GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186

GSJ: Volume 5, Issue 12, December 2022, Online: ISSN xxxx-xxxx
www.globalscientificjournal.com

Analytical and Experimental Study on the Influence of Large Seismic Deformations on the Out-of-plane Instability of Highly-Reinforced Shear Walls

Theodoros Chrysanidis[1], Vasileios Panoskaltsis[2]

[1] *Dr. Civil Engineer, MSc DIC, Civil Engineering Department, Democritus University of Thrace, Greece. E-mail: theodoros_gr@yahoo.com*
[2] *Professor, Civil Engineering Department, Democritus University of Thrace, Greece.*

KeyWords
Analytical Study, Elongation Degree, Transverse Buckling

ABSTRACT

In the context of the present work, the influence of the degree of tension on the phenomenon of transverse instability of reinforced concrete seismic walls is examined. The present investigation is both experimental and analytical and consists of 4 test specimens. These specimens simulate the extreme boundary edges of structural walls. All columns simulate only the extreme reinforced areas of the walls, in order to study the basic mechanism of the phenomenon. The detailing of the specimens consists of 4 rebars with a diameter of 10 mm for each bar and 2 rebars with a diameter of 8 mm for each of the two bars. The geometric dimensions are the same for all specimens. What differentiates the specimens from each other is the degree of tension they have sustained. More specifically, the tensile degrees used are 10‰, 20‰, 30‰ and 50‰. The loading stages of each specimen for all specimens are as follows: (a) Uniaxial central tensile loading on each test specimen; (b) Uniaxial central compression loading on each specimen till its failure due to buckling or due to an excess of its cross-section compressive strength. The present study focuses on the tensile loading stage only. Extreme tensile strengths are also used, e.g., 30‰ and 50‰, in order to take into account, the cases of extreme seismic excitations. The experimental study is followed by the numerical investigation of these 4 specimens using appropriate statistical software and finite elements. Useful conclusions are drawn regarding the influence of the degree of elongation on the phenomenon of transverse buckling. These conclusions are substantiated both experimentally and analytically, as the results of the experiments are compared with the corresponding results of the analytical investigation.

GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186

1. INTRODUCTION

Structural behavior and soil-structure interaction has troubled engineers worldwide for various types of structures [1–4]. One crucial type of failure of reinforced concrete seismic walls is the lateral buckling [5, 6]. In international bibliography, it can be found either as lateral buckling or transverse buckling or out-of-plane buckling. The terminology instability is used sometimes, too instead of buckling. Several researchers worldwide have investigated this particular phenomenon and the mechanical parameters influencing it [7, 8, 17–25, 9–16]. The basic parameters examined were degree of elongation, longitudinal reinforcement ratio and slenderness [26–32].

The present study uses experimental tests performed in the past by the first author trying to investigate the mechanical parameters affecting the transverse instability [16, 17]. These specimens were subjected to low, medium and high tensile strains equal to 10‰, 20‰, 30‰ and 50‰. In the framework of the present work, the four specimens subjected to tensile loading are modelled using finite element analysis and the results of this analytical investigation are compared to the existing experimental results concerning the tensile loading stage. It is noted that the experiments have taken place at the Laboratory of Strength of Materials of the Aristotle University of Thessaloniki and the analysis of the results has taken place at the Demokritos University of Thrace.

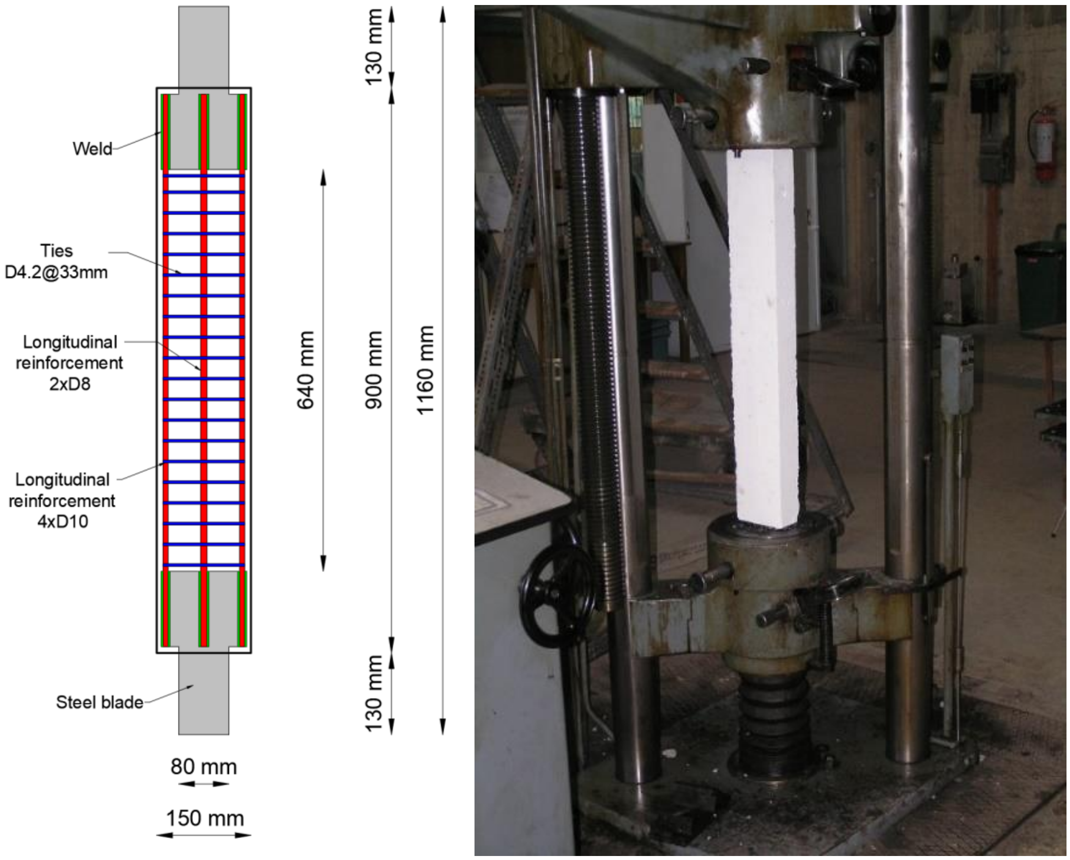
2. EXPERIMENTAL RESEARCH

2.1. Test Specimen Characteristics

The experimental investigation for the four test specimens has been described in detail by the first author in the past [16, 17]. Fig. 1a shows the geometrical characteristics of the four test specimens, while Fig. 1b displays the load test setup used for the application of the tensile loading. It is noted that the tensile loading is the first stage of the two loading stages. In the framework of the present study, only the experimental results of the tensile loading stage are compared to the analytical ones. Table 1 shows the test specimens' characteristics.

Table 1. Dimensions of the test specimens.

N/A	**Specimen**	**Dimensions (cm)**	**Longitudinal reinforcement**
1	PR-10	15x7.5x76	4xD10 + 2xD8
2	PR-20	15x7.5x76	4xD10 + 2xD8
3	PR-30	15x7.5x76	4xD10 + 2xD8
4	PR-50	15x7.5x76	4xD10 + 2xD8
N/A	**Transverse reinforcement**	**Longitudinal rebar ratio (%)**	**Elongation Degree (‰)**
1	D4.2@33 mm	6.03	10.00
2	D4.2@33 mm	6.03	20.00
3	D4.2@33 mm	6.03	30.00
4	D4.2@33 mm	6.03	50.00



(a) (b)

Fig. 1. (a) Vertical reinforcement layout, (b) Test setup for tensile loading.

2.2. Materials

For all test specimens, materials used for their construction and their characteristics were also described in the past [16, 17]. Table 2 displays the concrete resistance for all test specimens at 28 days and at the day the compression test has taken place while Table 3 shows the mechanical properties for the longitudinal steel and the transverse ties.

Table 2. Concrete mechanical properties.

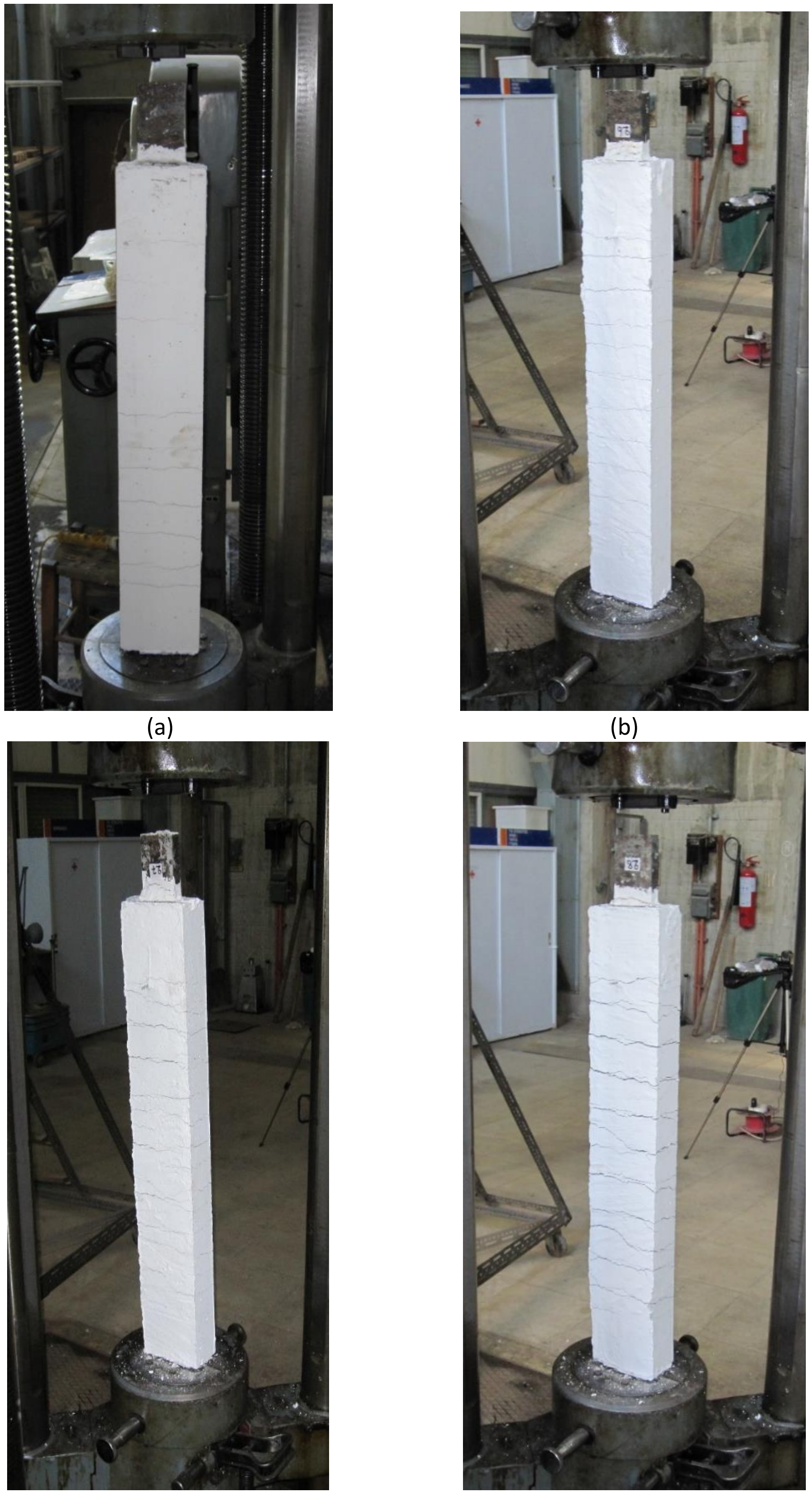
N/A	Specimen	Cube resistance (28 days) (MPa)	Cube resistance (Compression test) (MPa)	Cylinder resistance (Compression test) (MPa)
1	PR-10	22.82	25.78	20.78
2	PR-20	22.82	25.78	20.78
3	PR-30	22.82	25.78	20.78
4	PR-50	22.82	25.78	20.78

Table 3. Reinforcement mechanical properties.

Reinforcement	Yield strength (MPa)	Ultimate strength (MPa)
D8 (Longitudinal reinforcement)	603.77	743.10
D10 (Longitudinal reinforcement)	552.02	670.91
D4.2 (Transverse ties)	674.01	674.01

2.2. Experimental Results

Each one of the four test specimens has been subjected to a different degree of elongation [16, 17]. Fig. 2 displays the shape of specimens after the uniaxial tensile test has taken place. It is obvious that several cracks of different width have formed as it has happened in other similar experiments [33].



(a) (b)

(c) (d)

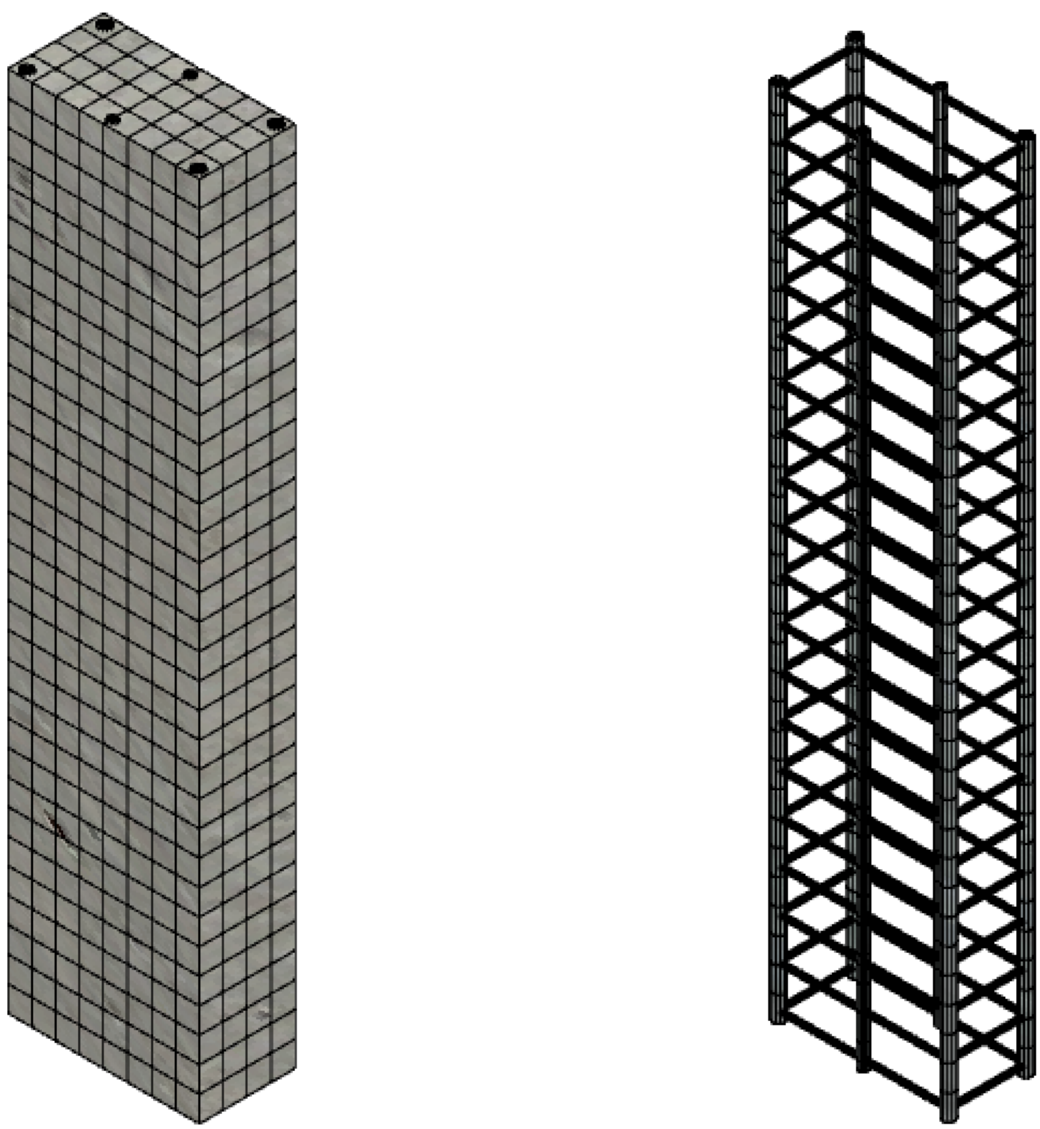
GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186

Fig. 2. Specimens with high reinforcement ratio after the uniaxial tensile test: (a) PR-10, (b) PR-20, (c) PR-30, (d) PR-50.

3. ANALYTICAL RESEARCH

3.1. Modelling of Test Specimens

The analytical research has taken place using a finite element software. 3D elements were used to model all four test specimens subjected to tensile loading. It is noted, as it has been mentioned before, that the present work focuses on modeling only the first stage of loading; meaning the tensile loading path till certain preselected and different degrees of elongation. For the concrete material, the inelastic concrete model of isotropic plasticity from the software library has been chosen. For the reinforcement bar material, the properties derived from experiments are implemented in the software in order to model the inelastic behavior of reinforcement steel. A bilinear isotropic model has been chosen for the behavior of rebar steel. The same inelastic model has been selected to model the behavior of the steel used for the transverse ties. 3D finite elements having an edge of 2 cm are used for the modeling of the concrete column section. Both the longitudinal reinforcement and the transverse ties are modelled using 3D finite elements having a length equal to 1 cm. Fig. 3 shows the 3D model of the column both for the whole column section and the reinforcement steel. The column model is considered fixed at its base.



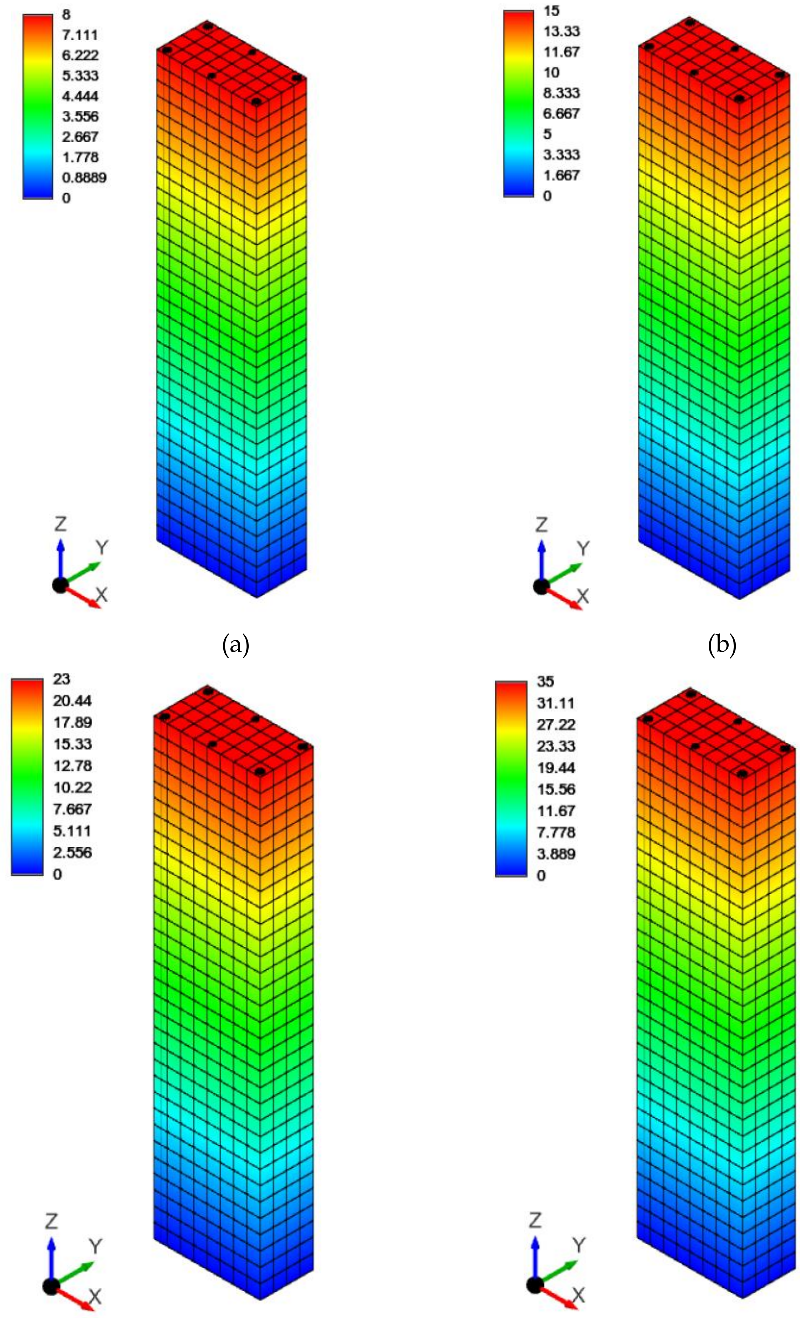
(a) (b)

Fig. 3. (a) 3D model for column, (b) 3D model for the column reinforcement

GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186

3.2. Analytical Results

Fig. 4 displays the displacement along the column height after the end of the tensile loading test.



(c) (d)

Fig. 4. Percentage change of concrete and steel weight per change of seismic zone.

4. ANALYSIS OF RESULTS

4.1. Analytical versus Experimental Results

A comparison takes place between the load versus elongation diagrams which have resulted from the experimental tensile tests and the numerical tensile tests (Fig. 5 - Fig. 8).

GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186

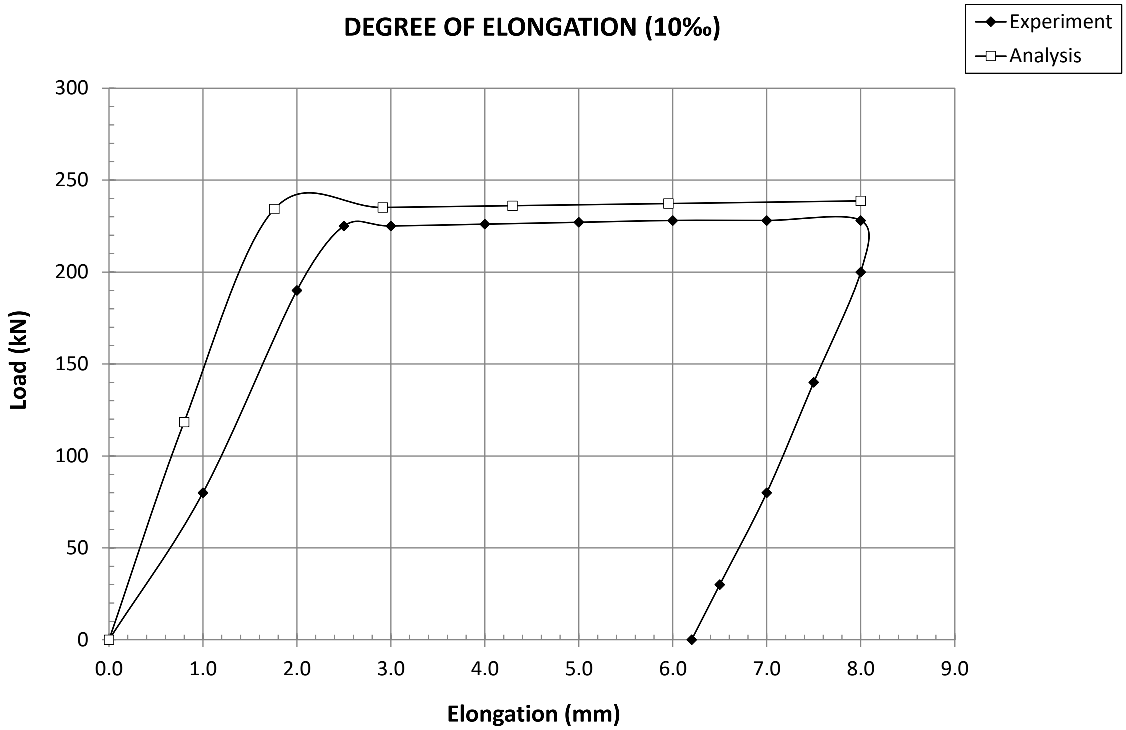


Fig. 5. Load versus elongation diagram for specimen C-10.

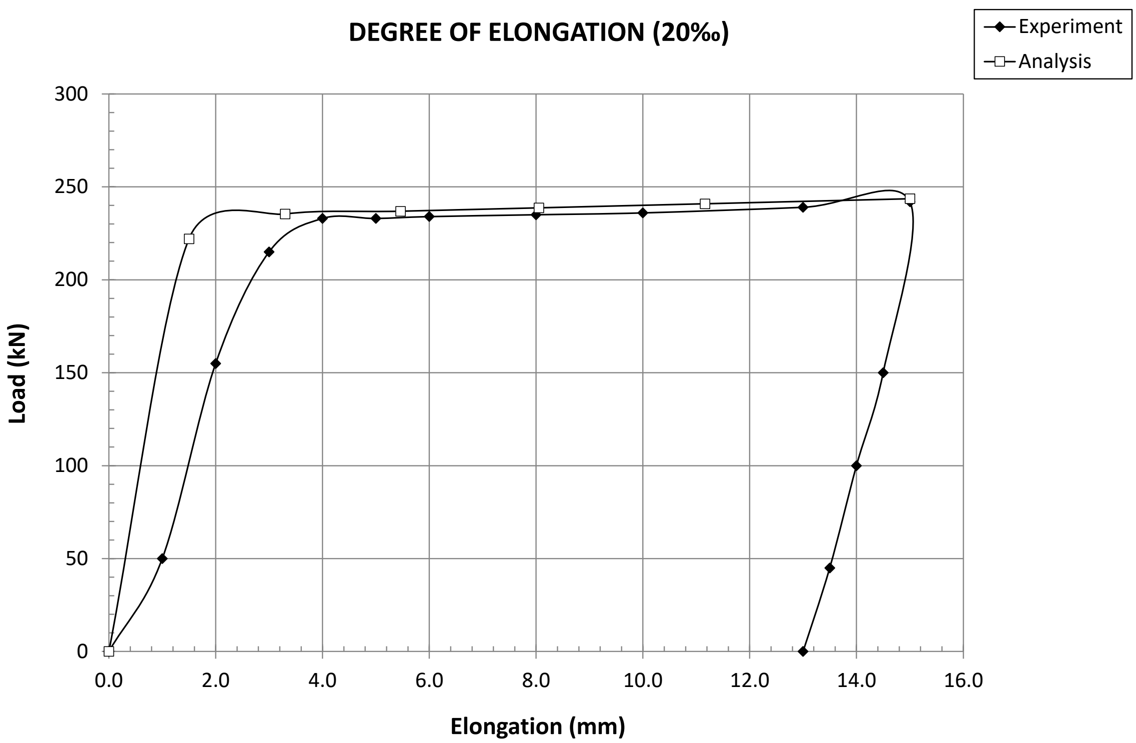


Fig. 6. Load versus elongation diagram for specimen C-20.

GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186

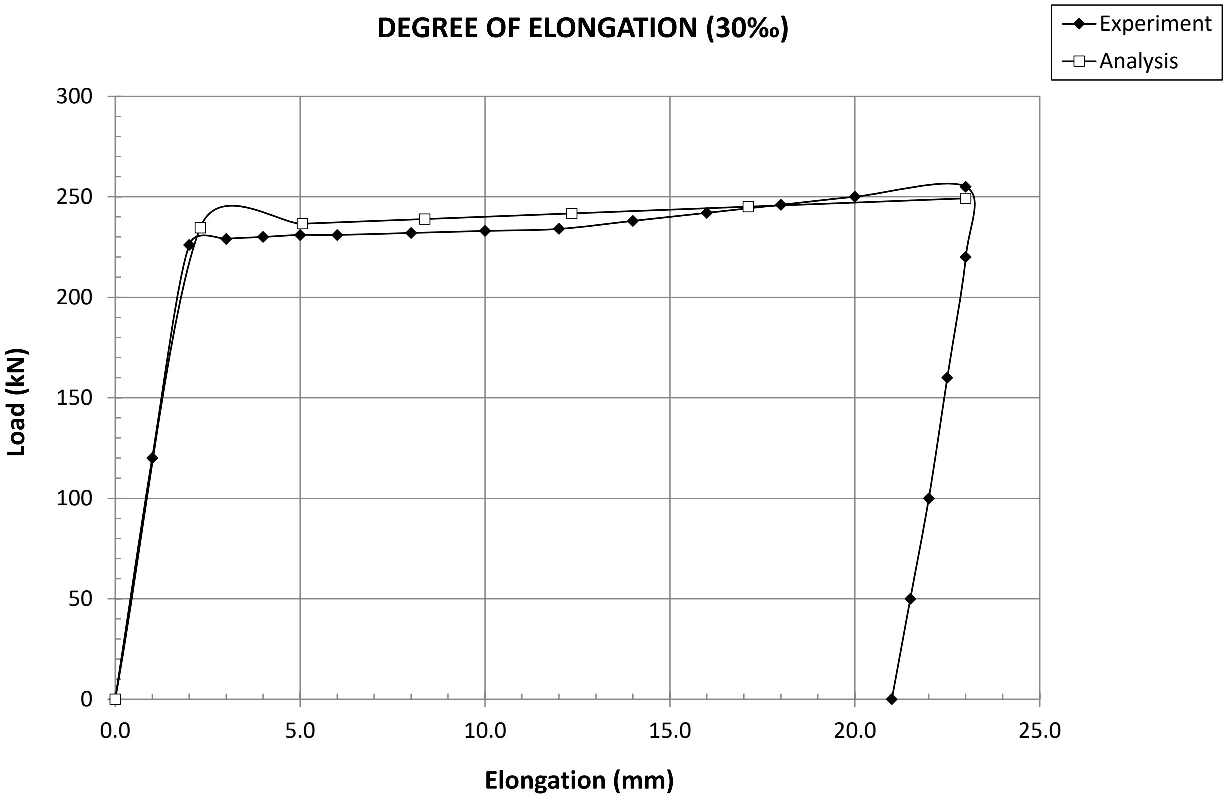


Fig. 7. Load versus elongation diagram for specimen C-30.

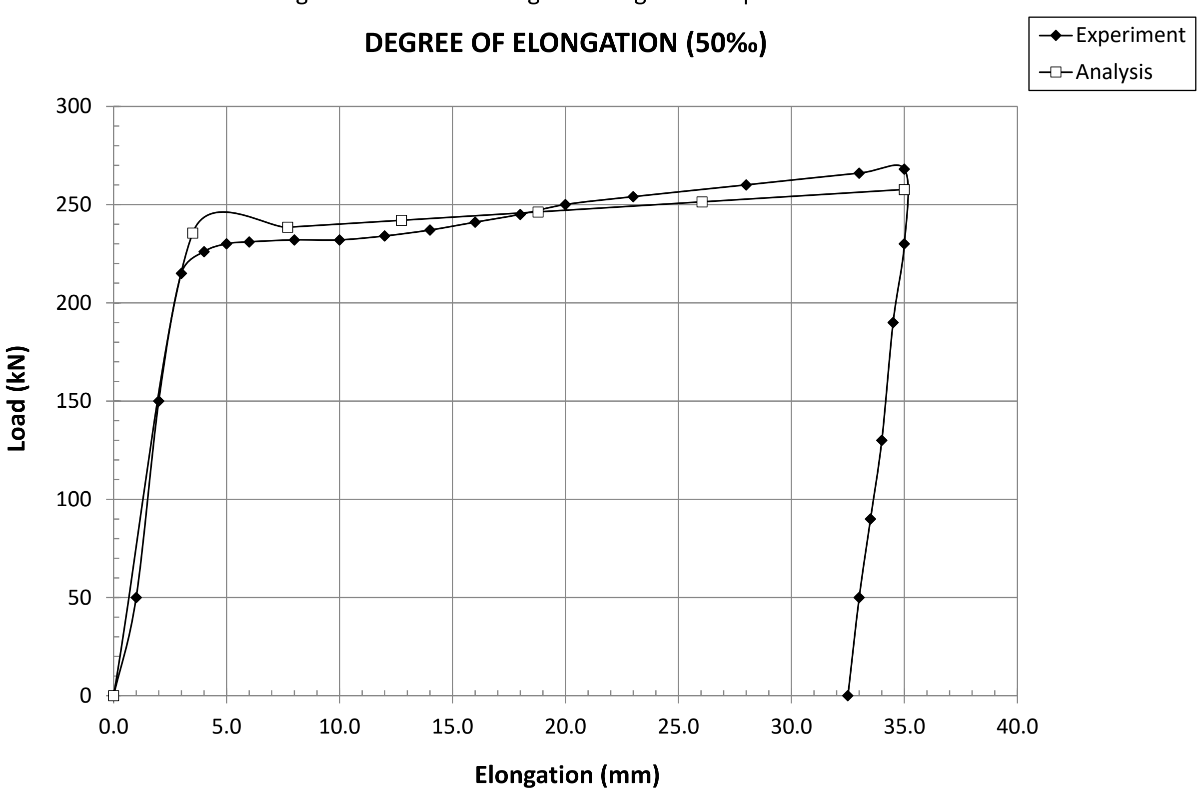


Fig. 8. Load versus elongation diagram for specimen C-50.

GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186

4.2. ANALYSIS OF RESULTS

The analysis of the previous results leads to the following:

1. Fig. 4 displays the displacement along the Z-axis which coincides with the height of the prism specimens modeling the extreme edges of seismic walls. All specimens are strained till the preselected displacement according to the preselected tensile degree.
2. The vertical displacement is zero at the base of the prisms since the base is fixed (Fig. 4). The maximum vertical displacement is found towards the upper part of the specimens where the tensile load is applied. The same phenomenon takes place in the tensile experiments where the tensile load is applied at the upper part of the test specimens while at the bottom part the test specimens are held rigidly by the grapples of the tensile machine.
3. It is obvious that there is a very good correlation between the experimental and the analytical results for all test specimens (Fig. 5 - Fig. 8). Both the elastic and the plastic branch coincide very well between the experiments and the analyses.
4. It is noteworthy that yielding takes place almost at the same load both for the tests and the analyses for all test specimens.
5. Only the effective length of the specimens has been modelled, since this is the length within which the tensile elongation appears (Fig. 1). The effective length is equal to 640 mm (Fig. 1).

Conclusion

1. There is a very good correlation between the experimental results and the analytical results concerning the load-displacement diagrams of the tensile loading.
2. The elastic branch, the yielding point and the plastic branch coincide very good for all four test specimens.
3. The degree of elongation is a very crucial mechanical parameter that affects tremendously the behavior of the boundary edges of structural walls and its investigation has to be applied in the proper and right way following a correct procedure. The convergence between the experimental and the numerical results proves that the procedure applied, in the present work, follows the right path.
4. Future research could and should model the whole test specimen and not only the effective length in order to simulate even more precisely the experimental behavior. Then this more precise analytical behavior could be compared again with the relevant experimental results.

Acknowledgment

This research is co-financed by Greece and the European Union (European Social Fund- ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project “Reinforcement of Postdoctoral Researchers - 2nd Cycle” (MIS-5033021), implemented by the State Scholarships Foundation (IKY).

Ευρωπαϊκή Ένωση
European Social Fund

Operational Programme
Human Resources Development, Education and Lifelong Learning
Co-financed by Greece and the European Union

ΕΣΠΑ 2014-2020
ανάπτυξη - εργασία - αλληλεγγύη

References

[1] Alamanis, N.: Influence of random soil strength properties on the earthquake vulnerability of slopes with embedded oil and natural gas pipelines. Energy Systems. (2020). https://doi.org/10.1007/s12667-020-00394-9.

[2] Alamanis, N., Papageorgiou, G., Chantzopoulou, P., Chouliaras, I.: Investigation on the influence of permeability coefficient k of the soil mass on construction settlements. Cases of infrastructure settlements in Greece. Wseas Transactions on Environment and Development. 15, 95–105 (2019).

[3] Papageorgiou, G., Alamanis, N., Chouliaras, I., Kapsali, P.: Decision making for designing infrastructure projects: The case of the city of Larissa, Greece. Journal of Engineering and Architecture. 7, 115–125 (2019). https://doi.org/10.15640/jea.v7n1a13.

[4] Alamanis, N., Dakoulas, P.: Effect of spatial variability of soil properties on the stability and permanent seismic displacements of highway slopes. In: The 17th European Conference on Soil Mechanics and Geotechnical Engineering. , Reykjavik, Iceland (2019).

[5] Penelis, G.G., Kappos, A.J.: Earthquake-resistant Concrete Structures. E & F N SPON (Chapman & Hall), London, UK (1996).

[6] Penelis, G., Stylianidis, K., Kappos, A., Ignatakis, C.: Reinforced Concrete Structures. A.U.Th. Press, Thessaloniki, Greece (1995).

[7] Chrysanidis, T.: The effect of longitudinal reinforcement ratio on the lateral buckling behavior of R/C walls modelled using prism elements. Journal of Building Engi-

GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186

neering. 42, (2021). https://doi.org/10.1016/j.jobe.2021.102456.

[8] Chrysanidis, T.: Evaluation of Out-of-Plane Response of R/C Structural Wall Boundary Edges Detailed with Maximum Code-Prescribed Longitudinal Reinforcement Ratio, (2020). https://doi.org/10.1186/s40069-019-0378-4.

[9] Chrysanidis, T.: Influence of elongation degree on transverse buckling of confined boundary regions of R/C seismic walls. Construction and Building Materials. 211, 703–720 (2019). https://doi.org/10.1016/J.CONBUILDMAT.2019.03.271.

[10] Chrysanidis, T., Tegos, I.: Does reinforcement ratio affect displacements due to lateral buckling behavior of concrete walls? International Journal of Applied Engineering Research. 12, 382–388 (2017).

[11] Chrysanidis, T.: Low Reinforced Shear Walls: Displacements and Failure Modes Due to Lateral Buckling. International Journal of Science and Engineering Investigations. 5, 143–148 (2016).

[12] Chrysanidis, T.: Degree of Elongation of Maximum Code-Prescribed Reinforced Walls: Modes of Failure and Displacements of Lateral Buckling Phenomenon. International Journal of Trend in Research and Development. 3, 435–440 (2016).

[13] Chrysanidis, T., Tegos, I.: Displacements and mode of failure of medium high reinforced walls due to transverse buckling. International Journal of Engineering Development and Research. 4, 628–634 (2016).

[14] Chrysanidis, T., Tegos, I.: Size of seismic tensile strain and its influence on the displacements due to transverse buckling of ultra-highly reinforced structural walls. ARPN Journal of Engineering and Applied Sciences. 11, 13884–13890 (2016).

[15] Chrysanidis, T., Tegos, I.: Influence of elongation degree on out-of-plane buckling of R/C structural walls with a medium high reinforcement ratio. International Journal of Civil Engineering and Technology. 7, 358–364 (2016).

[16] Chrysanidis, T.: Size of seismic tensile strain and its influence on the lateral buckling of highly reinforced concrete walls. IOSR Journal of Mechanical and Civil Engineering. 11, 18–22 (2014). https://doi.org/10.9790/1684-11121822.

[17] Chrysanidis, T., Tegos, I.: Out-of-plane buckling of highly reinforced seismic walls: Displacements and mode of failure. International Journal of Civil Engineering and Technology. 5, 101–107 (2014).

[18] Rosso, A., Jiménez-Roa, L., De Almeida, J.P., Zuniga, A.P., Guerrero, Blandón, C., Bonett, R., Beyer, K.: Cyclic tensile-compressive tests on thin concrete boundary elements with a single layer of reinforcement prone to out-of-plane instability. Bulletin of Earthquake Engineering. 16, 859–887 (2018). https://doi.org/10.1007/s10518-017-0228-1.

[19] Dashti, F., Dhakal, R., Pampanin, S.: Evolution of out-of-plane deformation and subsequent instability in rectangular RC walls under in-plane cyclic loading: Experimental observation. Earthquake Engineering and Structural Dynamics. 47, 2944–2964 (2018). https://doi.org/10.1002/eqe.3115.

[20] Rosso, A., Jiménez-Roa, L., Almeida, J., Beyer, K.: Experimental campaign on thin RC columns prone to out-of-plane instability: numerical simulation using shell element models. In: VIII Congreso Nacional de Ingeniería Sísmica. , Barranquilla, Colombia (2017).

[21] Almeida, J., Prodan, O., Rosso, A., Beyer, K.: Tests on thin reinforced concrete walls subjected to in-plane and out-of-plane cyclic loading. Earthquake Spectra. 33, 323–345 (2017). https://doi.org/10.1193/101915EQS154DP.

[22] Rosso, A., Almeida, J.P., Beyer, K.: Stability of thin reinforced concrete walls under cyclic loads: state-of-the-art and new experimental findings. Bulletin of Earthquake Engineering. 14, 455–484 (2016). https://doi.org/10.1007/s10518-015-9827-x.

[23] Taleb, R., Tani, M., Kono, S.: Performance of Confined Boundary Regions of RC Walls under Cyclic Reversal Loadings. Journal of Advanced Concrete Technology. 14, 108–124 (2016). https://doi.org/10.3151/jact.14.108.

[24] Rosso, A., Almeida, J., Beyer, K.: Out-of-plane behaviour of reinforced concrete members with single reinforcement layer subjected to cyclic axial loading: beam-column element simulation. In: Proceedings of the 2016 NZSEE conference. pp. 1–9. , Christchurch, New Zealand (2016).

[25] Rosso, A., Almeida, J.P., Jimenez, L., Guerrero, Z.P., Blandon, C., Bonett-Diáz, R., Beyer, K.: Experimental tests on the out-of-plane response of RC columns subjected to cyclic tensile-compressive loading. 16th World Conference on Earthquake Engineering. (2016).

[26] Chai, Y., Kunnath, S.: Minimum thickness for ductile RC structural walls. Engineering Structures. 27, 1052–1063 (2005). https://doi.org/10.1016/j.engstruct.2005.02.004.

[27] Chai, Y., Elayer, D.: Lateral stability of reinforced concrete columns under axial reversed cyclic tension and compression. ACI Structural Journal. 96, 780–789 (1999).

[28] Chrysanidis, T., Tegos, I.: The influence of the degree of elongation to the displacements of seismic walls with maximum code-prescribed reinforcement ratio. American Academic and Scholarly Research Journal. 7, 273–279 (2015).

[29] Chrysanidis, T., Tegos, I.: How does degree of elongation affect lateral buckling behavior of seismic walls? American Academic and Scholarly Research Journal. 7, 266–272 (2015).

[30] Chrysanidis, T., Tegos, I.: Does the web of seismic walls play a role to their out-of-plane stability? In: Gnana, S. (ed.) Advanced Aspects of Engineering Research Vol. 2. pp. 15–22. Book Publisher International, London, UK (2021). https://doi.org/https://doi.org/10.9734/bpi/aaer/v2/7485D.

[31] Chrysanidis, T.: Evaluation of lateral buckling phenomenon using R/C prisms detailed with an ultra high reinforcement ratio. In: Salisu, L. (ed.) Emerging Trends in Engineering Research and Technology Vol. 3. pp. 55–64. Book Publisher International, London, UK (2020). https://doi.org/http://dx.doi.org/10.9734/bpi/etert/v3.

[32] Chrysanidis, T., Tegos, I.: Can the diameter of longitudinal bars of extreme edges of R/C walls halt transverse buckling? In: Salisu, L. (ed.) Emerging Trends in Engineering Research and Technology Vol. 3. pp. 65–72. Book Publisher International, London, UK (2020). https://doi.org/http://dx.doi.org/10.9734/bpi/etert/v3.

[33] Chrysanidis, T., Panoskaltsis, V.: Experimental investigation of the influence of tensile strain on the cracking of R/C vertical structural elements. In: Papadrakakis, M., Fragiadakis, M., and Papadimitriou, C. (eds.) Proceedings of the XI International Conference on Structural Dynamics (EURODYN 2020). pp. 3174–3185. , Athens, Greece (2020). https://doi.org/10.47964/1120.9259.18582.

GSJ: Volume 10, Issue 12, December 2022
ISSN 2320-9186