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Does Reinforcement Ratio Affect Displacements Due To Lateral Buckling Behavior of Concrete Walls?

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Abstract

Studies of various buildings have shown explicitly 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. 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. It has to be noted that in order to examine experimentally the influence of the longitudinal reinforcement ratio, 5 test specimens of scale 1:3 simulating the boundary edges of structural walls were used. These specimens were reinforced with different longitudinal reinforcement ratios (varying from 1.79% to 4.02%). The degree of tension strain which was applied was the same for all specimens and equal to 30‰. The present article tries to investigate the influence of the ratio of longitudinal reinforcement to the displacements (horizontal and vertical) and the modes of failure of test specimens.

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

INTRODUCTION

Seismic design of reinforced concrete buildings usually utilizes a number of sufficient walls. Buildings with a large number of structural walls, have demonstrated exceptional behavior against seismic action, even if these walls had not been reinforced according to the modern perceptions [1]. Structural walls which were designed to be in a high ductility category according to modern international codes [2-6], are expected to present extensive tensile deformations, especially in the plastic hinge region of their base. According to Chai and Elayer [7], 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 [8] propose the use of flanges or enlarged boundary elements in the extreme regions of walls, which provide protection to the bending compression regions against transverse instability. Moreover, these elements are easier to be confined. New Zealand Concrete Code (NZS 3101: 2006) [3] 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 [9]. Many researchers have studied out-of-plane buckling phenomenon [10-17]. 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.

EXPERIMENTAL INVESTIGATION

Aim of experimental investigation

The main objective of the experimental investigation was to ascertain the influence of the longitudinal reinforcement ratio 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' longitudinal reinforcement ratio 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. Reinforcement of specimens varies both in the number of bars and in the diameters of them. The total number of specimens is equal to 11. Each specimen was submitted first in tensile loading of uniaxial type up to the preselected degree of elongation 30‰ and then was strained under concentric compression loading. The differentiation of specimens lies in the different longitudinal reinforcement ratio that each one had. Fig. 1 presents their front view both for tensile and compressive loading, while all specimen characteristics are brought together in Table 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.

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-4Ø8-179-30-1	15x7.5x90	4Ø8	Ø4.2/3.3cm	1.79	23.33	30.00
2	Y-6Ø8-268-30-2	15x7.5x90	6Ø8	Ø4.2/3.3cm	2.68	22.22	30.00
3	Y-4Ø8+2Ø10-319-30-3	15x7.5x90	4Ø8+2Ø10	Ø4.2/3.3cm	3.18	22.82	30.00
4	Y-4Ø10+2Ø8-368-30-4	15x7.5x90	4Ø10+2Ø8	Ø4.2/3.3cm	3.68	22.82	30.00
5	Y-4Ø12-402-30-5	15x7.5x90	4Ø12	Ø4.2/3.3cm	4.02	23.26	30.00

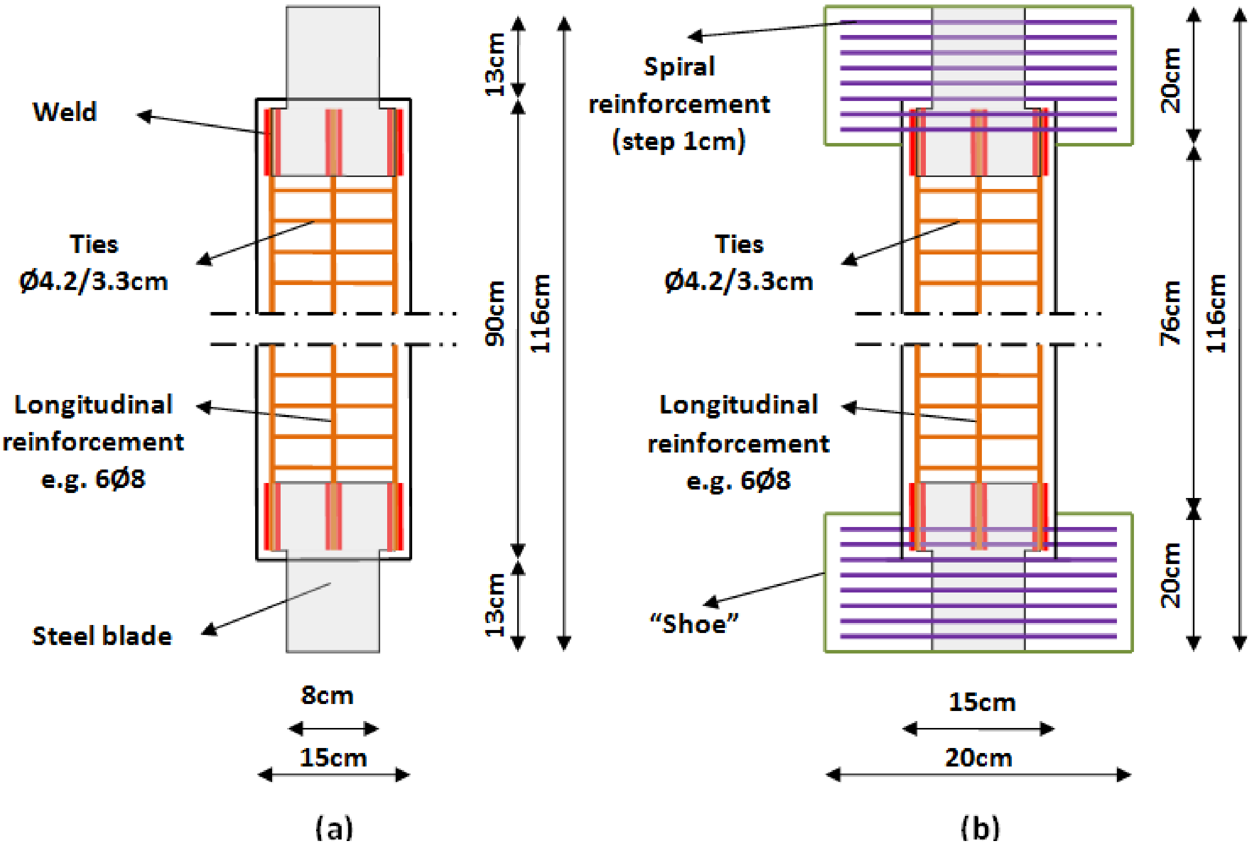

Figure 1: Sketch of front view of specimens for: (a) tension, (b) compression.
(Reinforcement differs for each specimen. Example shows a typical longitudinal reinforcement 6Ø8.)

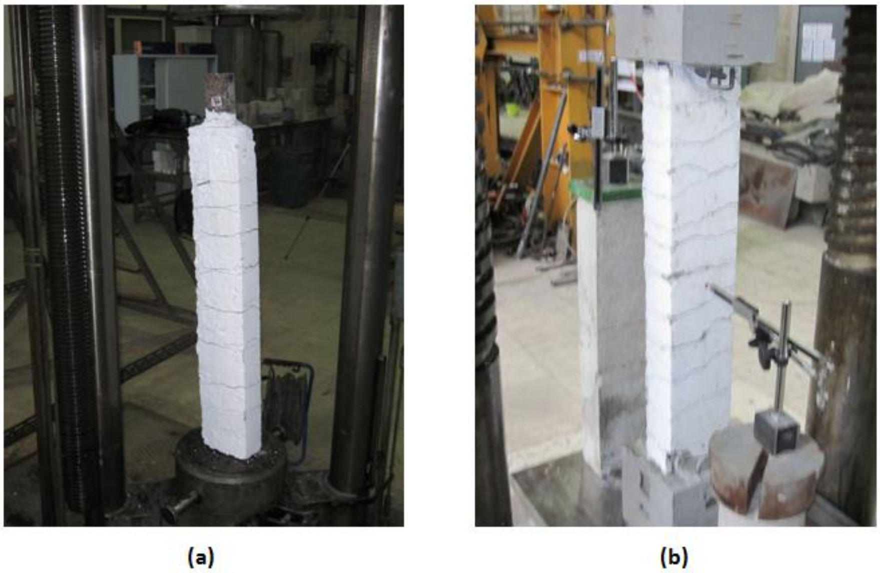

Figure 2: Test setup for application of: (a) Tensile loading, (b) Compressive loading

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.

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 degree of elongation (30‰). 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 compression loading.

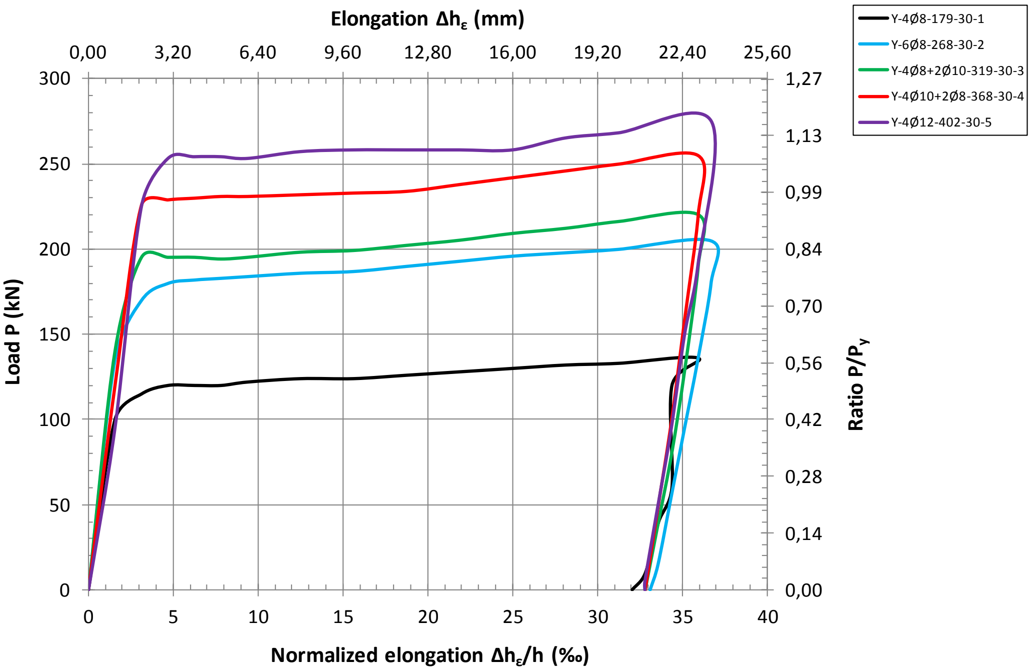

Figure 3: Diagram of tensile load [P(kN), P/P_y] - elongation [$\Delta h_\varepsilon/h$(‰), Δh_ε(mm)]

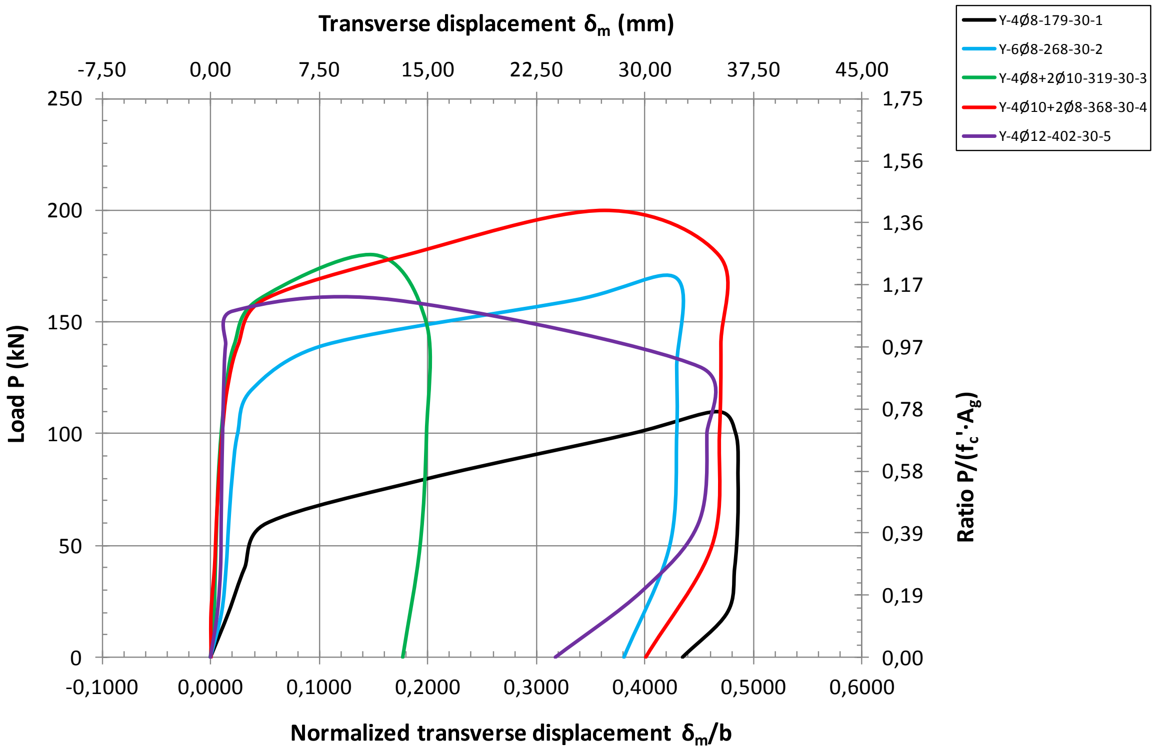

Figure 4: Diagram of compressive load [P(kN), P/(f_c'·A_g)] – transverse displacement at the midheight of test specimens [δ_m/b, δ_m(mm)]

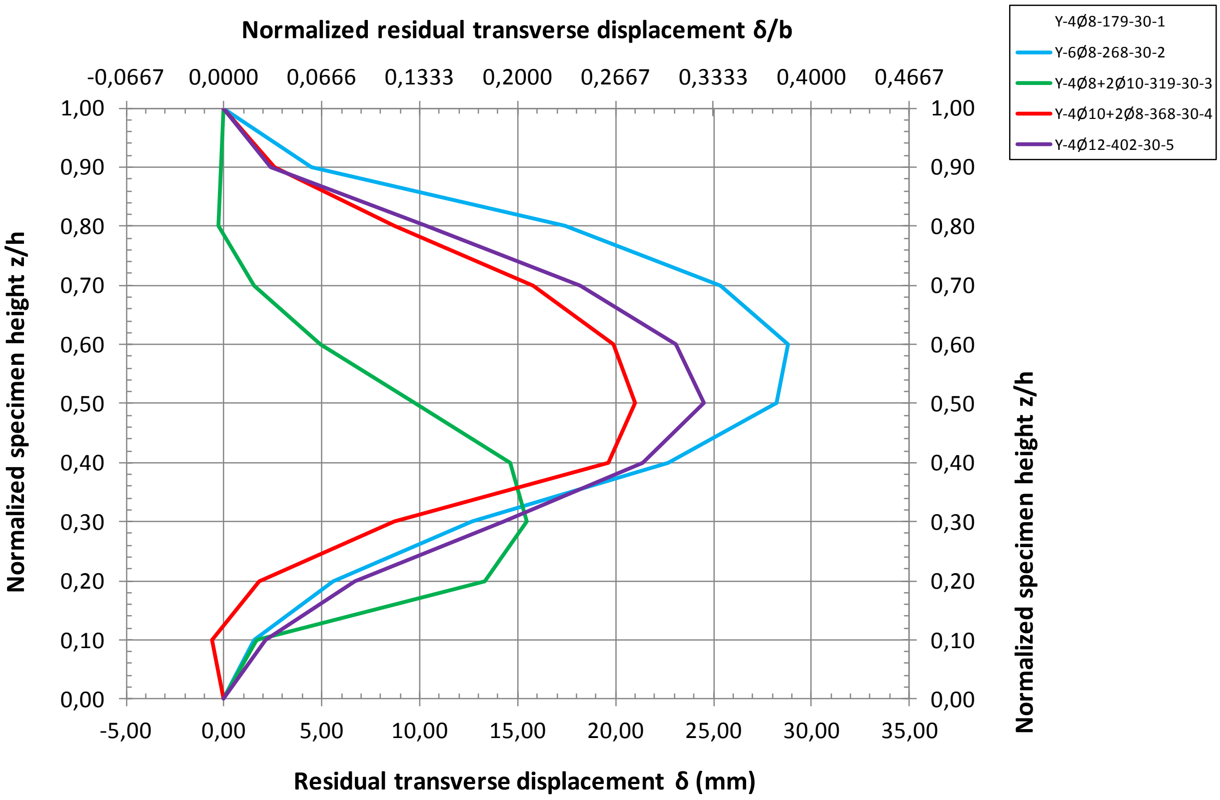

Figure 5: Diagram of normalized specimen height [z/h] – residual transverse displacement [δ(mm), δ/b]

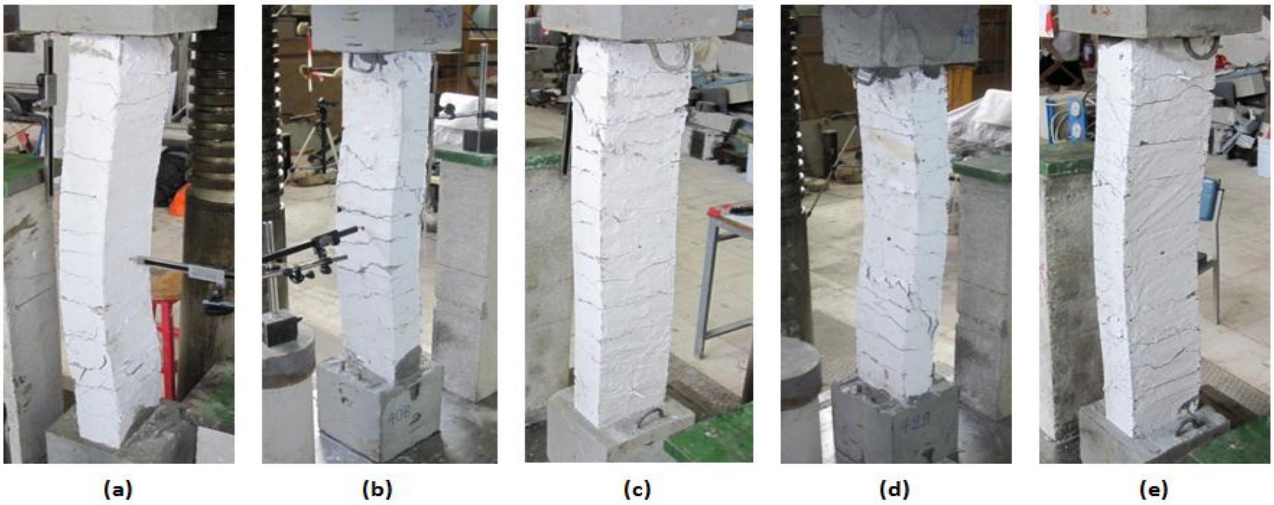

Figure 6. Modes of failure of specimens after the experiment of compression: (a) Y-4Ø8-179-30-1, (b) Y-6Ø8-268-30-2, (c) Y-4Ø8+2Ø10-319-30-3, (d) Y-4Ø10+2Ø8-368-30-4, (e) Y-4Ø12-402-30-5

ANALYSIS OF RESULTS

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

1. First, it is observed that the change of the reinforcement ratio does not change the failure mode of the specimens. Thus, for all reinforcement ratios failure takes place due to buckling.
2. It becomes readily apparent that there is substantial variation of the maximum failure load by varying the ratio of longitudinal reinforcement. It is generally observed that increasing the longitudinal reinforcement ratio results to an increased maximum failure load. This trend, however, is valid under certain conditions.
3. 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 reduced by increasing longitudinal reinforcement ratio (Figs. 7, 8). However, this is only a tendency and it is not true for all ratios of longitudinal reinforcement.

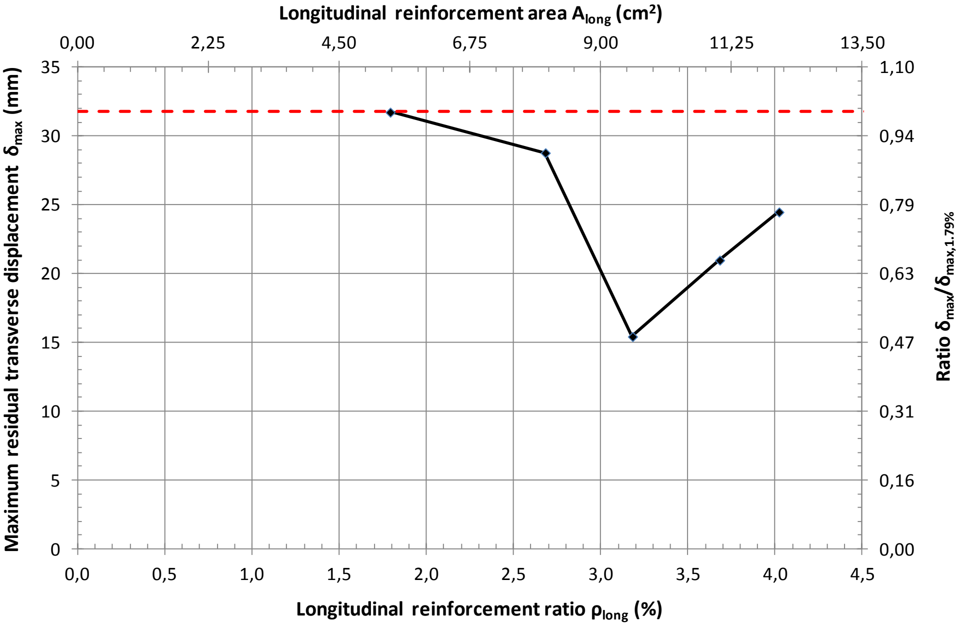

Figure 7: Diagram of maximum residual transverse displacement [δ_{max}(mm), $\delta_{max}/\delta_{max,1.79‰}$] – longitudinal reinforcement ratio and longitudinal reinforcement area [ρ_{long}(‰), A_{long}(cm^2)].

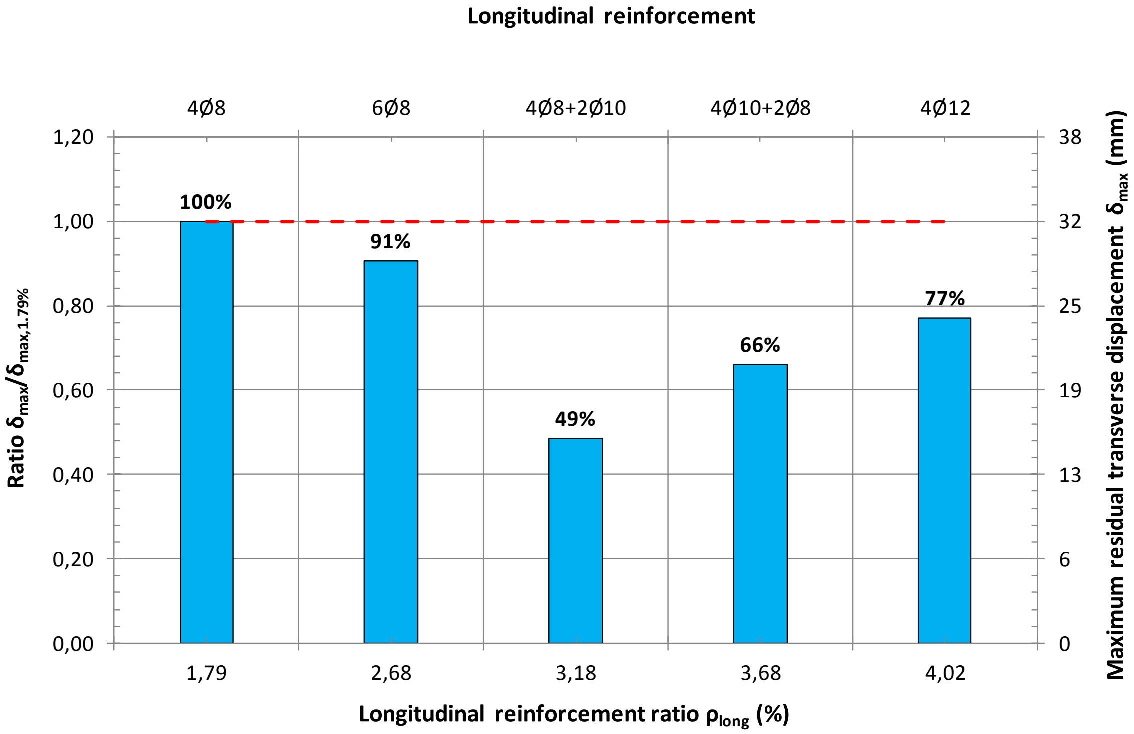

Figure 8: Column diagram of maximum residual transverse displacement [$\delta_{max}/\delta_{max,1.79‰}$, δmax(mm)] – longitudinal reinforcement ratio and type of longitudinal reinforcement [ρ_{long}(‰)].

CONCLUSIONS

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

1. Longitudinal reinforcement ratio does not affect failure mode of specimens.
2. It seems that there is not a clear relation between longitudinal reinforcement ratio and transverse displacements.

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