Does degree of elongation affect displacements of structural walls?

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Abstract. The past few years, it has become explicit that failure due to transverse instability is difficult to be observed in actual structures after the event of seismic excitation, even if it is certain that it exists as phenomenon and can even lead to general collapse of structures. 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 consists of 5 test specimens of scale 1:3 simulating the boundary edges of structural walls. These specimens were reinforced with the same medium high longitudinal reinforcement ratio (3.19%). The degree of elongation applied was different for each specimen. The present paper tries to investigate the influence of the degree of elongation to the displacements and the modes of failure of test specimens.

Keywords: elongation degree, structural walls, transverse instability, displacements.

1 INTRODUCTION

The utilization of a number of sufficient walls is usually considered a good practice by designers when forming the structural system of buildings. This conclusion is due to the fact 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 (Wallace and Moehle, 1992). Structural walls designed to be in a high ductility category according to modern international codes such as EC8 (2004) and NZS 3101 (2006) or designed with increased ductility requirements according to 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. Prominent researchers, like Paulay (1986), propose the use of flanges or enlarged boundary elements in the extreme regions of walls providing protection to the bending compression regions against transverse instability. Moreover, these elements are easier to be confined. New Zealand Concrete Code (NZS 3101, 2006) and other modern international codes propose the construction of such elements. The phenomenon of lateral buckling of RC walls depends basically on the size of tensile deformations which are imposed at the extreme regions of walls at the first semi-cycle of seismic loading and not so much on the size of flexural compression which is imposed at the reversal of seismic loading, according to Paulay and Priestley (1993). 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.

2 EXPERIMENTAL RESEARCH

2.1 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 4 bars of 8 mm diameter and 2 bars of 10 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 compressive loading. The differentiation of specimens lies in varying degrees of elongation imposed on each one of them. Fig. 1 presents their front view both for tensile and compressive loading, while all specimen characteristics are brought together in Table 1.

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-4Ø8+2Ø10-319-0-1	15x7.5x90	4Ø8 + 2Ø10	Ø4.2/3.3cm	3.19	22.82	0.00
2	Y-4Ø8+2Ø10-319-10-2	15x7.5x90	4Ø8 + 2Ø10	Ø4.2/3.3cm	3.19	22.82	10.00
3	Y-4Ø8+2Ø10-319-20-3	15x7.5x90	4Ø8 + 2Ø10	Ø4.2/3.3cm	3.19	22.82	20.00
4	Y-4Ø8+2Ø10-319-30-4	15x7.5x90	4Ø8 + 2Ø10	Ø4.2/3.3cm	3.19	22.82	30.00
5	Y-4Ø8+2Ø10-319-50-5	15x7.5x90	4Ø8 + 2Ø10	Ø4.2/3.3cm	3.19	22.82	50.00

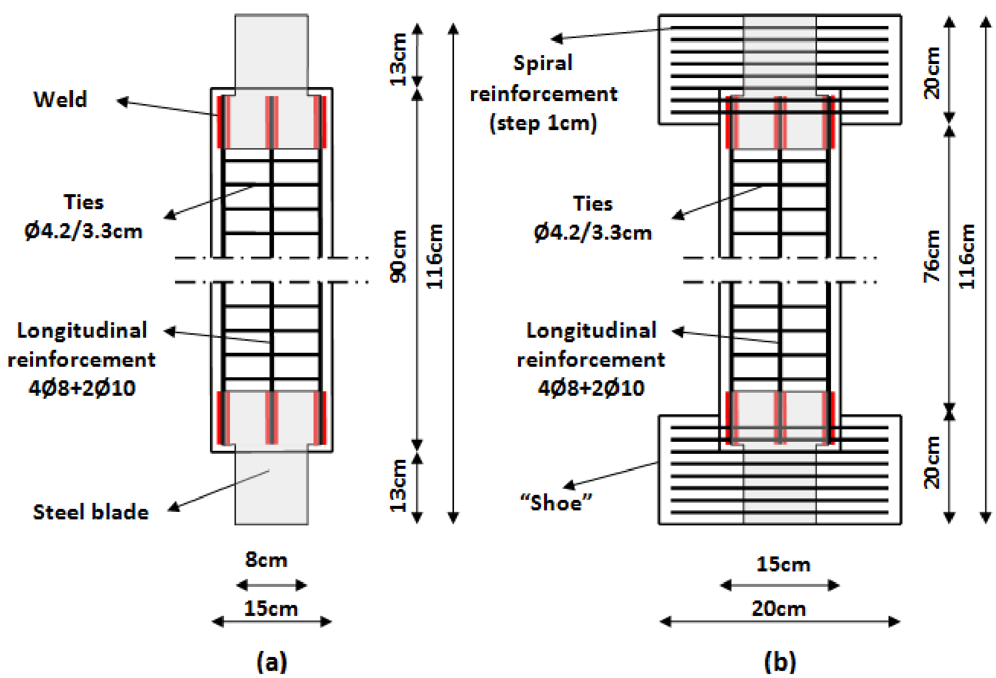

Fig. 1. Sketch of front view of specimens for: (a) tension, (b) compression.

(a) (b)

Fig. 2. Test setup for application of: (a) Tensile loading, (b) Compressive loading.

2.1 Loading of specimens

The experimental setups used in order to impose to the specimens a uniaxial tensile load (first semi cycle) and a concentric compressive load (second semi cycle) are shown in Fig. 2.

3 EXPERIMENTAL RESULTS

Fig. 3 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. Fig. 4 refers to the concentric compression test and shows the change of transverse displacement relative to the applied compressive load this time, while Fig. 5 depicts the residual transverse displacement in relation to the normalized specimen height. Finally, Fig. 6 shows the various failure modes of all specimens after the completion of the compressive loading.

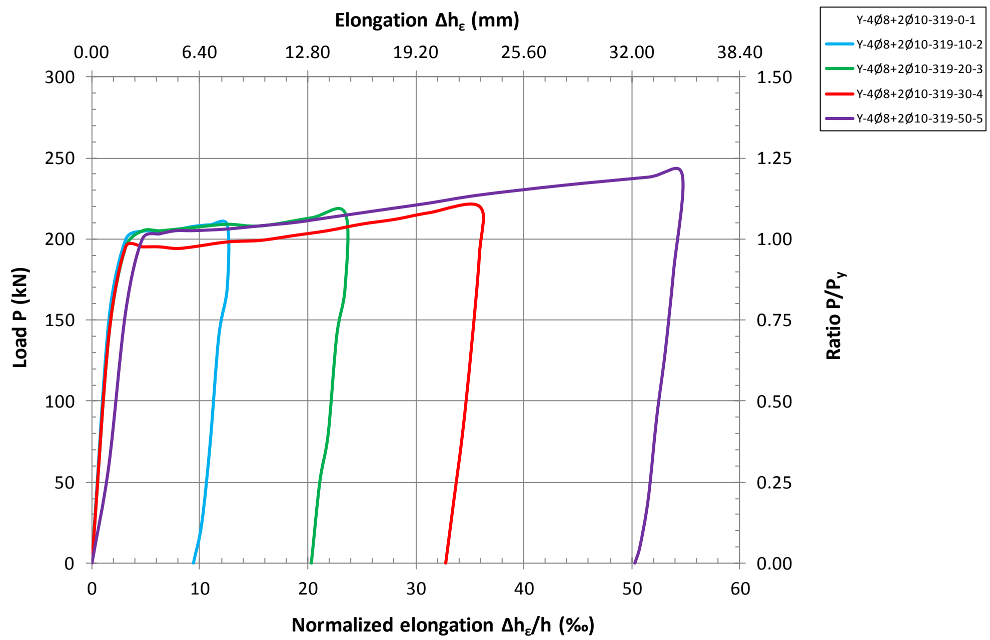

Fig. 3. Diagram of tensile load [P(kN), P/P_y] – elongation [$\Delta h_\varepsilon/h$(‰), Δh_ε(mm)].

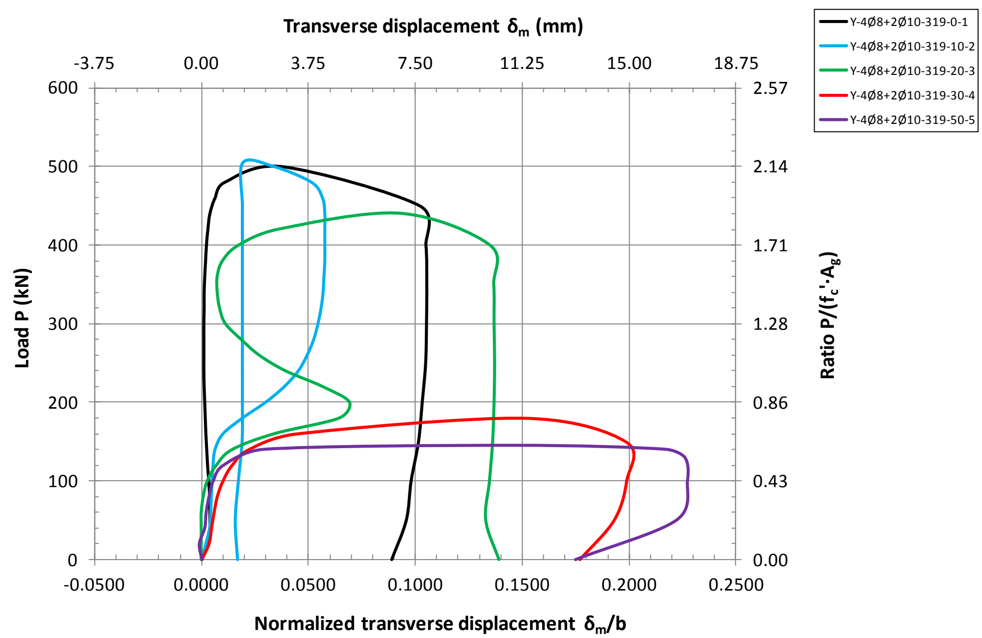

Fig. 4. Diagram of compressive load [P(kN), $P/(f_c'\cdot A_g)$] – transverse displacement at the midheight of test specimens [δ_m/b, δ_m(mm)].

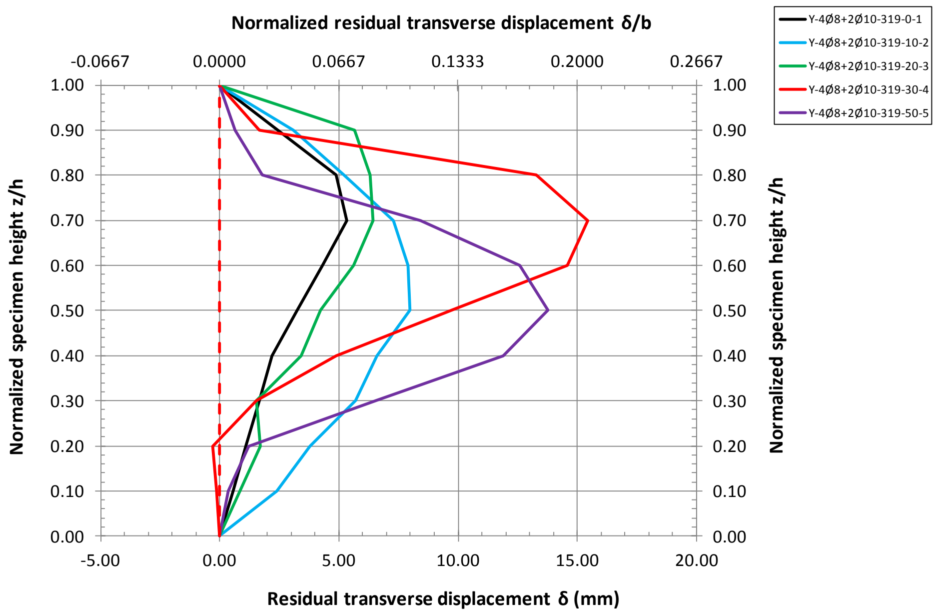

Fig. 5. Diagram of normalized specimen height [z/h] – residual transverse displacement [δ(mm), δ/b].

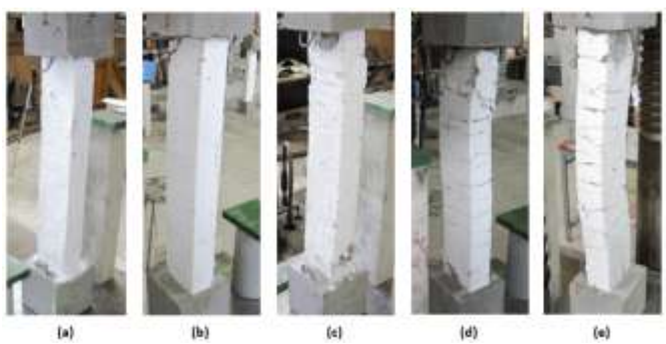

Fig. 6. Failure modes of specimens after the experiment of compression: (a) Y-4Ø8+2Ø10-319-0-1, (b) Y-4Ø8+2Ø10-319-10-2, (c) Y-4Ø8+2Ø10-319-20-3, (d) Y-4Ø8+2Ø10-319-30-4, (e) Y-4Ø8+2Ø10-319-50-5.

4 ANALYSIS OF RESULTS

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

1. 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 (Figs. 7, 8).

2. Secondly, it is observed 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. Specifically, 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 Fig. 6.

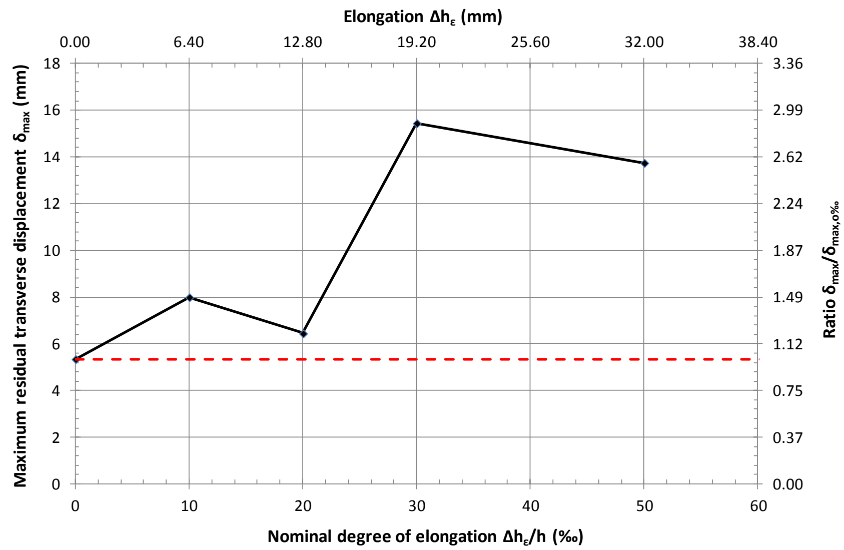

Fig. 7. Diagram of maximum residual transverse displacement [δ_{max}(mm), $\delta_{max}/\delta_{max,0‰}$] – elongation [$\Delta h_{\varepsilon}/h$(‰), Δh_{ε}(mm)].

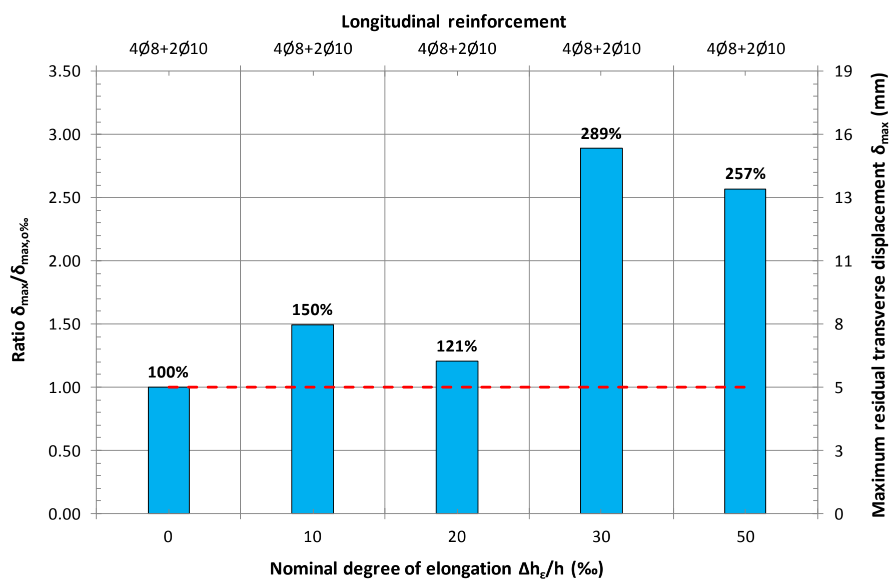

Fig. 8. Column diagram of maximum residual transverse displacement [$\delta_{max}/\delta_{max,0‰}$, δ_{max}(mm)] – elongation and type of longitudinal reinforcement [$\Delta h_{\varepsilon}/h$(‰)].

5 CONCLUSIONS

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

1. 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. So, no clear conclusion has been derived on this matter apart from a general tendency for the transverse displacements to be increased with an increase of degree of elongation.
2. 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.

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