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SIZE OF SEISMIC TENSILE STRAIN AND ITS INFLUENCE ON THE DISPLACEMENTS DUE TO TRANSVERSE BUCKLING OF ULTRA-HIGHLY REINFORCED STRUCTURAL WALLS

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ABSTRACT

In the past few years, a concern is observed internationally regarding the seismic mechanical behavior of reinforced concrete walls, especially against their transverse instability under extreme seismic loads. This is one of the reasons that relevant code provisions for minimum wall thickness exist in several modern international codes, as is e.g. EC8: 2004, NZS 3101: 2006. Consequently, because of the big importance of transverse instability and the role that plays in the seismic behavior and safety of constructions, a sedulous study is required about the mechanism of occurrence of this phenomenon and the factors that lead to its growth. The present work is experimental and tries to investigate the influence of the degree of elongation to the displacements (horizontal and vertical) and the modes of failure of test specimens using 5 test specimens with the same longitudinal reinforcement ratio (6.03%) but strained to different degrees of elongation.

Keywords: R/C walls, transverse instability, ultra high reinforcement ratio, longitudinal.

INTRODUCTION

Seismic design of reinforced concrete buildings usually utilizes a number of sufficient walls. Wallace and Moehle (1992) suggest that buildings with a large number of structural walls have demonstrated exceptional behaviour against seismic action, even if these walls had not been reinforced according to the modern perceptions. Structural walls which were designed to be in a high ductility category according to modern international codes such as EC8: 2004, NZS 3101: 2006, CSA: 2004, UBC: 1997 and Ε.Κ.Ω.Σ. 2000 (Greek Concrete Code 2000), are expected to present extensive tensile deformations, especially in the plastic hinge region of their base. According to Chai and Elayer (1999), tensile deformations until 30‰ are expected at the walls of the bottom storey height depending on their geometric characteristics and the level of ductility design of the walls. These tensile deformations, depending on their size, can cause out-of-plane buckling of walls. Premium researchers have studied the phenomenon in question (Penelis *et al*., 1995, 1996, Paulay and Priestley, 1993, Chai and Kunnath, 2005, Paulay, 1986,). The present work on the phenomenon of out-of-plane buckling constitutes a small part of an extensive research program that took place at the Laboratory of Reinforced Concrete and Masonry Structures of the School of Engineering of Aristotle University of Thessaloniki. Results for test specimens reinforced with different longitudinal reinforcement ratios than the ones shown in the current work have been presented in previous publications (Chrysanidis *et al*., 2008, 2009, 2013, 2014).

EXPERIMENTAL INVESTIGATION

Aim of experimental investigation

The main objective of the experimental investigation was to ascertain the influence of the degree of elongation at the end regions of a wall to the reduction of the walls' effective rigidity $(EI)_{eff}$ and hence to their horizontal displacements. The mode of failure according to the wall ends' degree of elongation is also examined. Degree of elongation represents the tensile strain imposed due to seismic loading at the longitudinal reinforcement of the end regions of R/C walls. Specifically, seismic bending moment of reversing sign imposes tensile deformations at the end regions of R/C walls at the first semi-cycle of seismic loading. Therefore, experimental loading takes place in two distinct semi-cycles of loading; the first semi-cycle imposes tensile deformations up to a certain degree of elongation while the second semi-cycle of loading imposes compressive deformations until failure of test specimens is reached.

Test specimen characteristics

The test specimens were constructed using the scale 1:3 as a scale of construction. The dimensions of specimens are equal to 7.5x15x90 cm. The reinforcement of specimens consists of 6 bars of 12 mm diameter. The total number of specimens is equal to 5. Each specimen was submitted first in tensile loading of uniaxial type up to a preselected degree of elongation and then was strained under concentric compression loading. The differentiation of specimens lies in varying degrees of elongation imposed on each one of them. Figure-1 and Figure-2 present their cross-section and their front view both for tensile and compressive loading, while all specimen characteristics are brought together in Table-1.

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Table-1. Test specimens' characteristics.

N/A	Description of specimens	Dimensions (cm)	Longitudinal reinforcement	Transverse reinforcement	Longitudinal reinforcement ratio (%)	Concrete cube resistance at 28 days (MPa)	Degree of elongation (%)
1	Y-6Ø12-603-0-1	15x7.5x90	6Ø12	Ø4.2/3.3cm	6.03	34.96	0.00
2	Y-6Ø12-603-10-2	15x7.5x90	6Ø12	Ø4.2/3.3cm	6.03	34.96	10.00
3	Y-6Ø12-603-20-3	15x7.5x90	6Ø12	Ø4.2/3.3cm	6.03	34.96	20.00
4	Y-6Ø12-603-30-4	15x7.5x90	6Ø12	Ø4.2/3.3cm	6.03	34.96	30.00
5	Y-6Ø12-603-50-5	15x7.5x90	6Ø12	Ø4.2/3.3cm	6.03	34.96	50.00

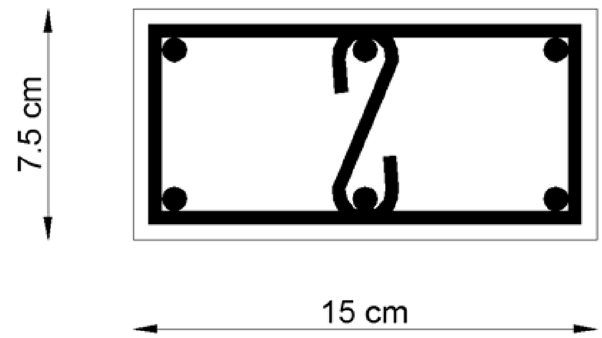

Figure-1. Cross section of test specimens.

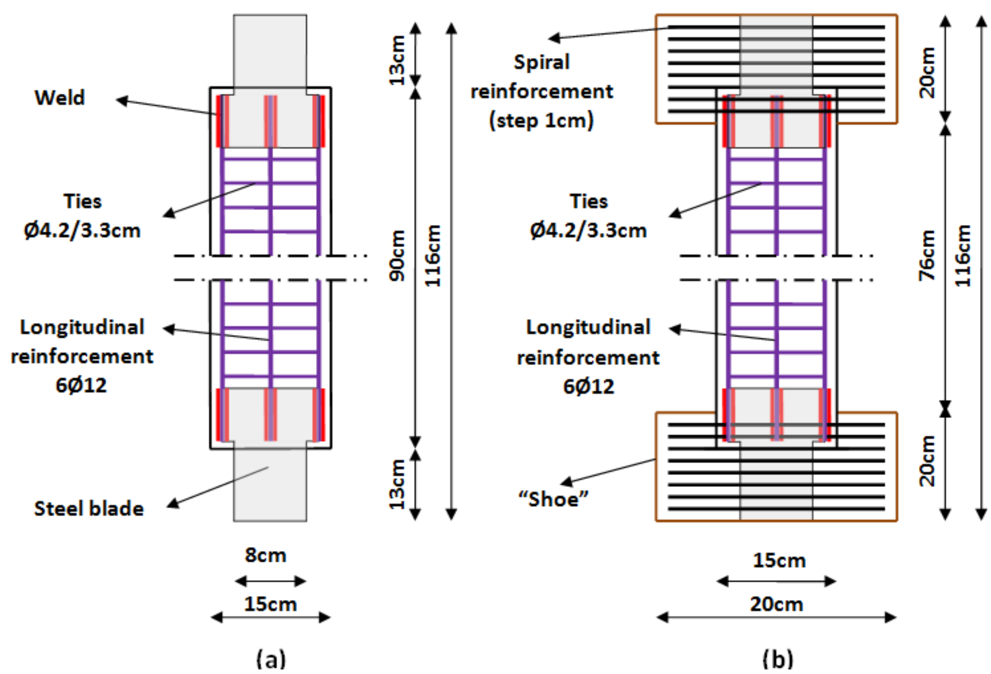

Figure-2. Sketch of front view of specimens for: (a) tension, (b) compression.

Loading of specimens

The experimental setups used in order to impose to the specimens in the first semi cycle of loading a uniaxial tensile load and in the second semi cycle of loading a concentric compressive load are shown in Figure-3.

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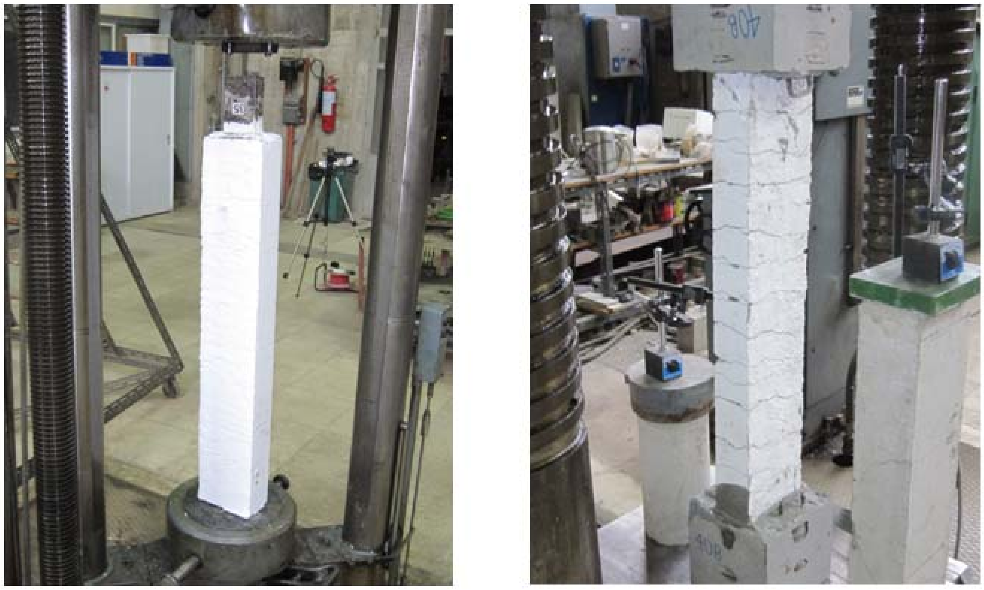

(a) (b)

Figure-3. Test setup for application of: (a) Tensile loading, (b) Compressive loading.

EXPERIMENTAL RESULTS

Figure-4 refers to the uniaxial tensile test and shows the variation of elongation of the specimens in relation to the applied tensile load. It becomes evident, from a simple observation of the diagram that the real degrees of elongation differ somewhat from the nominal degrees of elongation (10‰, 20‰, 30‰ and 50‰). However, in all cases, the differences are minor and negligible. Figure-5 refers to the concentric compression test and shows the change of transverse displacement relative to the applied compressive load this time, while Figure-6 depicts the residual transverse displacement in relation to the normalized specimen height. Finally, Figure-7 shows the various failure modes of all specimens after the completion of the compression loading.

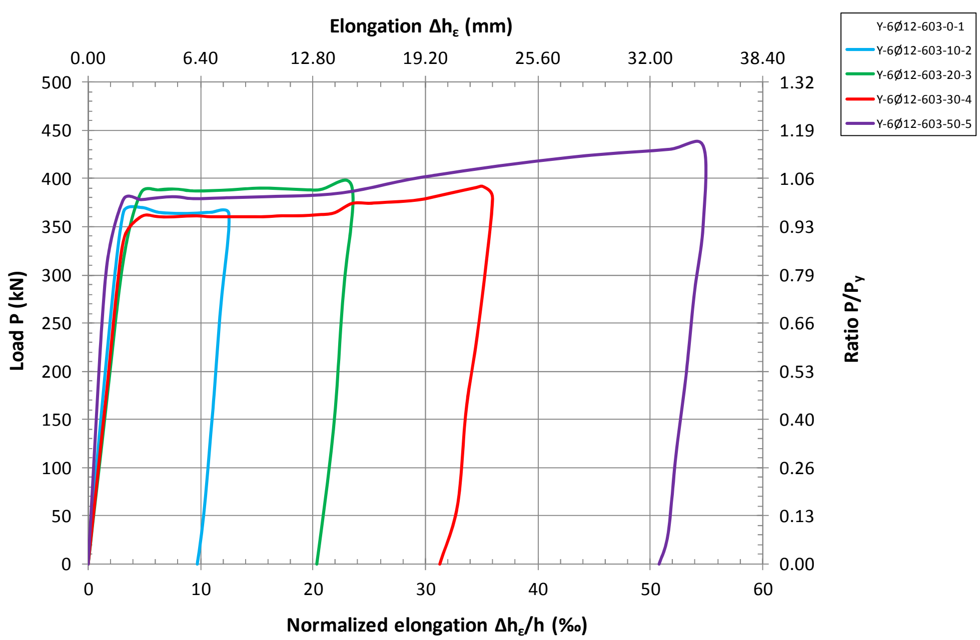

Figure-4. Diagram of tensile load [P(kN), P/P_y] – elongation [$\Delta h_\varepsilon/h$(‰), Δh_ε(mm)].

VOL. 11, NO. 23, DECEMBER 2016 ISSN 1819-6608
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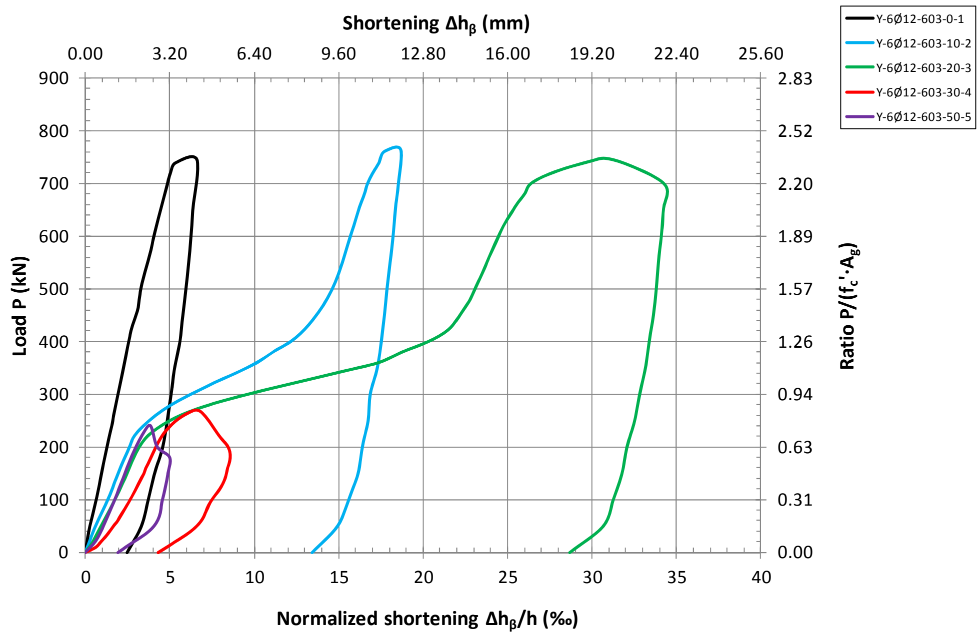

Figure-5. Diagram of compressive load [P(kN), $P/(f_c'\cdot A_g)$] – transverse displacement at the midheight of test specimens [δ_m/b, δ_m(mm)].

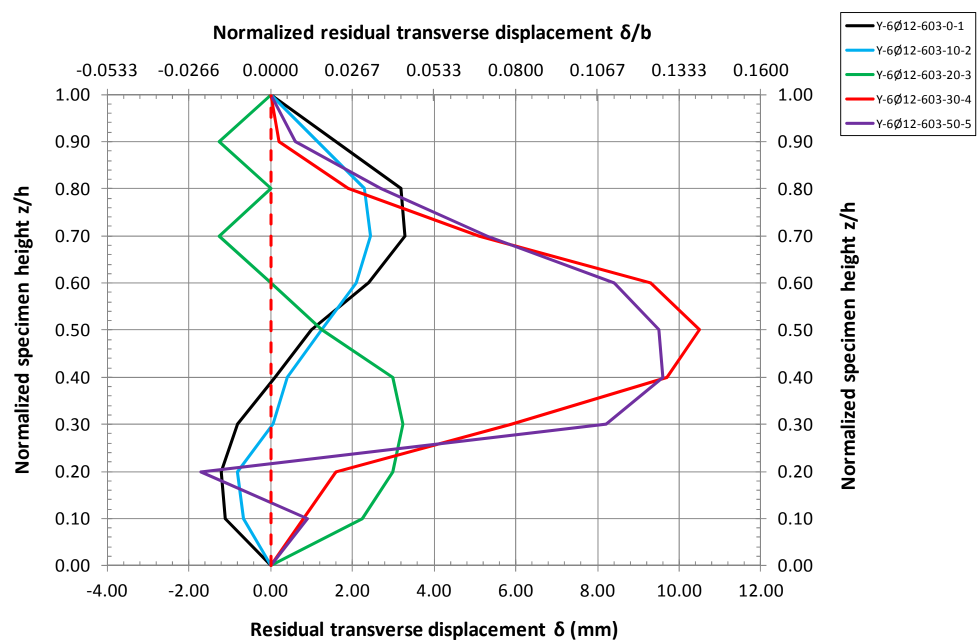

Figure-6. Diagram of normalized specimen height [z/h] - residual transverse displacement [δ(mm), δ/b].

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(a) (b) (c) (d) (e)

Figure-7. Failure modes of specimens after the experiment of compression: (a) Y-6Ø12-603-0-1, (b) Y-6Ø12-603-10-2, (c) Y-6Ø12-603-20-3, (d) Y-6Ø12-603-30-4, (e) Y-6Ø12-603-50-5.

ANALYSIS OF RESULTS

The observations from the conduct of the experimental investigation are as follows:

a) For degrees of elongation 0‰, 10‰ and 20‰, the failure of the test specimens comes from an excess of the compressive strength of their cross section and crash of the compression zone of the column specimens. For degrees of elongation 30‰ and 50‰, the failure of the specimens is due to their buckling around the weak axis, i.e. the axis perpendicular to their thickness. This observation is illustrated by a simple study of Figure-7. The aforementioned mean that the increase of the degree of elongation imposed on the test specimens in the first semi cycle of loading causes a change in the failure mode of the specimens during the second semi cycle of loading, where the compressive stress is exerted.

b) It is generally observed that increasing the degree of elongation results to a decreased maximum failure load. This trend, however, is valid under certain conditions.

c) The evaluation of maximum residual transverse displacements and failure transverse displacements (transverse displacements corresponding to the maximum failure load) indicates that there is a tendency for these types of displacements to be increased by increasing the degree of elongation. However, this is only a tendency and it is not true for all degrees of elongation.

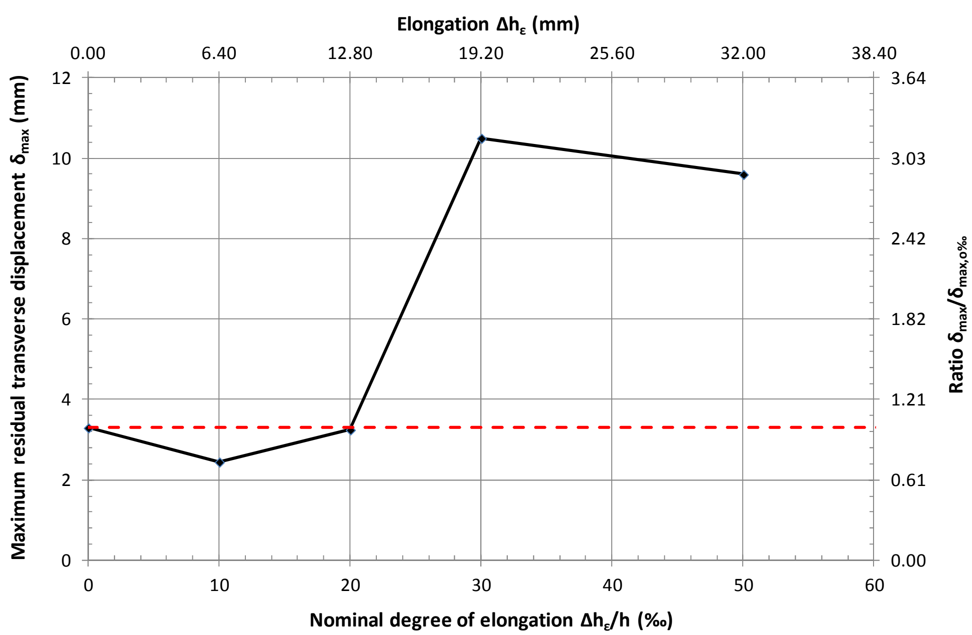

Figure-8. Diagram of maximum residual transverse displacement [δ_{max}(mm), $\delta_{max}/\delta_{max,0‰}$] - elongation [$\Delta h_\varepsilon/h$(‰), Δh_ε(mm)].

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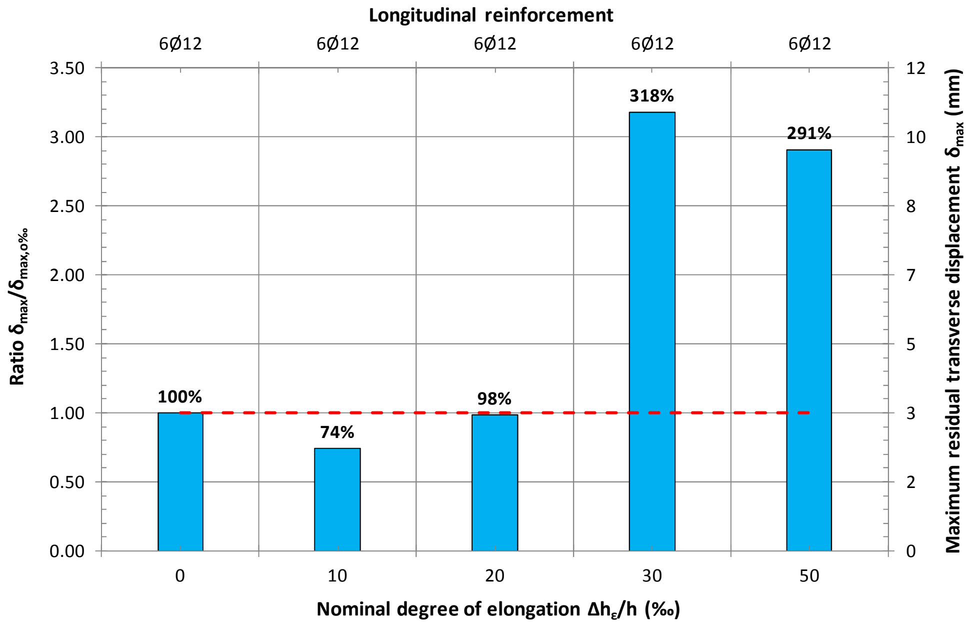

Figure-9. Column diagram of maximum residual transverse displacement [$\delta_{max}/\delta_{max,0‰}$, δ_{max}(mm)] - elongation and type of longitudinal reinforcement [$\Delta h_{\varepsilon}/h$(‰)].

CONCLUSIONS

Analysis and evaluation of experimental results lead to the following conclusions:

a) The imposed elongation degree in the first semi cycle of the tensile loading has a major influence, after a certain value, in the behaviour, in the failure mode, and in the maximum failure load during the second semi cycle of the compressive loading.
b) Generally, speaking, it can be stated that an increase to the degree of elongation brings a reduction to maximum failure load. Though, that is not the case for all degrees of elongation, yet it seems to be the case after a certain value for the degree of elongation.
c) As far as transverse displacements (maximum residual transverse displacements and failure transverse displacements) are concerned, it seems that there is not a clear relation between degree of elongation and transverse displacements.

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