



Journal of Materials and Engineering Structures

Research Paper

Experimental study of the long-term shortening of reinforced concrete columns under maintaining concentric axial load

Ngoc Long Tran^{a,}, The Truyen Tran^b, Manh Hung Nguyen^a, Van Quyet Truong^b*

^a Dept. Civil Engineering, Vinh University (VUNI), no.182 Le Duan, Vinh City, Nghe An, Viet Nam

^b Dept. Civil Engineering, University of Transport and Communication (UTC), Lang Thuong, Dong Da, Ha Noi, Vietnam

ARTICLE INFO

Article history :

Received : 13 September 2018

Revised : 14 January 2019

Accepted : 27 January 2019

Keywords:

Reinforced concrete columns

Deformation

Shrinkage

Creep

ABSTRACT

This paper presents the results of an experimental study to measure the shortening of reinforced concrete (RC) columns under long-term maintaining concentric axial load. Long-term axial deformation due to shrinkage and creep of the concrete were recorded beside deformation due to mechanical load. Eight RC cylinder - columns (content of reinforcement 1.5% and 2%) with diameter of 150 mm and height of 600 mm were tested during the period of 600 days to determine their shortening. The experimental results showed that the long-term deformation of RC columns occurs primarily during the first year of loading. The deformation creep of concrete is much greater than the shrinkage deformation. The reinforcement content has a significant effect on the long-term deformation of concrete columns.

1 Introduction

Creep and shrinkage of concrete are two important physical properties of concrete. Long term effects of creep and shrinkage on the deformation of concrete structures can result in structural failure. For structural applications, engineers are concerned with changes in the length of members due to time dependent deformations. It is important to have information about the long-term deformations before it can be recommended for usage in structural works.

Many experimental studies of the effects of loads on the behavior of RC columns have been conducted [1-6]. A research on long-term deformations of steel-reinforced concrete columns under sustained axial loads is conducted by Z. Chen et al. [7]. A.E. Schultz et al. [8] present an experimental research to define the effects of long-term deformations on the RC columns to cyclic loading. M.A. Salau [9] reports the comparative study of long-term deformations of normal concrete short columns

* Corresponding author. Tel.: +84 913 973 392.

E-mail address: longtn@vinhuni.edu.vn

under sustained loading. A. B-Jahromi et al [10] investigated the effects of ambient temperature, relative humidity on concrete column shortening. This study showed that environmental factors, ambient temperature and relative humidity have impact on column shortening. The experiments show that the long-term deformations in RC columns caused by creep and shrinkage under long-term loading. A few researchs show also that the concrete structure under the effect of long-term load, non-elastic deformation due to the creep can increase a few times the initial deformation [11, 12].

The objective of this study is to evaluate the long-term shortening of RC columns under concentric axial load. The results include long-term deformations of RC columns due to the effects of long-term maintaining load with considering shrinkage and creep in concrete. In addition, the effect of longitudinal steel reinforcement content on the long-term deformations of RC columns was also investigated.

2 Experimental program

2.1 Materials and composition of mixtures

Portland cement were used to prepare plain cement concrete mixture C30. Crushed limestone was used as the coarse aggregate while dune sand was used as the fine aggregate. The aggregate grading conformed to ASTM C33 limits [13]. The specific gravity and water absorption of the coarse aggregate were 2.92 and 0.86 %, respectively. For fine aggregates, these values were 2.64 and 0.8 %, respectively. The concrete mix was designed in accordance with ACI 211.1 [14]. The compositions of the concrete are shown respectively in Table 1.

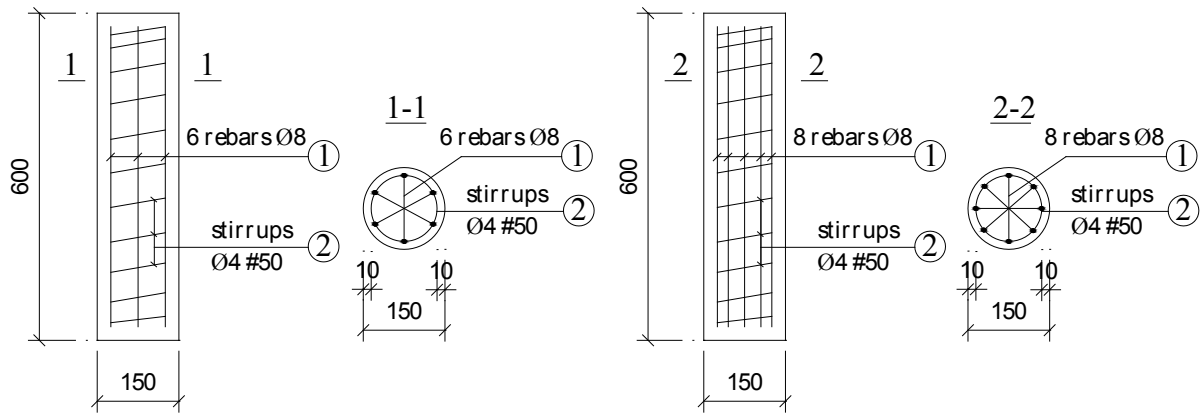
Table 1 - The composition of mixtures for 1m³ of concrete

Materials	Concrete C30
Cement, kg	385
Sand, kg	605
Coarse aggregate, kg	1135
Water, kg	175
Dry Density, kg/m ³	2300
Water/binder	0.45
Compressive strength, MPa	38

2.2 Specimens design and experimental setup

Experimental models are RC columns cylinders with the diameter $D = 150\text{mm}$ and height $H = 600\text{mm}$. As references in the standards ASTM C512 [15], RILEM TC 107-CSP [16] and AS 1012.16 [17], the ratio $H/D = 4$ is suitable for studying the behavior of RC columns under the long-term loads. Two groups of specimens of RC columns used in this study based on the content of longitudinal steel reinforcement (1.5% and 2%). All of the columns were reinforced with 8-mm-diameter deformed bars and the 4-mm-diameter smooth round stirrups.

In each group, among the four RC columns, three specimens were used to determine the long-term deformations under the concentric axial load, on which these specimens were subjected to both deformations due to load and due to shrinkage (RSCL1.5 and RSCL2 – average value). The remaining column specimen is used to determine the long-term deformations due to shrinkage. The specimen is not affected by the experimental load but only the impact of the ambient temperature and humidity (RSC1.5 and RSC2). The RC columns were made with concrete C30. All of the specimens were stored in the same room at the same temperature and moisture conditions. The cross-section and detailing of reinforcement in RC columns are shown in Fig 1.



a- Specimens with longitudinal steel reinforcement content of 1.5% b- Specimens with longitudinal steel reinforcement content of 2%

Fig 1. RC column specimen dimensions and reinforcement detailing

The mechanical characteristics of the concrete are determined including the compressive strength and the elastic modulus. Experimental results for the compressive strength and modulus of elasticity of concrete over time are shown in Figs 2 and 3.

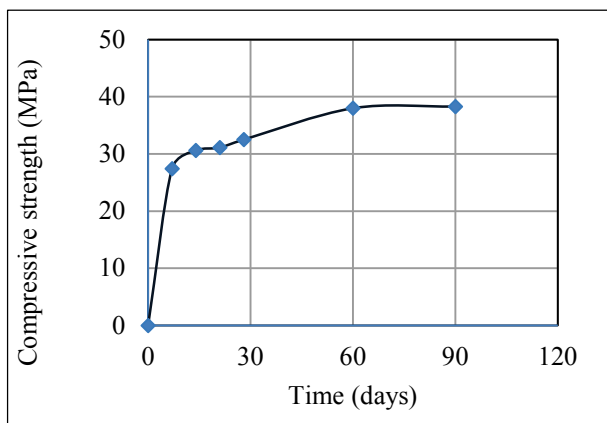


Fig 2. Development of compressive strength with time

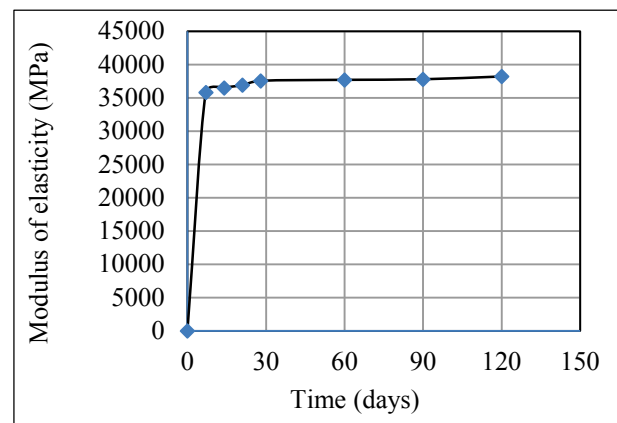


Fig 3. Development of modulus of elasticity with time

2.2.1 Experimental of reinforced concrete column specimens under long-term load

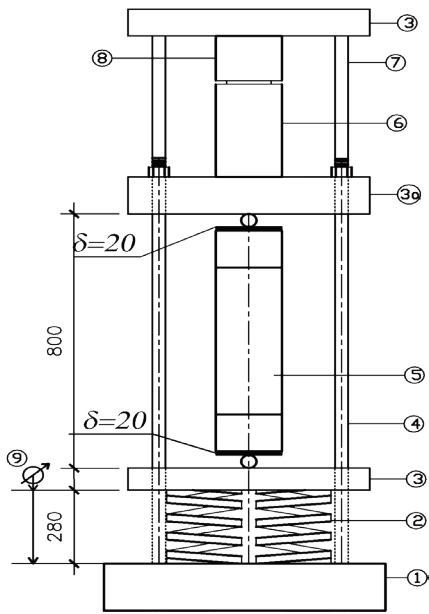
2.2.1.1 Long-term service load value

For long-term load bearing specimens, the concrete worked during the elastic phase, the stress in concrete caused by in-built load does not exceed 40% of the concrete ultimate compressive strength. This has been specified in the ASTM C512, RILEM TC 107-CSP and AS 1012.16 standards.

Here, the compression force applied to the specimens is 35% of the compressive strength of the concrete at the time when starting to bear the load (7 days of age). The average compression force of concrete at the 7 days after casting is 484.3 kN, from which the compressive force applied to the specimens: $P = 35\% * 484.3 = 169.5 \text{ kN} \sim 170 \text{ kN}$ (17 tons).

2.2.1.2 Equipment creates long-term load on the columns

The experimental equipment is a loading system to create the concentric axial load, long-term, to apply the loads on the column specimens. Fig 4 shows the general view of the setup for the experimental testing. The loading system includes two main parts: the initial loading system and the long-term load generating system.



1- Base plate; 2- Spring; 3- Steel bracket bottom; 3a- Steel bracket above; 4- Frame
 5- Testing specimen; 6- Lifting jack; 7- Initial frame; 8- Load cell; 9- Indicator
 a. Detail of the loading system
 b. Photo of loading system

Fig 4. General view of testing setup

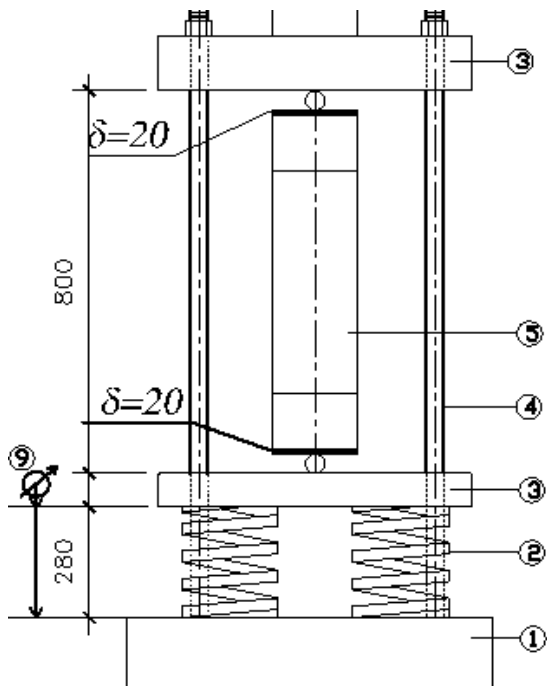


Fig 5. Testing of compressive RC columns

After the load is applied to the specimens to reach test load value (P), turn the bolts to fix the position of the steel bracket bottom. Then remove the original loading system from the long-term load generating system. At this time, the compressive load applied to the specimen produced by the jet of the two springs. This is the long-term loads applied on the specimens. Details of the long-term load system to create the long-term compression load on the specimens are shown in Fig 5.

2.2.1.3 Selection of spring create compression force

The basic requirement is when applying the load, springs work in the elastic region (the relationship between the load and the deformation of the springs is linear). Thus, in this study, two springs were chosen with the same geometry and materials (Figs 6, 7). To test the elastic working region of the spring, the spring compression test has been performed and the deformation of the spring was determined. With a request load of $P = 170 \text{ kN}$, the compressive load on the spring is $0.5P$. The results show that when the compressive load on the spring is $0.5P$, the spring completely works in the elastic region.

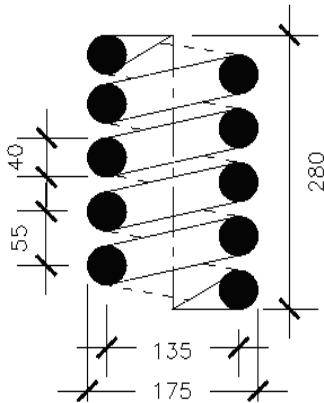


Fig 6. Detailed structure of spring

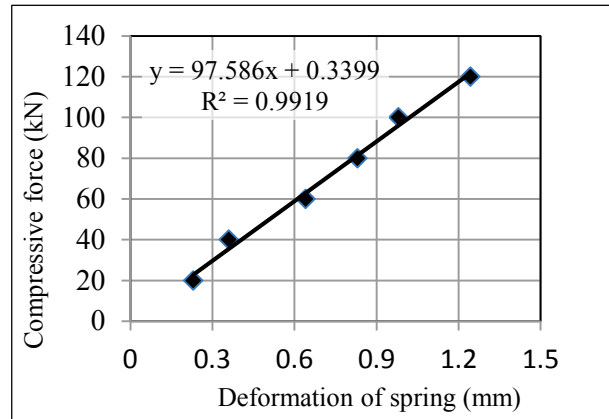


Fig 7. Relation of compression force and deformation of spring

During the testing, the compression force produced by the springs on the specimens can be reduced. Control and monitoring of compressive strength reduction are achieved through the spring expansion [15, 16]. In this study, using the Indicator (9) to measure the spring expansion (see Fig 8). Based on the value of spring expansion and spring stiffness (according to the Fig 7), the reduction of compressive force of the spring is calculated. When the compression force of the spring decreases by more than 3% [16, 17], the initial loading system needs to be used to supplement the reduced load.



Fig 8. Arrangement of deformation spring indicator

2.2.1.4 Arrangement of deformation measuring devices

Use Indicators to measure the deformation of specimens. In this experiment, 5 positions were measured on a cross section (Fig. 9) and numbered respectively I_1, I_2, I_3, I_4, I_5 . Deformation value at each time is determined by the value on the measuring equipment and calculated according to the following formula:

$$\epsilon(t) = \frac{I_i(t) - I_i(0)}{K.L_0} = 2,5.10^{-5} \cdot [I_i(t) - I_i(0)] \tag{1}$$

Where, $I_i(t)$ is the reading value on Indicator i at time t after loading; $I_i(0)$ is the reading value on the Indicator i before uploading the specimen; K is the indicator's gain factor ($K = 100$) and L_0 is the measurement length ($L_0 = 400$ mm).

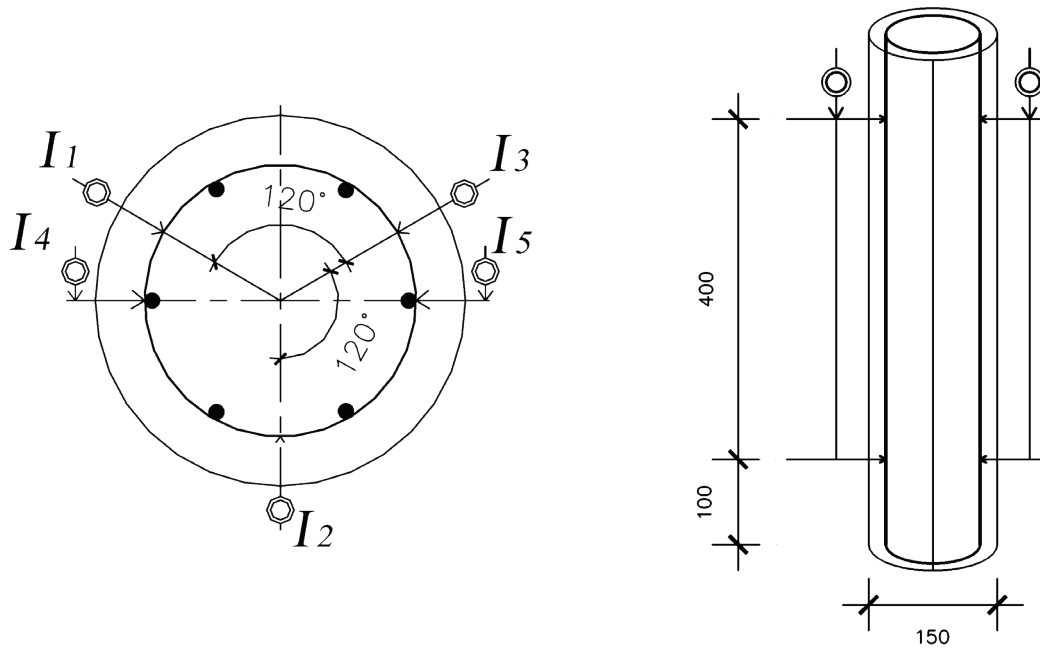


Fig 9. Arrangement of deformation measuring devices

2.2.1.5 Testing time

Long-term deformation including creep and shrinkage. Creep developed over time with the decelerating. When starting to load the creep increases rapidly and decreases as the time increases. The value of the creep value is 50% of the final value for the first 2 -3 months, and after 2 -3 years it reaches 90% of the final value. After a few years of load bearing, the creep will increase very small [18]. According to standards such as [15-17], the test time measured creep, shrinkage of concrete is at least 6 months. In this study, the time of the long-term deformation test of reinforced concrete column is 20 months (600 days). All of the specimens placed in the laboratory to ensure the monitoring and recording of results (Fig 10). During the experiment, set the devices to measure the temperature, humidity environment of the experimental area.



Fig 10. RC columns specimens

2.2.2 Experimental of reinforced concrete column samples without load

The long-term deformation of the specimens in this case, is mainly due to the shrinkage of the concrete. Measurement of the deformation of these specimens is done at the same time, and at the same time with the load-bearing specimens. The testing standard ASTM C157 [19] describes a way to estimate the potential of volumetric expansion of concrete. The deformation of the without load-bearing specimens are very small. So, to measure deformation values, it is necessary to use Indicators with a gain factor of $K = 1000$. In this case, 3 positions were measured on a cross section (Fig. 11).



Fig 11. Arranging measuring indicator on specimens without load

3 Results and discussion

In order to evaluate the deformation test results for the experimental models, it is necessary to mention the measurement results of the environmental conditions. The results of humidity and temperature measurements are shown in Figs 12, 13.

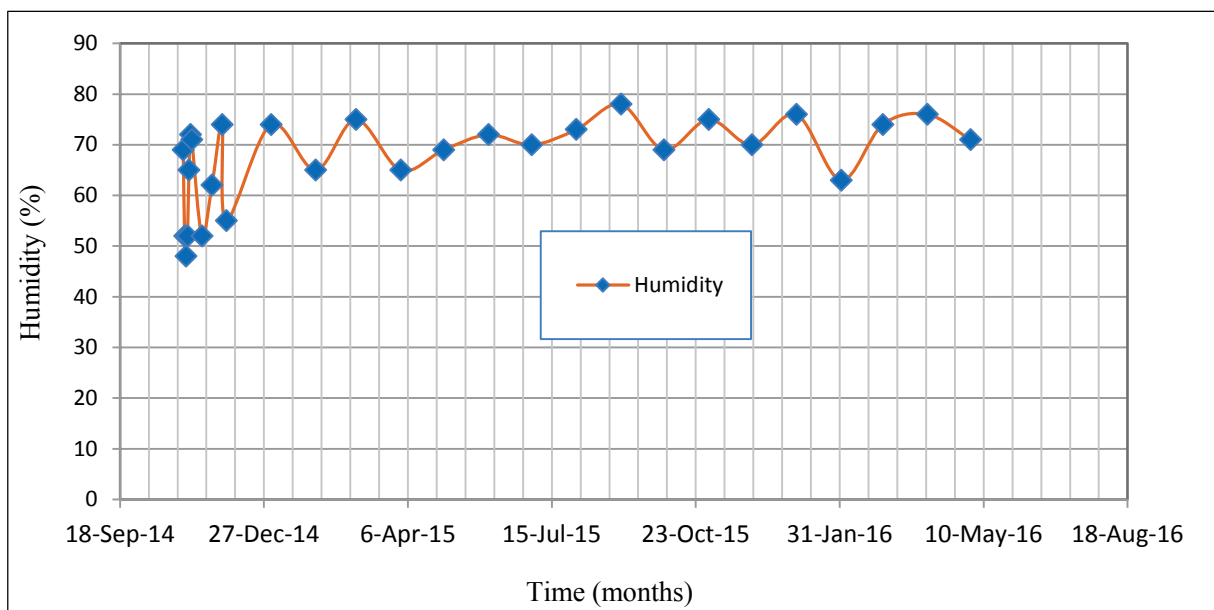


Fig 12. The environmental humidity condition

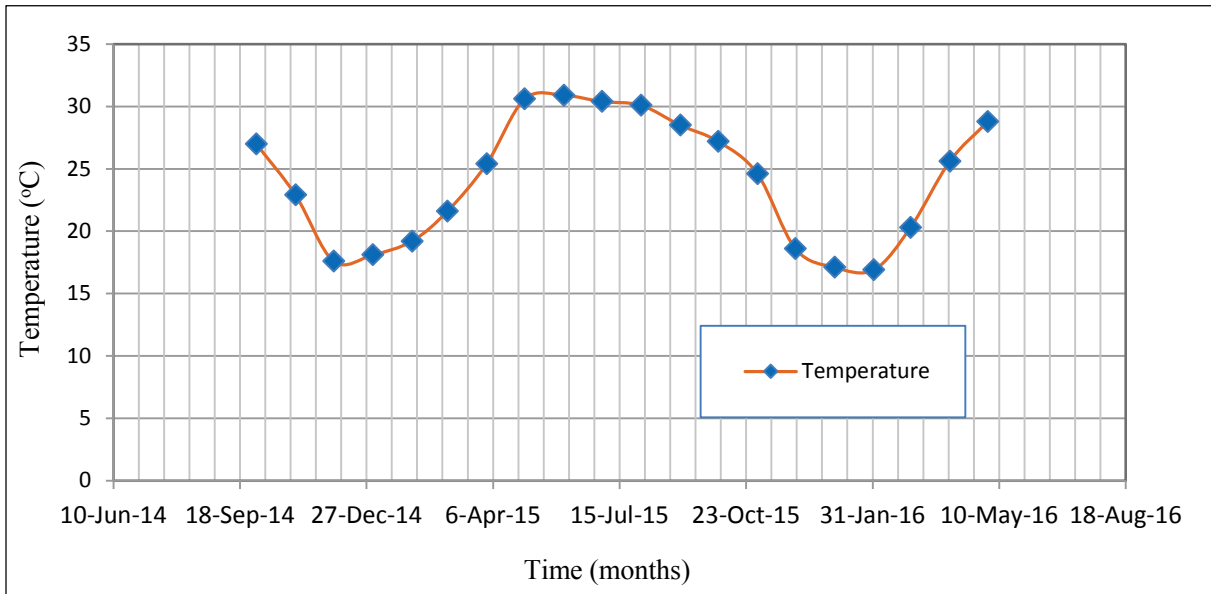


Fig 13. The environmental temperature condition

The results of deformation testing of reinforced concrete column specimens under long-term load (including elastic deformation and creep deformation) and deformation of reinforced concrete column specimens (shrinkage deformation) after 600 days were shown in Figs 14, 15.

Through the results of deformation test of RC columns can be show that:

The difference showing on Indicators recorded between the previous measurement and the following measurement within the monitoring period is consistent with the development rule of long-term deformation (increasing rapidly in initial age concrete without load and decreasing as time increases).

Deformation monitoring of RC columns (RCSL1.5 and RCSL2) under axial load showed that the deformation value from the fourth month (120 days) to seventh month (210 days) was noticeably smaller than the previous months. This can be explained as follows, in addition to the effects of concrete age, during that time, the humidity of the laboratory environment is higher. Deformation monitoring of RC columns (RSC1.5 and RSC2) without load showed that the smallest deformation value occurring during high humidity months (April and May – see Fig 12). A. B-Jahromi et al [10] have also indicated that the deformation of columns can be reduced by 20% to 10% by increasing the relative humidity from 50% to 80%.

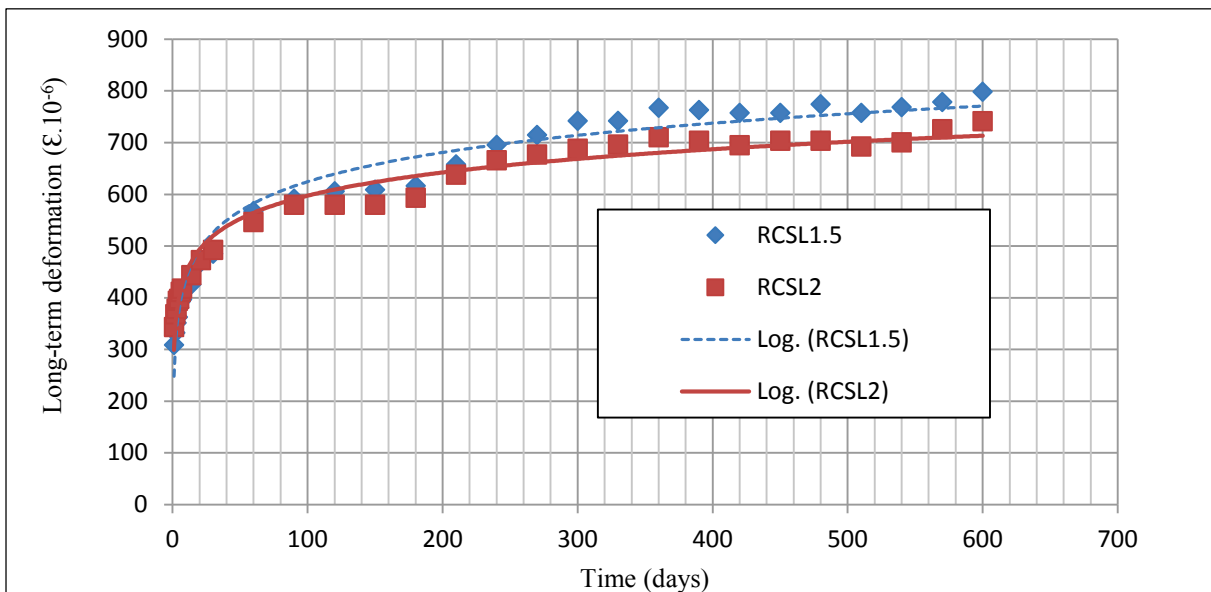


Fig 14. Time-dependent long-term deformation of specimens with reinforced content 1.5% and 2%

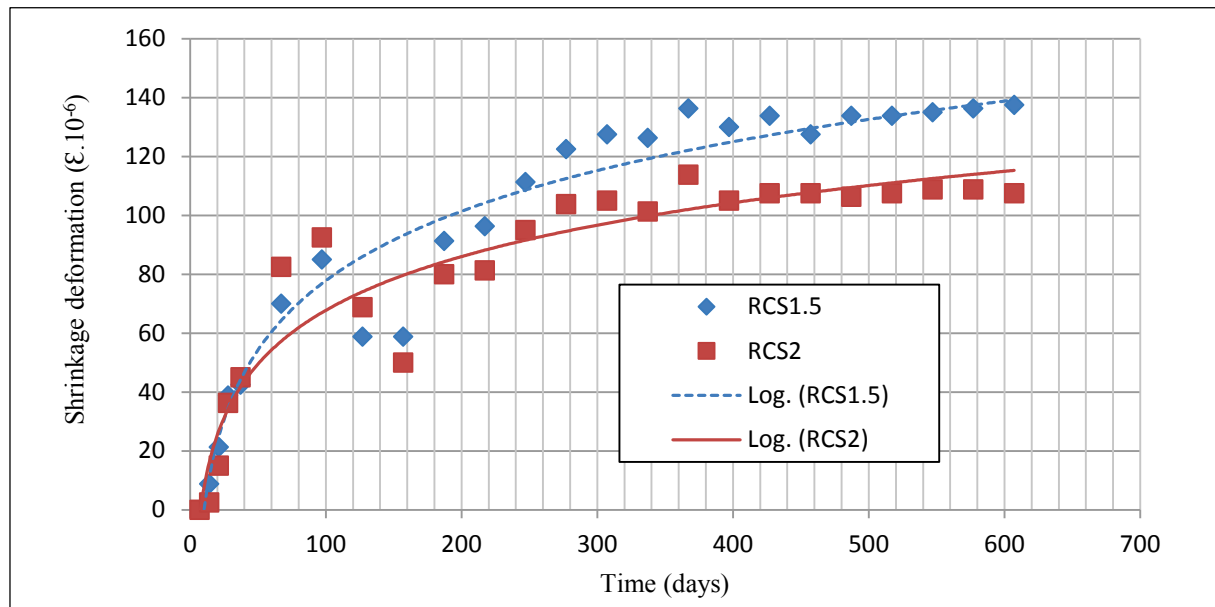


Fig 15. Time-dependent shrinkage deformation of specimens with reinforced content 1.5% and 2%

From Fig 14 and Fig 15, it can be seen that the deformation speed decreases over time, the two curves (with different reinforced content 1.5% and 2%) are nearly parallel in the later period. At the end of a 600 days loading period, the long-term deformation of the columns was 798.1×10^{-6} and 741.1×10^{-6} in specimens RCSL1.5 and RCSL2, respectively and the shrinkage deformation of the columns was 137.5×10^{-6} and 107.5×10^{-6} in specimens RSC1.5 and RSC2, respectively. The shrinkage deformation curves tend to converge after about one year. The results show that the long-term deformation after 600 days was 3.2 times larger (for the reinforced content of 1.5%) than instantaneous deformation, corresponding to 2% reinforcement content, this value was 2.73 times. For specimens with a small steel content, the deformation is larger and reverse. The results of this study are similar to those of Z. Chen et al. [7]. The long-term deformations of the columns decreased as the steel area ratio increased.

4 Conclusion

From the results of this study, some conclusions can be given as follow:

The results have shown that the long-term deformations decreased as the steel content increased. The long-term deformations of RC columns under maintaining concentric axial load were large after 600 days. However, the curves (reinforced content 1.5% and 2%) converge in the later period (after one year). The results experimentals have also shown that the shrinkage deformation of RC columns increases as the age increases. The shrinkage deformations curves also converge after about one year.

The changing environmental conditions (temperature and humidity) affect the long-term deformations and shrinkage of concrete column. Under the influence of higher humidity and temperature, RC column exhibit lower deformation. The experiment results proved that a reduction in value deformation as the high humidity.

From the datasets measured on the long-term deformations, can be calculated the time-depended creep coefficient. This coefficient has practical significance applicable in designing structures reinforcement concrete.

REFERENCES

- [1]- M.T.R. Jayasinghe, W.V.P.K. Jayasena, Effects of Axial Shortening of Columns on Design and Construction of Tall Reinforced Concrete Buildings. *Pract. Periodic. Struct. Des. Constr.* 9(2) (2004), 70-78. doi:10.1061/(ASCE)1084-0680(2004)9:2(70).
- [2]- Z. Chen, T. Dai, Effects of sustained axial loads on steel-reinforced concrete columns. *HKIE Transactions* 22(1) (2015) 16-22. doi:10.1080/1023697X.2015.1008590.

-
- [3]- M. Husem, S. Pul, S.E. Gorkem, S. Demir, The behaviour of high-strength reinforced concrete columns under low eccentric loading. *Eur. J. Environ. Civ. En.* 20(4) (2016) 486-502. doi:10.1080/19648189.2015.1047534
- [4]- H. Rodrigues, A. Arêde, H. Varum, A.G. Costa, Experimental evaluation of rectangular reinforced concrete column behaviour under biaxial cyclic loading. *Earth. Eng. Struct. D.* 42(2) (2013) 239-259. doi:10.1002/eqe.2205
- [5]- U.K. Sharma, P. Bhargava, S.K. Kaushik, Behaviour of Confined high strength concrete columns under axial compression. *J. Adv. Concrete Technol.* 3(2) (2005) 267-281. doi:10.3151/jact.3.267.
- [6]- H. Rodrigues, A. Arêde, J.P. Silva, P. Rocha, A. Furtado, Behaviour of RC columns under variable load and bidirectional horizontal loading. In: *Proceedings of the Second European Conference on Earthquake Engineering and Seismology*, 25-29 August, Istanbul, 2014.
- [7]- Z. Chen, Y. Wang, J. Wu, Long-term deformations of steel-reinforced concrete columns under sustained axial loads. *Mech. Mater.* 351-352 (2013) 645-649. doi:10.4028/www.scientific.net/AMM.351-352.645
- [8]- A.E. Schultz, S.S. Welton, L.E. Rey, Long-term effects on response of reinforced concrete columns to cyclic loading. *J. Struct. Eng-ASCE* 130(9) (2004) 1320-1332. doi:10.1061/(ASCE)0733-9445(2004)130:9(1320)
- [9]- M.A. Salau, Long-term deformations of laterized concrete short columns. *Build. Environ.* 38(3) (2003) 469-477. doi:10.1016/S0360-1323(02)00014-8
- [10]- A. B-Jahromi, A. Rotimi, S. Tovi, C. Goodchild, J. Rizzuto, Evaluation of the influence of creep and shrinkage determinants on column shortening in mid-rise buildings. *Adv. Concrete Constr.* 5(2) (2017) 155-171. doi:10.12989/acc.2017.5.2.155
- [11]- G. Ranzi, Simplified approach for calculating creep deflections of reinforced concrete members. *Concrete Australia* 41(1) (2015) 58-64.
- [12]- A. Gholamhoseini, R.I. Gilbert, M.A. Bradford, Long-term deformations in continuous composite concrete slabs. *Aust. J. Struct. Eng.* 17(3) (2016) 197-212. doi:10.1080/13287982.2016.1238531
- [13]- ASTM C33-13, Standard Specification for Concrete Aggregates. American Society for Testing and Materials, ASTM International, West Conshohocken, PA, USA, 2013.
- [14]- ACI 211.1-91, Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete. ACI Committee 211, 2002.
- [15]- ASTM C512/C512M-15, Standard Test Method for Creep of Concrete in Compression. American Society for Testing and Materials, ASTM International, West Conshohocken, PA, USA, 2015
- [16]- RILEM Subcommittee 4: Standardized Test Methods for Creep and Shrinkage, Measurement of time-dependent strains of concrete. *Mater. Struct.* 31(1998) 507-512. doi:10.1007/BF02481530
- [17]- AS1012.16, Methods of testing concrete. Determination of creep of concrete cylinder in compression. Standards Australia Committee BD/42, Standard of Australia, Australia, 1996
- [18]- R.I. Gilbert, G. Ranzi, *Time-Dependent Behavior of Concrete Structures*. CRC Press, Taylor & Francis Group, 2010.
- [19]- ASTM C157/C157M-08, Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete, American Society for Testing and Materials, ASTM International, West Conshohocken, PA, USA. 2014