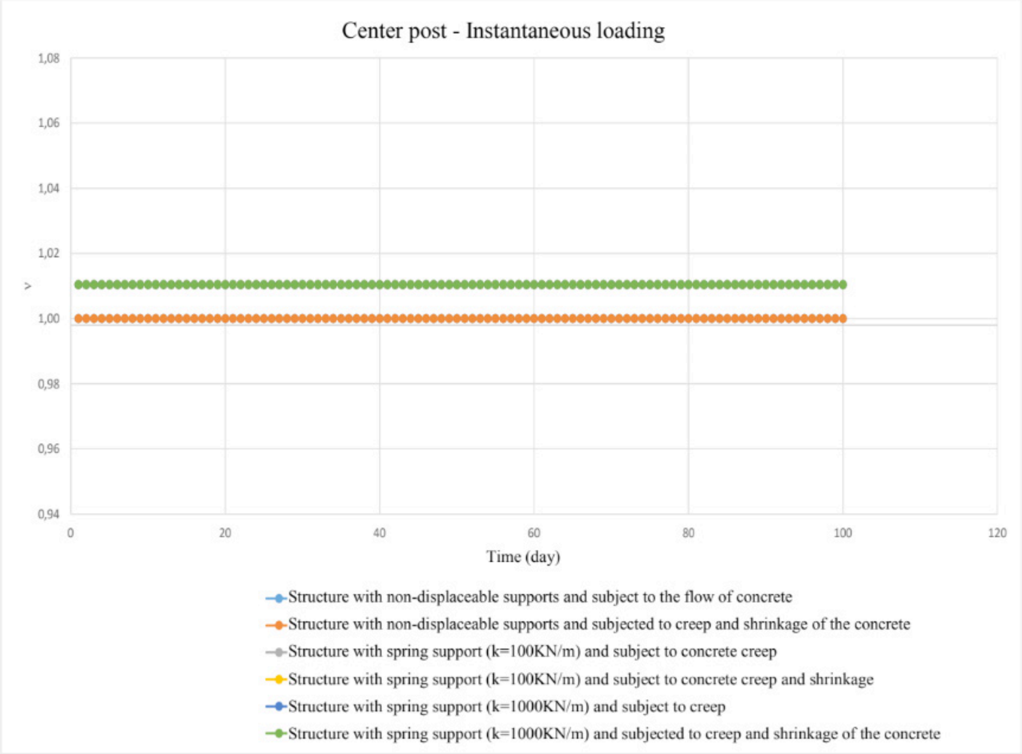



Figure 4. Normal effort on the central column of the building versus time for the instantaneous loading situation.

From Figure 3, it is observed that the corner columns present constant normal stress over time for all six study situations. There was no redistribution of requests over time. This result may be linked to the simplicity of the model (very low stress values – between 99 and 192 kN, same stiffness for all structural elements and model symmetry).

It is worth mentioning that, for the situation of a structure with non-displaceable supports and subjected to creep, the normal effort normalized in relation to the normal effort in time equal to zero presents a result equal to one. This result was expected, since, in fact, according to Carneiro (1978), the first Theorem of the Elasticity-Visco elasticity Correspondence consists in the fact that the internal efforts (stresses or stresses in the sections) arising from the action of loads are not modified by creep. At any instant t the internal efforts are those that would occur in a body with the same geometric characteristics and attachment and requested by the same loads, but made of elastic material.

It can be seen from Figure 4 that the central pillar also did not undergo redistribution of requests.

Figures 5 and 6 show, respectively, the normal forces for the corner columns and the central column for the 3-stage loading situation.

The normal efforts were normalized in relation to the normal effort in time equal to zero for the situation of non-displaceable supports and elastic structure material also through expression 1.

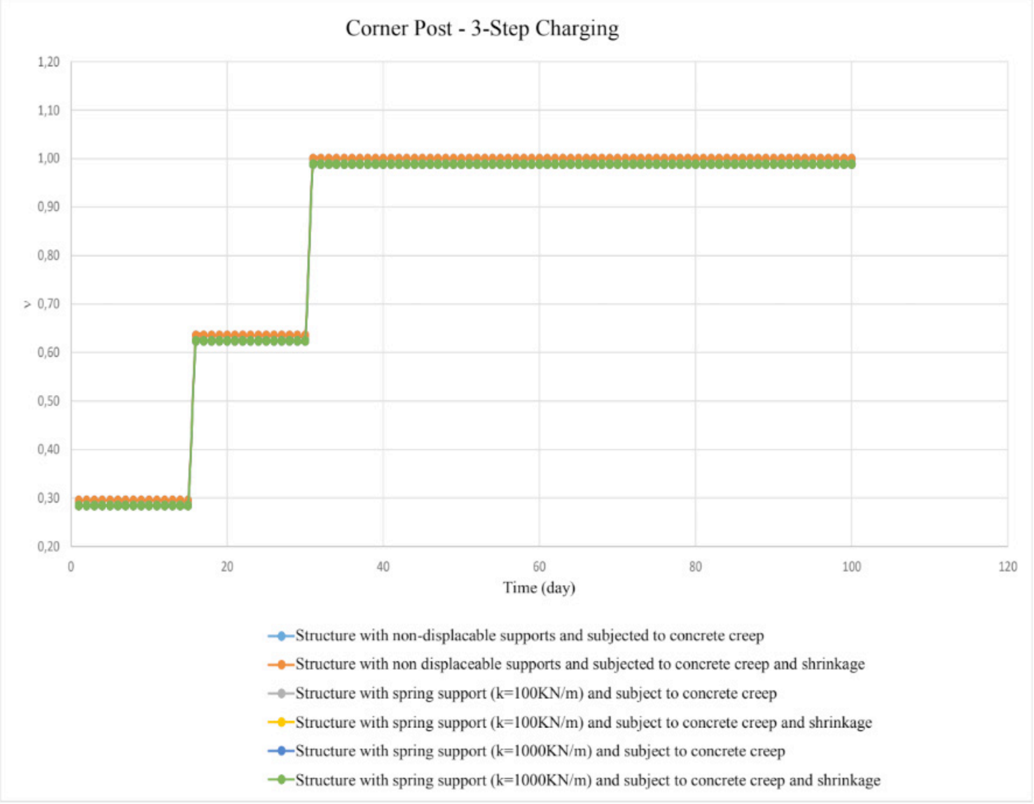



Figure 5. Normal stress on building corner columns versus time for the 3-stage loading situation.

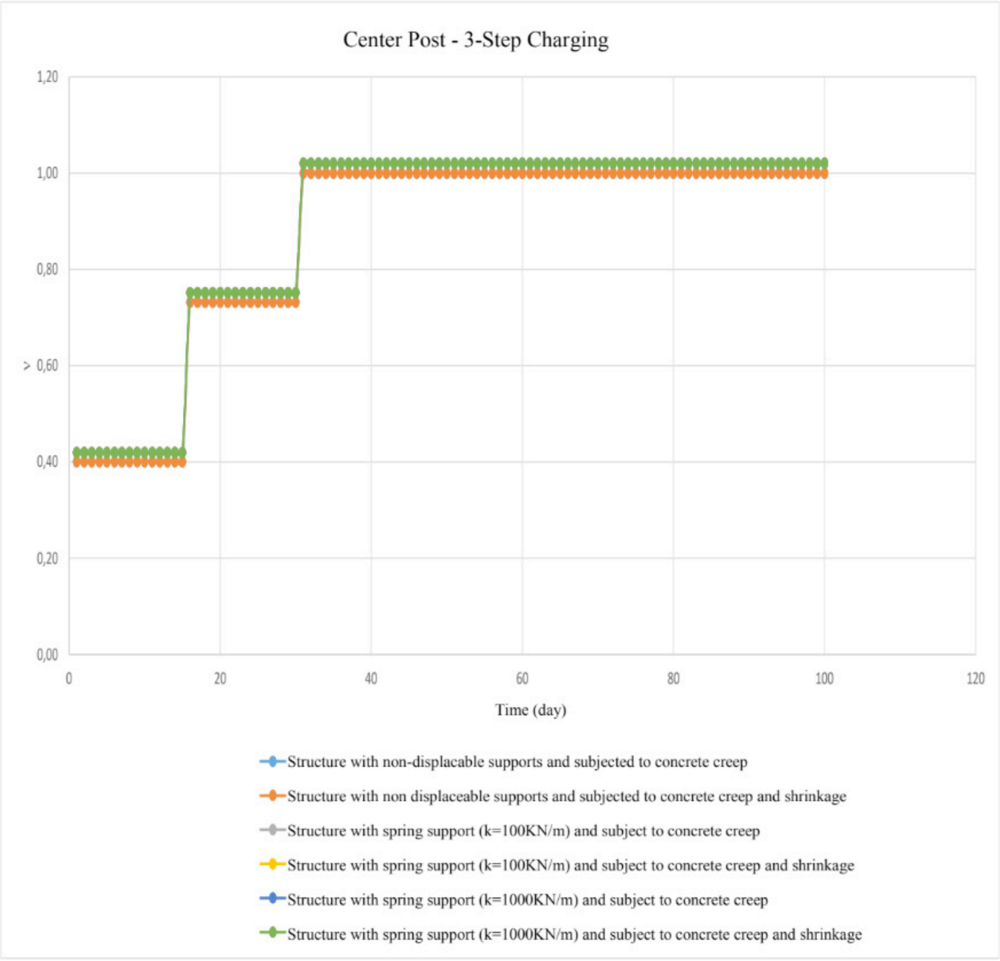



Figure 6. Normal effort on the building's central column versus time for the 3-stage loading situation.

From Figure 5, the loading of the corner column in 3 stages can be seen. In the last step, the corner pillar presents constant normal stress over time for all six study situations. There was no redistribution of requests over time. As previously mentioned, this result may be linked to the simplicity of the model (very low stress values – between 94 and 213 kN, same stiffness for all structural elements and model symmetry).

It must be noted that, for the situation of a structure with non-displaceable supports and subjected to creep, the first Elasticity-Visco elasticity.

It can be seen from Figure 6 that the central pillar also did not undergo redistribution of requests.

For all situations studied, the effect of concrete shrinkage was imperceptible.

## CONCLUSIONS

The following conclusions are listed:

(i) With regard to the elastic analysis with instantaneous loading and in 3 steps, it was found that the values of normal efforts in the columns are low. This happened due to the consideration made in the study (structure submitted only to its own weight). Even for the low values of normal efforts, a redistribution of requests on the columns was noticed when the construction in stages was considered – a situation closer to reality.

Thus, the importance of considering the influence of the constructive sequence on the redistribution of efforts in reinforced concrete structures is highlighted. It appears that future investigations are needed, also considering the influence of masonry, coatings and occupancy overload, in addition to structures with elements (especially beams and pillars) of different stiffness.

(ii) Regarding the analysis carried out over time, both for the instantaneous loading situation and for the 3-stage loading situation, it was noticed that there was no redistribution of requests. This result may be linked to the simplicity of the model (very low stress values, same stiffness for all structural elements and model symmetry).

(iii) The first Elasticity-Visco elasticity Correspondence Theorem, which says that the internal efforts (stresses or stresses in the sections) arising from the action of loads are not modified by creep, was met.

(iv) For all situations studied, the effect of concrete shrinkage was imperceptible.

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