v. 2, n. 7, 2022

Journal of
Engineering
Research

ANALYSIS OF THE EFFECT OF TIME ON FOUNDATION REQUESTS FOR THREE-DIMENSIONAL STRUCTURES DISCRETIZED IN FINITE ELEMENTS

Mariana Larissa Antunes da Costa
Civil Engineering Student, Federal University of Juiz de Fora
Juiz de Fora, Brazil

Juliane Crisitna Goncalves
Professor, Federal University of Juiz de Fora
Juiz de Fora, Brazil

DOI 10.22533/at.ed.317272210052

Abstract: In this article, requests over time are presented, obtained from modeling three-dimensional structures of different stiffnesses in finite elements. Eight situations are studied, namely: (i) structure with non-displaceable supports and material of the structure 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 material of the structure subject to creep; (iv) structure with spring supports (k = 100 kN/m) and structure material subject to creep and shrinkage (v) structure with spring supports (k = 1000 kN/m) and material of the structure subject to creep (vi) structure with spring supports (k = 1000 kN/m) and structure material subject to creep and shrinkage (vii) structure with viscoelastic supports and structure material subject to creep and, finally, (viii) structure with viscoelastic supports and material of the structure subject to creep and shrinkage. For 50% of the columns, there was a redistribution of stresses with values tending over time (viscoelastic model) to the values of the elastic model. It was also found that the effect of concrete creep was greater than that of shrinkage.

Keywords: Time Effect, Foundation Requests, Three-Dimensional Structures, Finite Elements.

INTRODUCTION

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

The creep phenomenon is more pronounced in reinforced concrete structures than, for example, in metallic structures and, according to Santa Maria et al. (1999), the interaction between the behavior of the structure and the foundation over time can result in efforts with sign and intensity not foreseen in projects elaborated from an elastic analysis. This way, it is important to carry out comparative studies between elastic and viscoelastic analyses, the latter considering the portion of the deformation that is time-dependent, whether referring to the material of the structure or to the foundation element.

Bjerrum (1963) already pointed out that the time factor is very important in distortional settlements and that the settlement criterion is different for sand and clay buildings. A building is able to withstand, without damage, major distortional settlements over time.

This article presents a comparison between stresses over time obtained from structural modeling in finite elements of three-dimensional structures of different stiffnesses. This study aims to provide elements for the interpretation of results of more sophisticated structures such as, for example, multi-story buildings of reinforced concrete with the consideration of soil-structure interaction over time.

STRUCTURE MODELING

For the development of this study, the program SAP2000 (version 15) is used, which allows elastic and viscoelastic analysis. This version 15 of the SAP2000 program brings the possibility of considering creep and shrinkage of materials such as, for example, concrete based on CEB-FIP (1990).

For the modeling of the three-dimensional structures, the beams and columns were discretized using bar elements. Plate elements were used for the slabs. The specific weight of the concrete was considered equal to 24 kN/

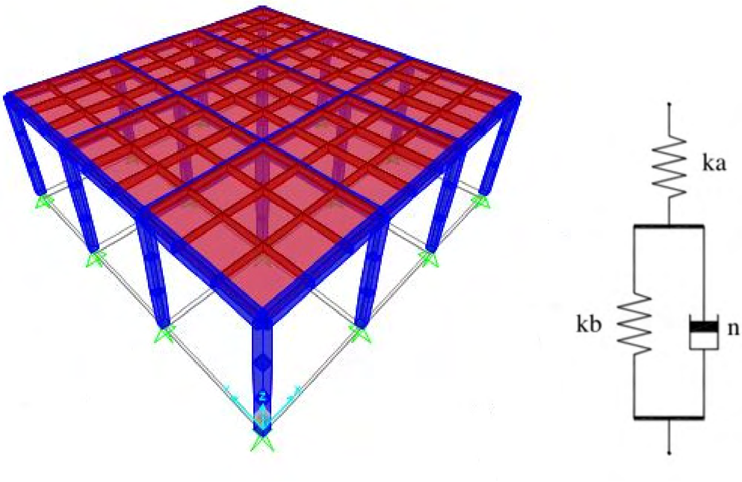
m^3 and an initial modulus of elasticity, at 28 days, of 24 GPa was adopted. The structures are subject to their own weight.

For the foundations, situations of non-displaceable supports, spring supports (k = 100 kN/m and k = 1000 kN/m) and viscoelastic supports represented by the series association of the Hookean model with the Kelvin model were admitted. The model's damping coefficient parameters were assumed with the value of 10000000 kNdia/m, based on Vyalov (1986). Figure 1(a) shows the three-dimensional finite element model and 1(b) the rheological model adopted for the viscoelastic supports.

The three-dimensional structure has 16 pillars. All spans are 3 meters. Two structures with different stiffness are analyzed: three-dimensional structure – stiffness 1 and three-dimensional structure – stiffness 2. The three-dimensional structure – stiffness 1 has the cross sections of beams and columns equal to 20 x 20 cm and slabs with a height of 20 cm. The three-dimensional structure – rigidity 2 has the cross sections of the beams and columns equal to 40 x 40 cm and slabs with a height of 40 cm.

NORMAL EFFORTS OBTAINED ON PILLARS

Eight situations are studied for the requests obtained from the structural modeling in finite elements of the two three-dimensional structures (rigidity 1 and rigidity 2), namely: (i) structure with non-displaceable supports and material of the structure 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 material of the structure subject to creep; (iv) structure with spring supports (k = 100 kN/m) and structure material subject to creep and shrinkage; (v) structure with spring supports (k = 1000 kN/m) and material of the structure subject to creep. (vi) frame with spring supports (k = 1000 kN/m) and frame material subject to creep and shrinkage. (vii) structure with viscoelastic supports and material of the



(a) (b)

Figure 1. (a) Three-dimensional model of the finite element structure with non-displaceable supports and (b) Rheological model adopted for the supports.

structure subject to creep and, finally, (viii) structure with viscoelastic supports and material of the structure subject to creep and shrinkage.

Figures 2, 3 and 4 show, respectively, the normal stresses for corner pillars, peripheral pillars and central pillars for the three-dimensional structure – stiffness 1.

The normal stresses were normalized in relation to the normal stress in time equal to zero for the situation of undisplaceable supports and elastic structure material through expression 1:

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

With these features:

ν = Normalized normal effort.

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

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

From Figure 2, it can be observed, in general, that the corner pillars absorb stress, but there is a decrease in this over time. It appears that for the first situation – three-dimensional structure with non-displaceable supports and material of the structure subject to creep – the corner pillars present a constant normal stress over time. The normal effort normalized in relation to the normal effort in time equal to zero gives a result equal to one. In fact, according to Carneiro (1978), the first Elasticity-Viscoelasticity Correspondence Theorem consists of the fact that the internal forces (tensions or stresses in the sections) arising from the action of loads are not modified by creep. At any instant t the internal forces are those that would occur in a body with the same geometric characteristics and binding and requested by the same loads, but made of elastic material. It is worth mentioning that the so-called Correspondence theorems apply to homogeneous structures, constituted, therefore, of a single material; that exhibit linear creep and provided that the types of boundary conditions (stress conditions or prescribed displacement conditions) do not change in each boundary region during the history of the structure.

For the second situation – three-dimensional structure with non-displaceable supports and material of the structure subject to creep and retraction – it is noted that, as illustrated in Figure 2, the corner columns show a decrease in normal stress over time. For the third situation – three-dimensional structure with spring supports (k = 100 kN/m) and material of the structure subject to creep – it can be seen that the corner columns show a decrease in normal stress over time. The effect of retraction does not appear for the situation of spring supports with spring stiffness (k) equal to 100 kN/m. For the fifth and sixth situations - three-dimensional structure with spring supports (k = 1000 kN/m) and material of the structure subject to creep and material of the structure subject to creep and retraction - normal efforts are observed approaching the situation of supports undisplaceable, as expected, since you have a higher spring stiffness coefficient value (k = 1000 kN/m). For the seventh and eighth situations – three-dimensional structure with viscoelastic supports and material of the structure subject to creep and material of the structure subject to creep and shrinkage – it is noticed that the values of normal efforts also tend to the values of the elastic model. It is noteworthy that the introduction of shrinkage in the material of the spatial frame did not change the results for the situation of viscoelastic supports.

It can be seen from Figure 3 that the peripheral pillars, in general, absorb requests and these tend to remain constant over time. The retraction effect does not appear for all situations. It can be seen that for the first situation – three-dimensional structure with

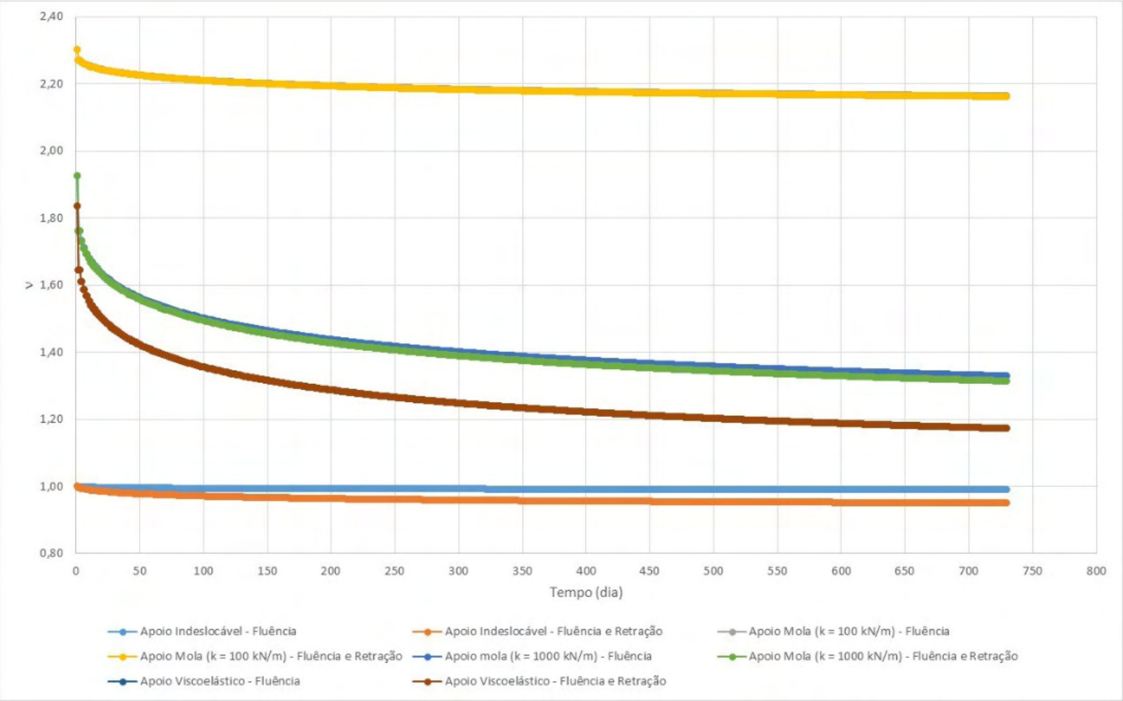


Figure 2. Normal stress on the corner pillars of the three-dimensional structure – stiffness 1 versus time.

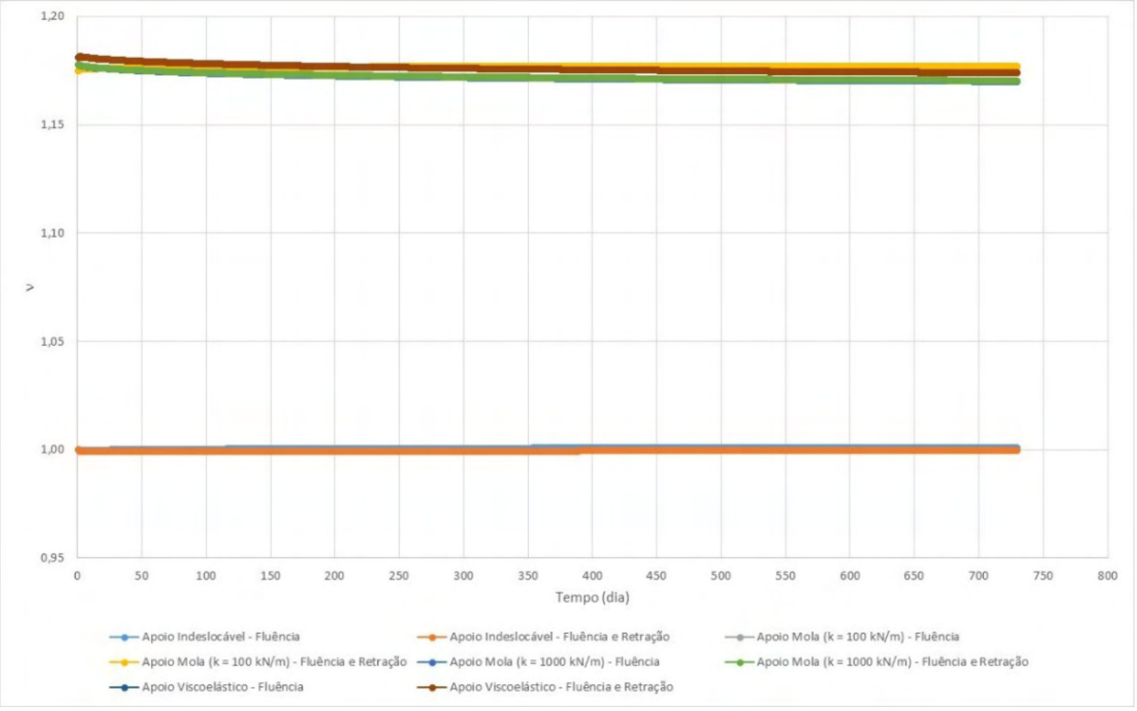


Figure 3. Normal stress on the peripheral pillars of the three-dimensional structure – stiffness 1 versus time.

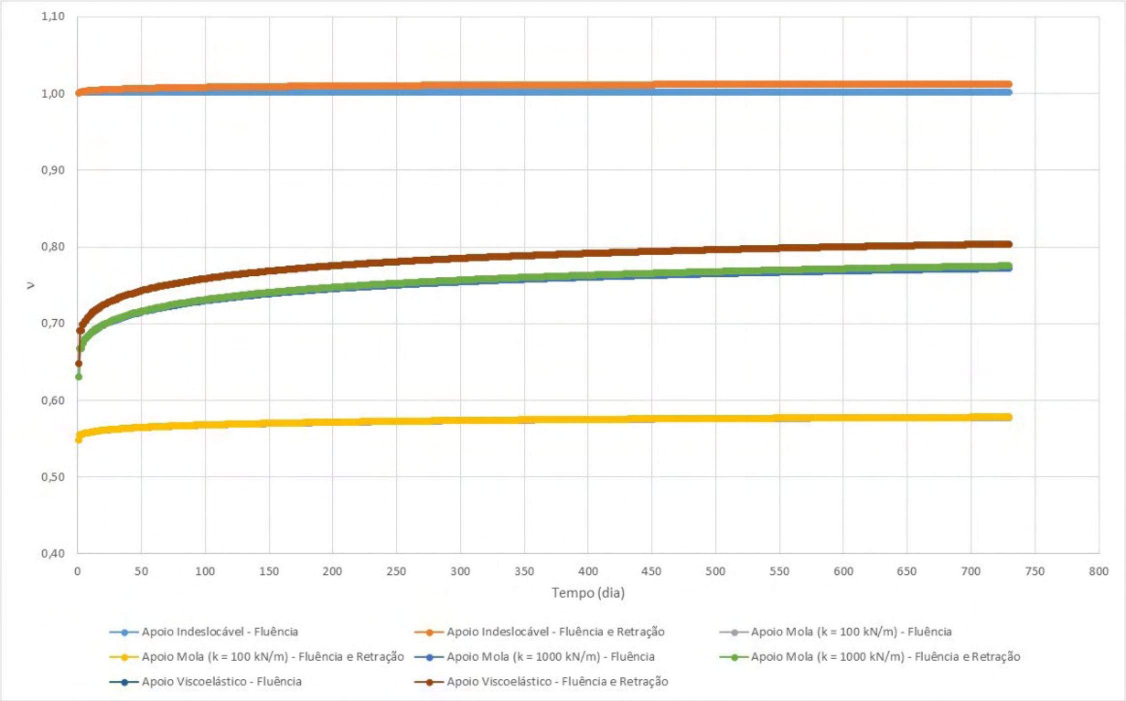


Figure 4. Normal stress on the central pillars of the three-dimensional structure – stiffness 1 versus time.

non-displaceable supports and material of the structure subject to creep – the peripheral columns present a constant normal stress over time. The normal effort normalized in relation to the normal effort in time equal to zero presents a result equal to one, that is, they meet the first Elasticity-Viscoelasticity Correspondence Theorem.

From Figure 4, it can be observed, in general, that the central pillars suffer a stress relief, but there is an increase in stress over time. It appears that for the first situation – three-dimensional structure with non-displaceable supports and material of the structure subject to creep – the central pillars present a constant normal stress over time. The first Elasticity-Viscoelasticity Correspondence Theorem is satisfied.

For the second situation – three-dimensional structure with non-displaceable supports and material of the structure subject to creep and shrinkage – it is noted that, as illustrated in Figure 4, the effect of shrinkage almost does not appear. For the third situation – three-dimensional structure with spring supports (k = 100 kN/m) and material of the structure subject to creep – it can be seen that the central columns present an increase in normal stress over time. The effect of retraction does not appear for the situation of spring supports with spring stiffness (k) equal to 100 kN/m. For the fifth and sixth situations - three-dimensional structure with spring supports (k = 1000 kN/m) and material of the structure subject to creep and material of the frame subject to creep and retraction - normal efforts are observed approaching the situation of supports undisplaceable, as expected, since the value of the spring stiffness coefficient is ten times greater than in the previous situation (k = 1000 kN/m). For the seventh and eighth situations – three-dimensional structure with viscoelastic supports and material of the structure subject to creep and frame material subject to creep and shrinkage – it can be seen that the values of normal forces also tend to the values of the elastic model. It must be noted that the introduction of shrinkage in the material of the structure did not change the results for the situation of viscoelastic supports.

Figures 5, 6 and 7 show, respectively, the normal stresses for corner pillars, peripheral pillars and central pillars for the three-dimensional structure – stiffness 2.

The normal stresses were normalized in relation to the normal stress in time equal to zero for the situation of undisplaceable supports and elastic three-dimensional structure material also through expression 1.

From Figure 5, it is observed that the corner pillars of the three-dimensional structure - stiffness 2 present the same behavior of the three-dimensional structure - stiffness 1. It is noteworthy that for the second situation - three-dimensional structure with non-displaceable supports and subject structure material creep and shrinkage – the corner pillars show a decrease of approximately 22% in the time of 730 days. In addition, for the fifth and sixth situations – three-dimensional structure with spring supports (k = 1000 kN/m) and material of the structure subject to creep and material of the structure subject to creep and shrinkage – normal stresses approaching the situation of undisplaceable supports, as expected. Comparing these results with those of the three-dimensional structure – stiffness 1, the influence of the relative structure-foundation stiffness on the normal stress values over time can be seen.

From Figure 6, it can be seen that the peripheral pillars of the three-dimensional structure – stiffness 2 present the same behavior as the three-dimensional structure – stiffness 1, that is, in general, they absorb the load and this tends to remain constant

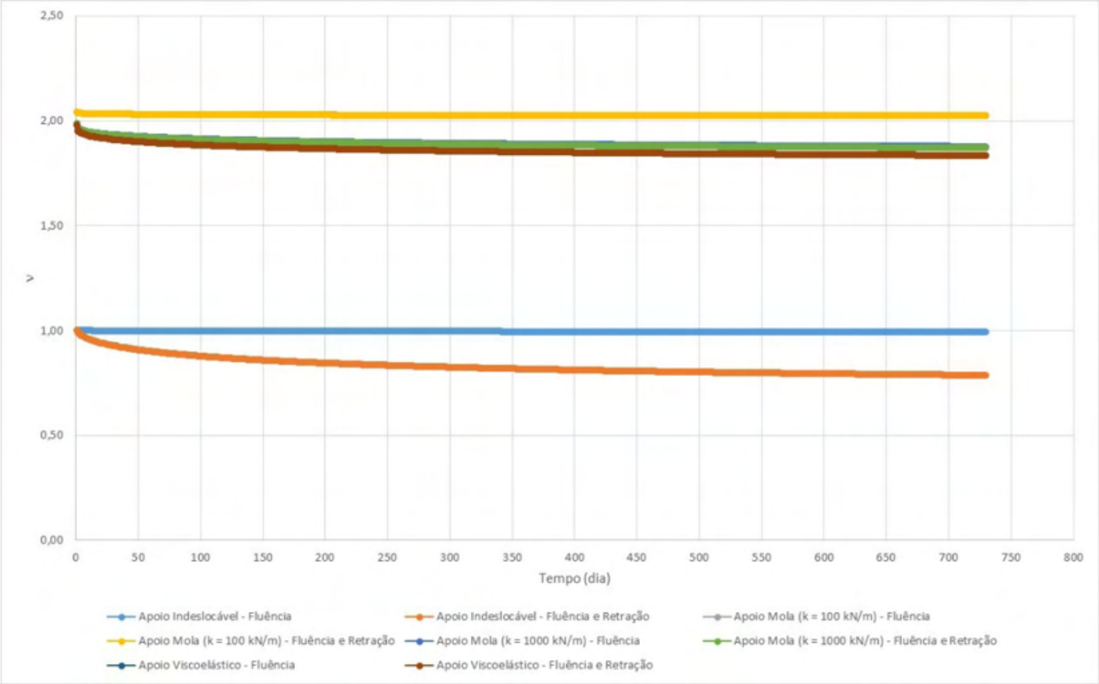


Figure 5. Normal stress on the corner pillars of the three-dimensional structure – stiffness 2 versus time.

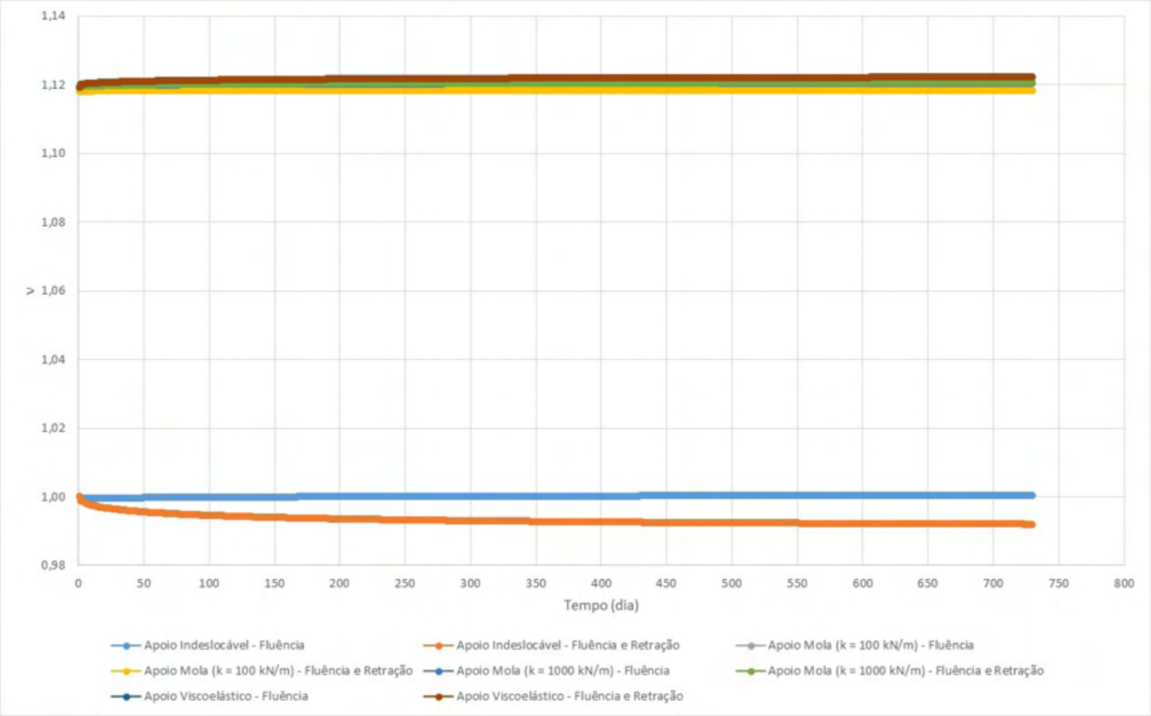


Figure 6. Normal stress on the peripheral pillars of the three-dimensional structure – stiffness 2 versus time.

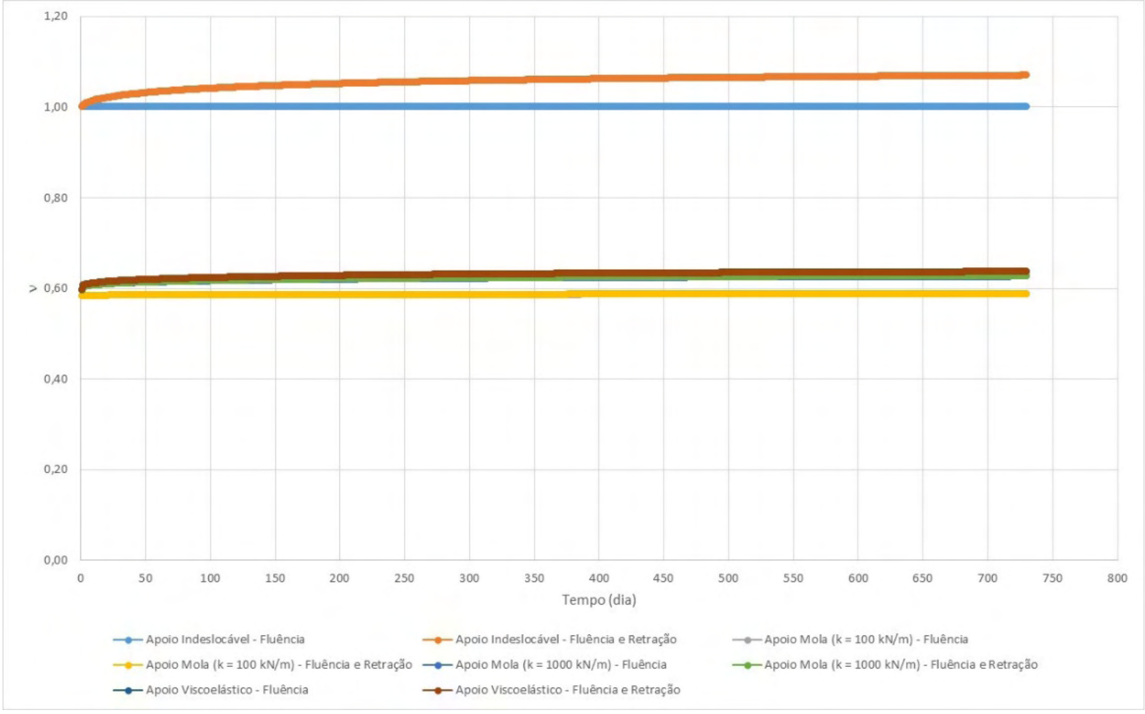


Figure 7. Normal stress on the central pillars of the three-dimensional structure – stiffness 2 versus time.

throughout the period. time (the maximum variation does not reach 1% in the time of 730 days). It is emphasized that the first Elasticity-Viscoelasticity Correspondence Theorem is satisfied.

From Figure 7, it can be observed, in general, that the central columns suffer a stress relief (such relief reaches up to approximately 41% in the time of 730 days for the situation of a three-dimensional structure with spring supports – k = 100 kN/m – and material of the structure subject to creep and material of the structure subject to creep and shrinkage), but there is a small increase in stress over time (the maximum variation of this increase does not reach 7% in the time of 730 days for the situation of a three-dimensional structure with non-displaceable supports and material of the structure subject to creep and shrinkage). It is verified that the first Elasticity-Viscoelasticity Correspondence Theorem is met and, also, that the shrinkage effect does not appear except in the case of a three-dimensional structure with undisplaceable supports. For the fifth and sixth situations - space frame with spring supports (k = 1000 kN/m) and frame material subject to creep and frame material subject to creep and retraction - normal efforts are observed approaching the support situation unmovable, as expected. For the seventh and eighth situations – spatial frame with viscoelastic supports and frame material subject to creep and frame material subject to creep and shrinkage – it can be seen that the values of normal forces also tend to the values of the elastic model.

The analysis performed on the structures (stiffness 1 and 2) showed, for 50% of the columns, a redistribution of stresses with values tending over time (viscoelastic model) to the values of the elastic model. However, the variation of requests can be significant. In fact, it reached about 83% (three-dimensional structure – stiffness 2). Table 1, below, indicates these results – columns selected with gray color.

CONCLUSIONS

The following conclusions are listed:

(i) The corner pillars of three-dimensional structures (stiffness 1 and stiffness 2), in general, absorb stresses in the initial time (which represents the condition of soil-structure interaction) and these stresses decrease over time. (ii) The peripheral pillars of the three-dimensional structures (rigidity 1 and stiffness 2) absorb requests in the initial time (which represents the condition of soil-structure interaction) and these requests remain practically constant over time. (iii) The central pillars of the three-dimensional structures (rigidity 1 and stiffness 2), in general, suffered stress relief in the initial time and these stresses increase over time. (iv) From the increase in the spring stiffness of the supports from k = 100 kN/m to k = 1000 kN/m and, also, from the increase in the rigidity of the three-dimensional structure, the influence of the relative structure-foundation stiffness on the normal stress values over time. (v) When the rigidity of the three-dimensional structure is increased, the creep effect decreases significantly. (vi) The effect of retraction was practically imperceptible in all situations studied. (vii) The analysis of the structures (stiffness 1 and 2) showed, for 50% of the columns, a redistribution of stresses with values tending over time (viscoelastic model) to the values of the elastic model. However, the variation of requests can be significant. In fact, it reached about 83% (three-dimensional structure – stiffness 2).

Cornerstone		Three-dimensional Structure - Rigidity 1				Three-dimensional Structure - Rigidity 2			
		Program Request (Kn)			Δ(%)	Program Request (Kn)			Δ(%)
		Viscoelastic Model		Elastic Model		Viscoelastic Model		Elastic Model	
	1	24	15	13	17	74	65	37	83
Peripheral	7 25	24	15	13	17	74	65	37	83
	31	24	15	13	17	74	65	37	83
		24	15	13	17	74	65	37	83
Peripheral	3 5 9 15 17 23 27 29	31 31 31 31 31 31 31 31	31 31 31 31 31 31 31 31	26 26 26 26 26 26 26 26	-	76 76 76 76 76 76 76 76	76 76 76 76 76 76 76 76	68 68 68 68 68 68 68 68	
	11 13 19				20 20	78 78	83 83	131 131	36 36
centric	21				20	78	83	131	36
					20	78	83	131	36
Σ		495	495	495	-	1216	1216	1216	-
time(day)		1	730	0	1	730	0		

Table 1. Effect of creep on the stresses on the pillars

REFERENCES

Bjerrum, L. (1963) **Allowable Settlement of Structures**. *Proceeding European Conference on Soil Mechanics and Foundation Engineering*, Weisbaden, v. II, pp. 135-137.

Carneiro, F.L.L.B. (1978) **Considerations on the Influence of Shrinkage and Creep of Concrete in the Calculation of Structures**. Colloquium on Shrinkage and Slow Deformation of Concrete, IBRACON, São Paulo, pp. 1-23.Comite Euro-International Du Beton (1990) **Ceb-Fip Model Code**, Design Code, Thomas Telford.

Santa Maria, P.E.L., Santa Maria, F.C.M. & Santos, A.B. (1999) **Analysis of Continuous Beams with Viscoelastic Supports and Their Application to Soil-Structure Interaction Problems**. *Solos & Rochas*, v.22, nº 3, pp. 179-194.

SAP 2000 (2015) CSI **Analysis Reference Manual v.15.0**. Computers and Structures Inc., California, USA, 415 p.

Vyalov, S.S. (1986) ***Rheological Fundamentals of Soil Mechanics***. 1st Edition, Elsevier Science, 564 p.