The influence of the degree of tensile strain to the ultimate strength and mode of failure of seismic walls with low-reinforced end-sections

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Abstract. It is considered logical to be expected that walls designed either with increased ductility requirements according to the Greek Concrete Code 2000 or designed to be in a high ductility category according to EC8: 2004, NZS 3101: 2006 and other modern international codes, present extensive tensile deformations, especially in the plastic hinge region of their base. Large tensile deformations are expected depending on the geometric characteristics and the level of ductility design of walls. Due to the cycling nature of loading, these tensile deformations can cause lateral instability of seismic walls depending on the size of tensile deformations. In the framework of the current work, it is experimentally investigated one of the most crucial parameters affecting the stability of structural walls, which is the degree of tensile strain of the longitudinal reinforcement of the extreme edges of load-bearing RC walls. The present paper tries to investigate the influence of the degree of tensile strain to the ultimate strength and the modes of failure of test specimens using 5 test specimens reinforced with the same longitudinal reinforcement ratio (1.79%) but strained to different degrees of elongation.

Keywords: tensile strain, seismic walls, reinforcement, stability.

1 INTRODUCTION

Walls designed with high ductility requirements following the provisions of modern international Codes (Eurocode 8, 2004, NZS 3101, 2006, Greek Concrete Code, 2006) present extensive tensile deformations, especially in the plastic hinge region of their base. According to Chai and Elayer (1999), tensile strains up to 30‰ are expected at the walls of the ground floor according to their geometrical characteristics and the ductility class according to which were designed. The phenomenon of the lateral buckling of reinforced concrete walls depends largely on the size of the tensile strains occurring in the end regions of the walls during the first semi cycle of loading and not so much on the size of the bending compression imposed during the reversal of loading according to Paulay and Priestley (1993). This work is a small part of an extensive work that took place at the Laboratory of Reinforced Concrete and Masonry Structures of the School of Engineering of the Aristotle University of Thessaloniki on the phenomenon of out-of-plane buckling and on the factors which affect it. Results for test specimens reinforced with different longitudinal reinforcement ratios than the ones shown in the current work have been presented in previous publications.

2 EXPERIMENTAL RESEARCH

2.1 Test specimen characteristics

The test specimens were constructed using construction scale 1:3. The dimensions of the specimens are equal to 7.5x15x90 cm. The reinforcement of specimens consists of 4 bars of 8 mm diameter. The total number of specimens is equal to 5. First, each specimen was stressed under uniaxial tensile loading to a specific and default elongation degree and then was stressed under concentric compressive loading. Differentiation of specimens lies in varying degrees of elongation imposed on each one. The characteristics of the specimens are shown collectively in Table 1, while Fig. 1 shows the front view of specimens both for tensile and compressive loading.

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-4Ø8-179-0-1	15x7.5x90	4Ø8	Ø4.2/3.3cm	1.79	24.89	0.00
2	Y-4Ø8-179-10-2	15x7.5x90	4Ø8	Ø4.2/3.3cm	1.79	24.89	10.00
3	Y-4Ø8-179-20-3	15x7.5x90	4Ø8	Ø4.2/3.3cm	1.79	24.89	20.00
4	Y-4Ø8-179-30-4	15x7.5x90	4Ø8	Ø4.2/3.3cm	1.79	23.33	30.00
5	Y-4Ø8-179-50-5	15x7.5x90	4Ø8	Ø4.2/3.3cm	1.79	24.89	50.00

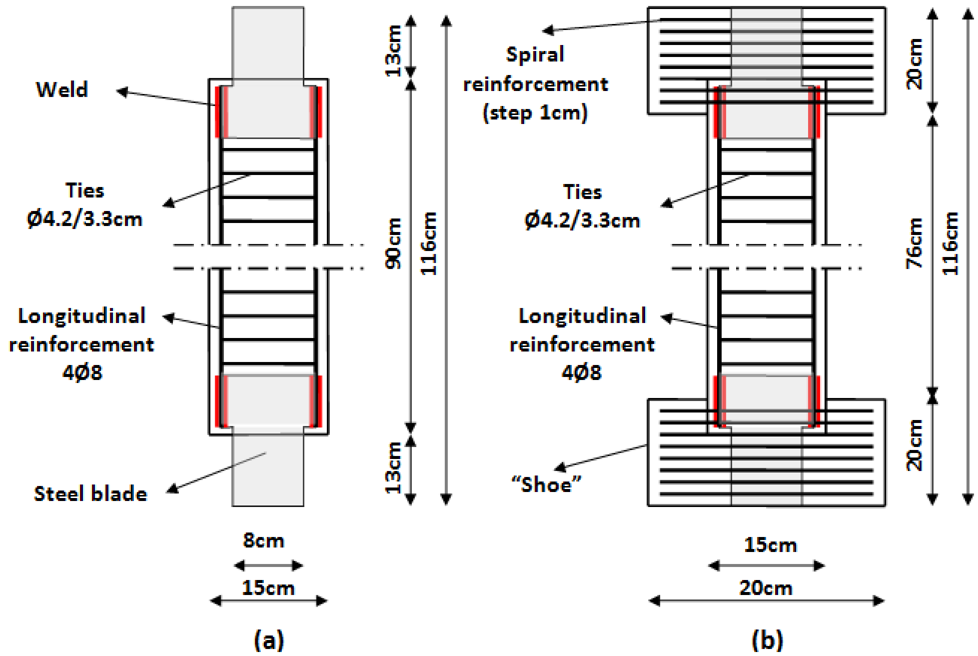

Fig. 1. Sketch of front view of specimens for: (a) tension, (b) compression.

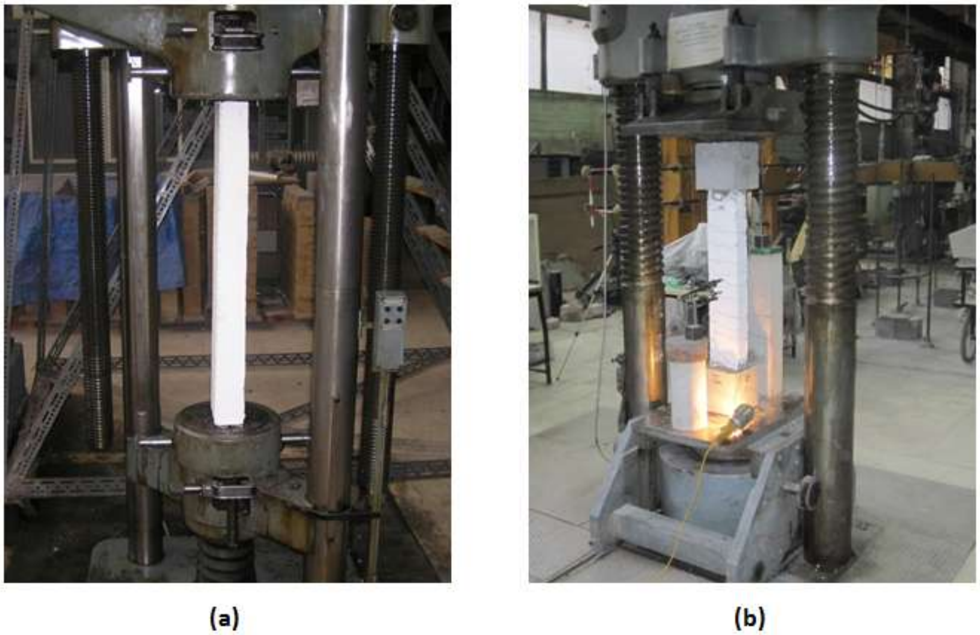

Fig. 2. Test setup for application of: (a) Tensile loading, (b) Compressive loading.

2.1 Loading of specimens

The experimental setups used in order to impose to the specimens 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 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 shortening relative to the applied compressive load this time. It is, clearly, apparent the large drop that exists in the specimens' resistance for the cases of elongation degrees equal to 30‰ and 50‰. Finally, Fig. 5 shows the various failure modes of all specimens after the completion of the compressive loading.

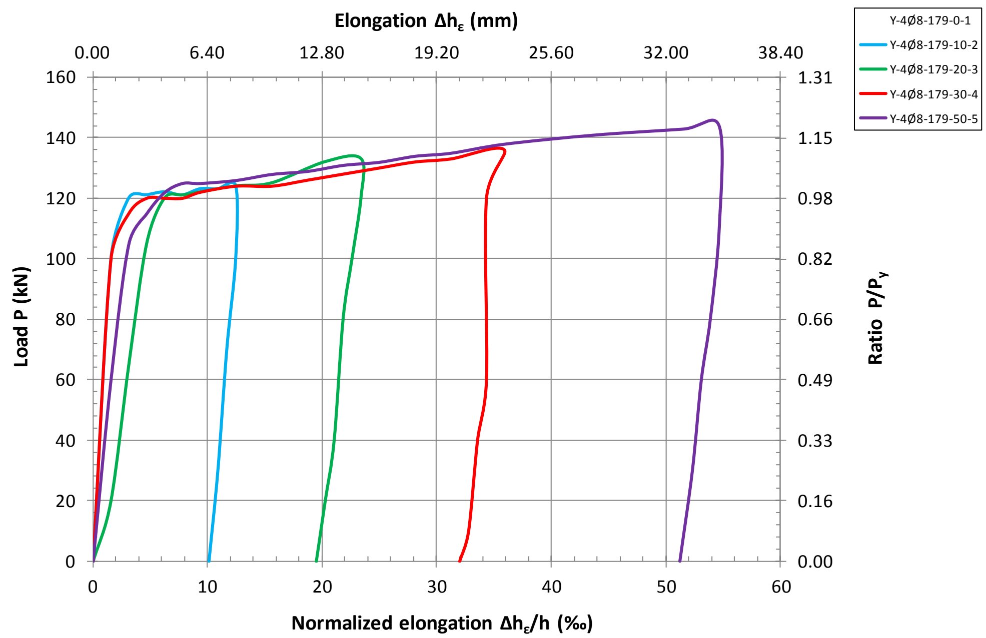

Fig. 3. Diagram of tensile load [P(kN), P/P_y] – elongation [$\Delta h_\varepsilon/h$(‰), Δh_ε(mm)].

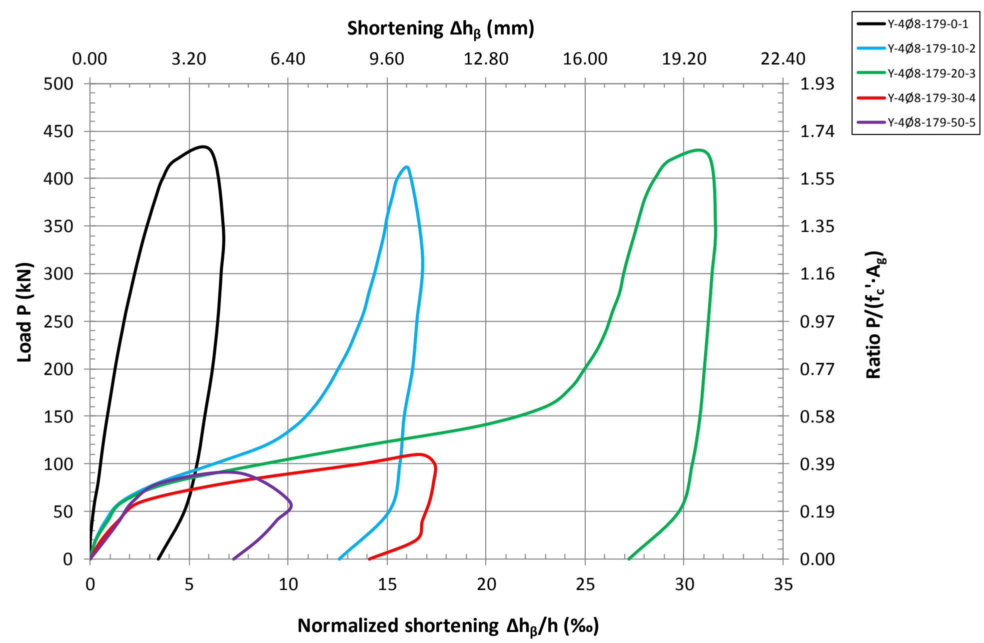

Fig. 4. Diagram of compressive load [P(kN), $P/(f_c'\cdot A_g)$] – shortening [$\Delta h_\beta/h$(‰), Δh_β(mm)].

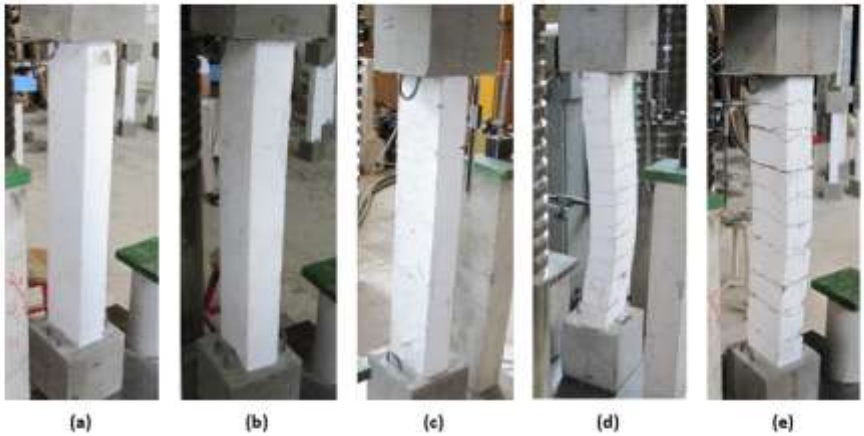

Fig. 5. Failure modes of specimens after the experiment of compression: (a) Y-4Ø8-179-0-1, (b) Y-4Ø8-179-10-2, (c) Y-4Ø8-179-20-3, (d) Y-4Ø8-179-30-4, (e) Y-4Ø8-179-50-5.

4 ANALYSIS OF RESULTS

The conduct of the experimental research and the evaluation and analysis of the experimental results generate interesting comments regarding the behavior of the test specimens. These observations are as follows:

1. 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. 5.
2. For elongation degrees 30‰ and 50‰, the increase in the degree of elongation imposed on the test specimens in the first semi cycle of loading causes a reduction in maximum failure load (specimen strength) during the second semi cycle of loading where the compressive stress is exerted. Specifically, for elongation degree 30‰, critical failure load of the specimen is equal to 26% of the failure load of the corresponding "virgin" specimen (Figs. 6, 7). Regarding the degree of elongation 50‰, the critical failure load of the specimen is equal to 21% of the failure load of the corresponding "virgin" specimen (Figs. 6, 7). It is shown, namely, that the increase of the degree of elongation significantly affects the resistance of the test specimens against lateral instability, since there may be a reduction in specimen resistance of the order of 75-80% compared to the specimen which has not undergone any form of tensile stress ("virgin" specimen).
3. For elongation degrees 10‰ and 20‰, the increase in the degree of elongation imposed on the test specimens in the first semi cycle of loading does not cause any significant differentiation in the value of the maximum failure load during the second semi cycle of loading, where the compressive stress is exerted. Specifically, for elongation degree 10‰, critical failure load of the specimen is equal to 95% of the failure load of the corresponding "virgin" specimen (Figs. 6, 7). Regarding the degree of elongation 20‰, the critical failure load of the specimen is equal to 99% of the failure load of the

corresponding "virgin" specimen (Figs. 6, 7). Note that for these degrees of elongation, closure of cracks is performed leading to the contribution of concrete strength to the specimens' strength. It is emphasized that generous efforts were made in order to provide, as much as possible, the same concrete quality between different specimens by concreting all specimens together using concrete from the same mixer.

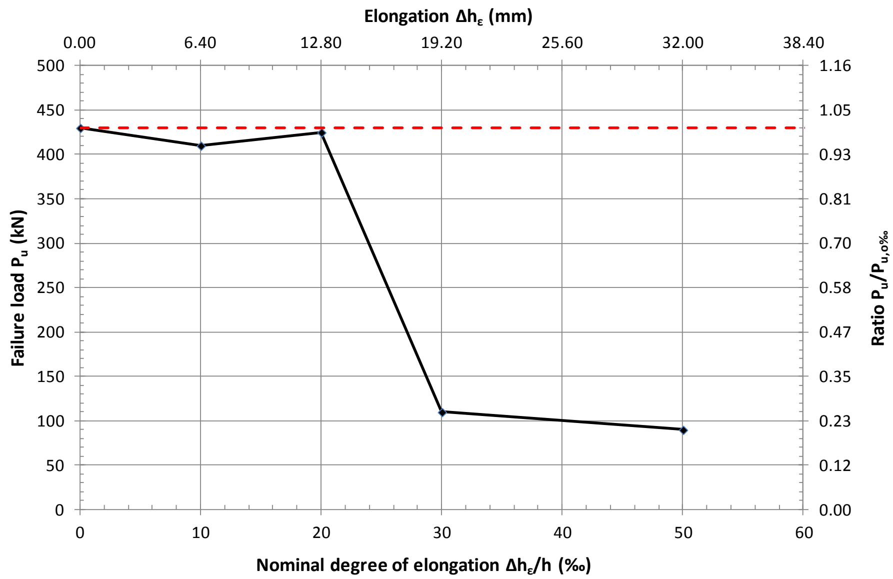

Fig. 6. Diagram of maximum failure load [P_u(kN), $P_u/P_{u,0‰}$] – elongation [$\Delta h_\varepsilon/h$(‰), Δh_ε(mm)].

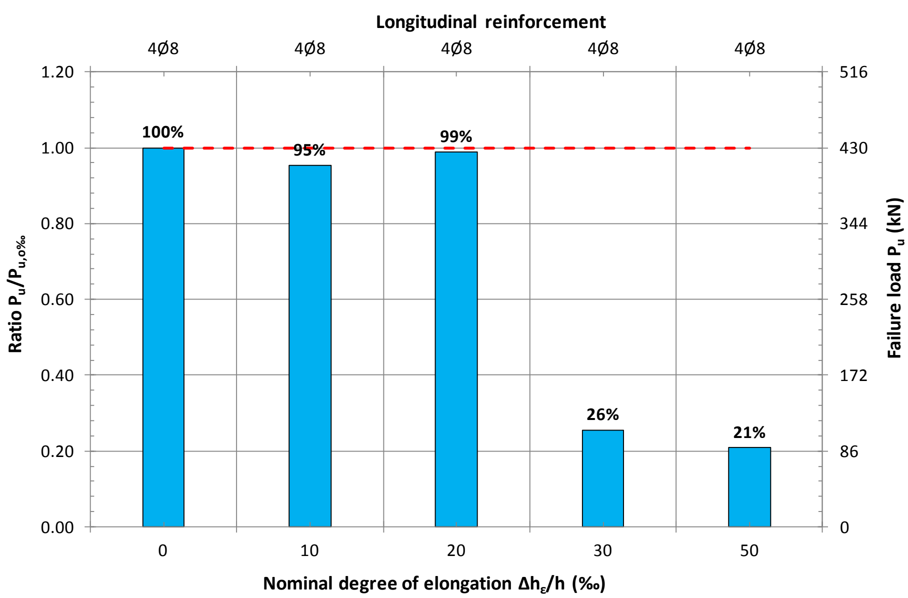

Fig. 7. Column diagram of failure load [$P_u/P_{u,0‰}$, P_u(kN)] – elongation and type of longitudinal reinforcement [$\Delta h_\varepsilon/h$(‰)].

5 CONCLUSIONS

The following conclusions have been derived from the aforementioned experimental research:

1. The imposed elongation degree in the first semi cycle of the tensile loading has a catalytic 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.
2. Generally, the phenomenon of transverse instability is affected drastically by the imposed degree of elongation.
3. General conclusion of this study is that the transverse instability of the RC walls is a complex phenomenon, which depends not only on the ground floor height (as implied by the vast majority of modern international codes) but on other mechanical parameters, too, such as the degree of elongation.

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