The influence of ratio of the longitudinal reinforcement of the boundary edges of structural walls to the resistance against lateral instability of earthquake- -resistant reinforced concrete structural walls

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ABSTRACT:
One important aspect of seismic design of buildings with a dual reinforced concrete structural system is the lateral stability of structural walls, when they face this danger basically due to flexural overstrain. The deep excursion in the yield region of the boundary parts of bearing walls increases dramatically their flexibility and since at the same time they are liable, because of the earthquake vibration, to a reversing axial loading (tension - compression), their lateral stability is at stake. The possibility of failure because of lateral instability is limited significantly with the proper choice of an adequate thickness, which is specified by (most) modern seismic codes as a percentage of the height of the bottom storey. The current work investigates one of the most basic parameters affecting the stability of structural walls, which is (apart from the wall thickness) the ratio of the longitudinal reinforcement of the boundary edges of load-bearing walls. The present work is experimental. It has to be noted that in order to examine experimentally the influence of the longitudinal reinforcement ratio, 11 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 10,72%). 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 ultimate bearing capacity of test specimens.

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

1. INTRODUCTION

In the past few years, a concern is observed internationally regarding the seismic mechanical behavior of walls, especially against their transverse instability (Fig. 1.1) under extreme seismic loads. This increasing concern is connected directly to the types of damage that are observed in reinforced concrete structures. Indicatively, the bibliography (Penelis and Kappos, 1990) reports the following usual and main types of damage that are observed in the reinforced concrete walls of actual structures after the event of seismic excitation:

1. Cross shear cracks.

2. Slipping at the construction joint.

3. Bending type damage (horizontal crackings - crash of compression zone).

It is observed that the relevant bibliography (Penelis and Kappos, 1990) does not refer and does not include as damage the out-of-plane buckling of walls. Indeed, for the case of bending type of damage of walls, crash of the compression zone is refered as a result for the compression zone for this specific type of damage. However, it is known that bending type of failure can be manifested as buckling of compression zone and not necessarily with its crash, a fact that leads to the so-called failure of transverse buckling.

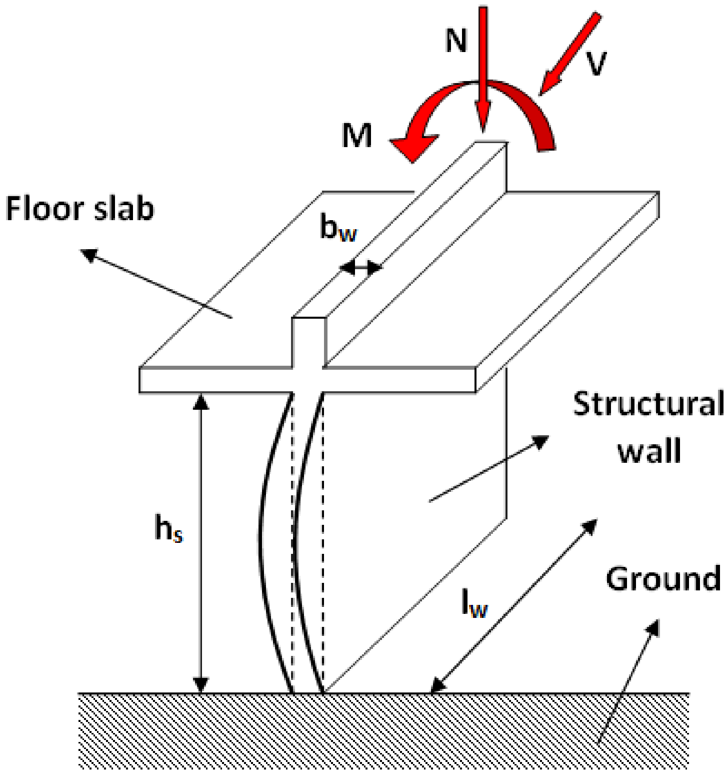

Figure 1.1. Out-of-plane buckling of wall

It becomes 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. Consequently, it is concluded that the phenomenon of transverse buckling at the compression edges of walls in the plastic hinge region (base of wall) is a no warning (and consequently very dangerous) phenomenon since it leads to total collapse of the structures and in particular without leaving proofs that the total collapse and failure emanated from this specific phenomenon. Moreover, this is also one of the reasons that relevant code provisions 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 occurence of this phenomenon and the factors that lead to its growth. The present work constitutes a small part of an extensive research program that took place in the Laboratory of Reinforced Concrete and Masonry Structures of the Faculty of Engineering of A.U.Th., on the phenomenon of out-of-plane buckling and the factors that influence it.

2. RESEARCH SIGNIFICANCE

The influence of ratio of longitudinal reinforcements of extreme regions of walls in the resistance of seismic walls against transverse instability is experimentally examined. The test results are based on experiments that were carried out in columns that model the extreme zones of walls. These columns had each one of them different longitudinal reinforcement ratio, were strained in the same degree of elongation (equal with 30‰ in all cases) and then were submitted in compressive loading. Degree of elongation 30‰ was chosen because it has been observed in actual structures (Chai and Elayer, 1999), and thus, it simulates the large sizes of tensile deformations which are applied at the plastic hinge regions of ductile walls and then are followed by the compressive loading that is imposed due to alternation of sign of seismic loading. The test results are analyzed and important conclusions are formulated with regard to the influence of ratio of longitudinal reinforcement to the problem of out-of-plane buckling of reinforced concrete walls.

3. EXPERIMENTAL INVESTIGATION

3.1. Aim of experimental investigation

The main objective of the experimental investigation was to ascertain the influence of longitudinal reinforcement ratio of extreme zones of walls against the risk of transverse instability, since this influence will have as a consequence the increase of critical buckling load, when the same flanges are submitted then in compression. Also, an objective of the experimental investigation is to determine if the increase of longitudinal reinforcement ratio beyond some reasonable limit leads also to a halt of the buckling mode of failure.

3.2. 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 with 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 loading of concentric compression. The differentiation of specimens lies in the different longitudinal reinforcement ratio that had each one from them. Specimen characteristics are brought together in Tab. 3.1, while Fig. 3.1 and 3.2 present their cross-section and their end plan both for tensile and compressive loading.

Table 3.1. Specimen characteristics

N/A	Description of specimens	Dimensions (cm)	Longitudinal reinforcement	Transverse reinforcement	Longitudinal reinforcement ratio (%)	Concrete 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
6	Y-6Ø10-419-30-6	15x7.5x90	6Ø10	Ø4.2/3.3cm	4.19	23.26	30.00
7	Y-4Ø14-547-30-7	15x7.5x90	4Ø14	Ø4.2/3.3cm	5.47	23.26	30.00
8	Y-6Ø12-603-30-8	15x7.5x90	6Ø12	Ø4.2/3.3cm	6.03	23.26	30.00
9	Y-4Ø16-715-30-9	15x7.5x90	4Ø16	Ø4.2/3.3cm	7.15	23.26	30.00
10	Y-6Ø14-821-30-10	15x7.5x90	6Ø14	Ø4.2/3.3cm	8.21	23.26	30.00
11	Y-6Ø16-1072-30-11	15x7.5x90	6Ø16	Ø4.2/3.3cm	10.72	23.26	30.00

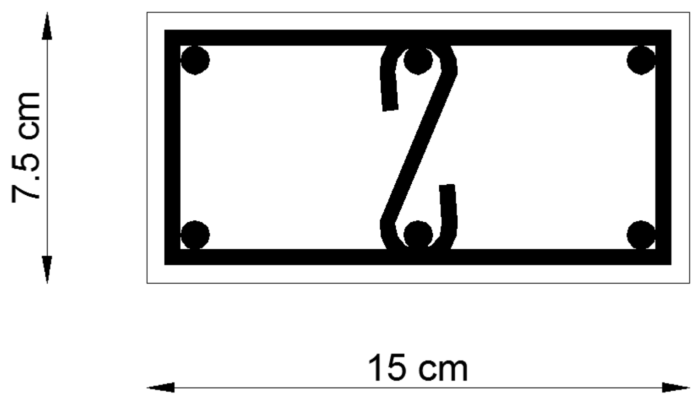

Figure 3.1. Cross-section of test specimen Y-6Ø8-268-30-2.
(Reinforcement differs for each specimen. Example shows a typical specimen with longitudinal reinforcement 6Ø8.)

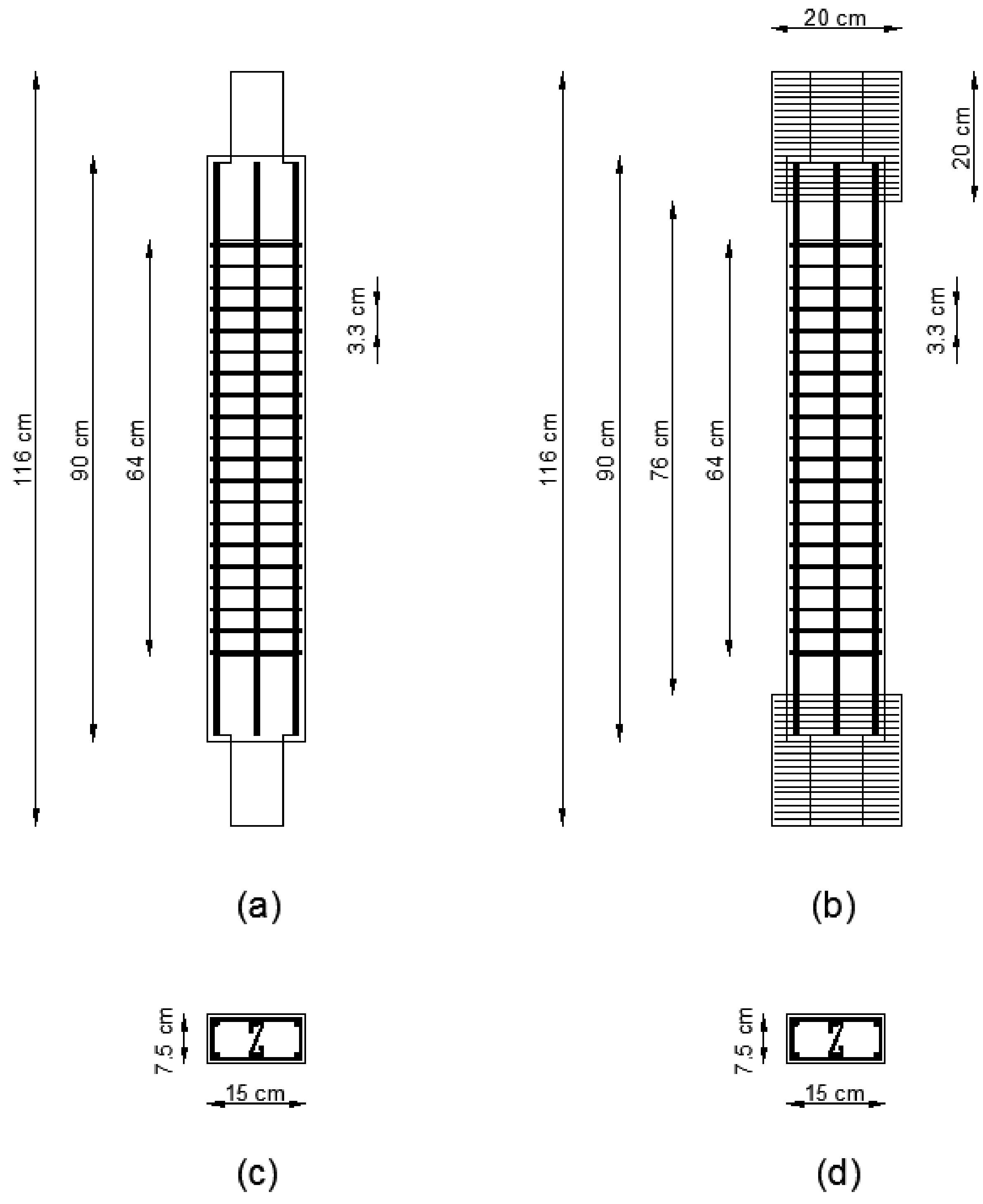

Figure 3.2. Column specimen Y-6Ø8-268-30-2: (a) End plan in tension, (b) End plan in compression, (c) Section, (d) Section.
(Reinforcement differs for each specimen. Example shows a typical specimen with longitudinal reinforcement 6Ø8.)

3.3. Loading of specimens

The test setups used to impose on the specimens in the first semi-cycle of loading the uniaxial tensile load and in the second semi-cycle of loading the concentric compression load are presented in the Fig. 3.3.

(a) (b)

Figure 3.3. Test setup for application of: (a) tensile loading, (b) compressive loading

4. EXPERIMENTAL RESULTS

Fig. 4.1 refers to the experiment of uniaxial tension and presents the change of elongation of specimens with regard to the imposed tensile load. It becomes obvious from a simple observation of the diagram that actual degrees of elongation differ in all specimens a little bit from the nominal degree of elongation that is equal with 30‰. However, in all cases, the differences are small and negligible. Fig. 4.2 refers to the experiment of concentric compression and presents the change of shortening with regard to the imposed compressive load this time. It becomes, easily, obvious that there is an almost monotonous increase (with certain exceptions) of the critical failure load of specimens with the increase of the longitudinal reinforcement ratio. Finally, Fig. 4.3 presents the various modes of failure of specimens after the completion of compressive loading.

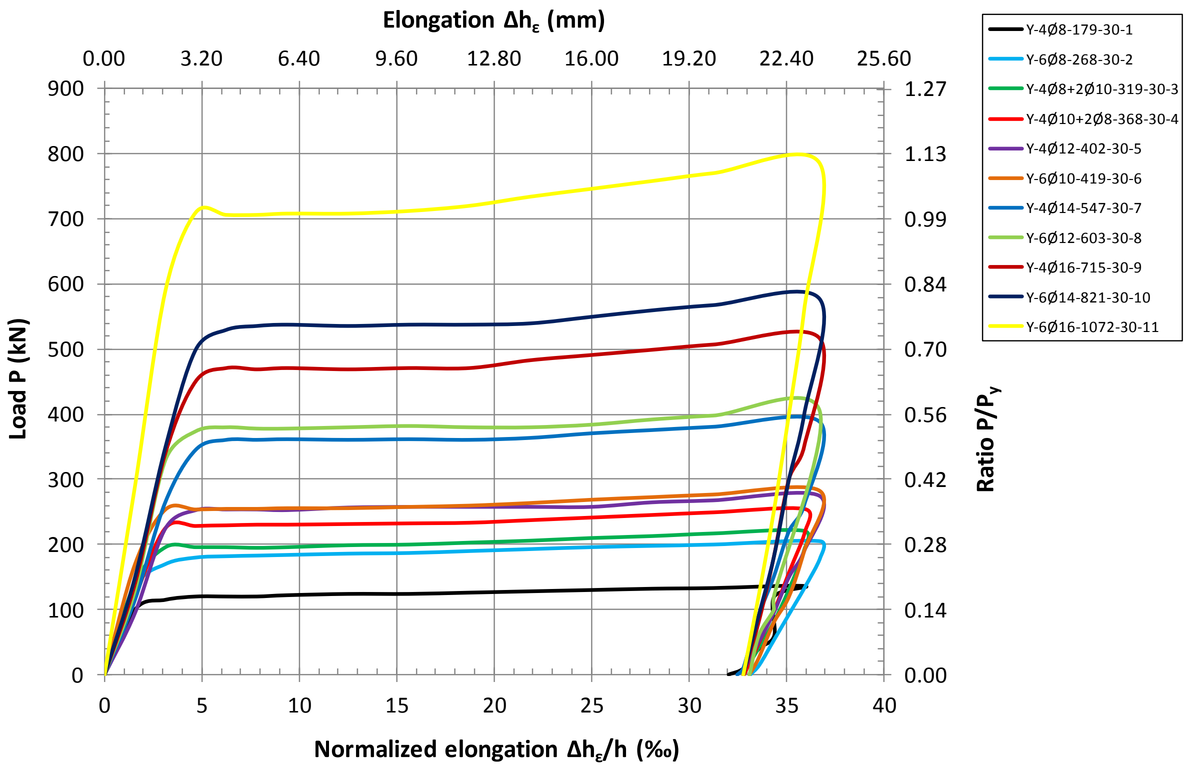

Figure 4.1. Diagram of tensile load [P(kN), P/P_y] - elongation [$\Delta h_\varepsilon/h$(‰), Δh_ε(mm)]

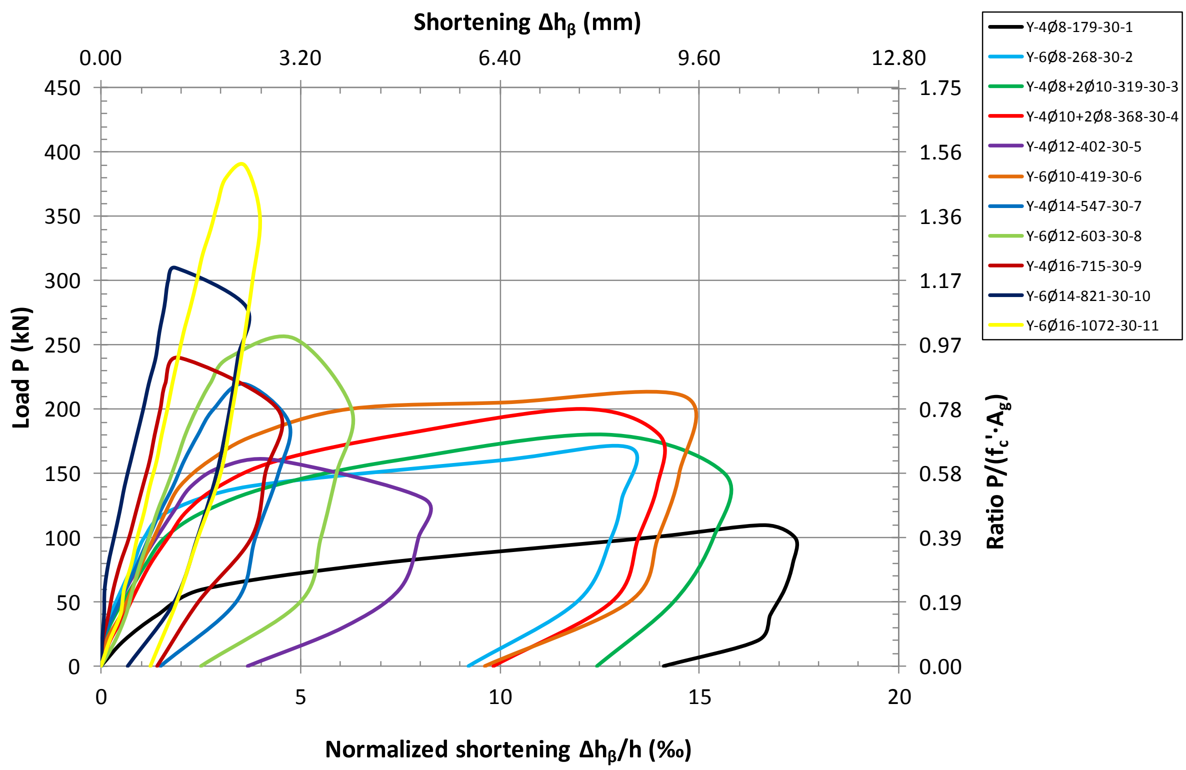

Figure 4.2. Diagram of compressive load [P(kN), $P/(f_c'\cdot A_g)$] - shortening [$\Delta h_\beta/h$(‰), Δh_β(mm)]

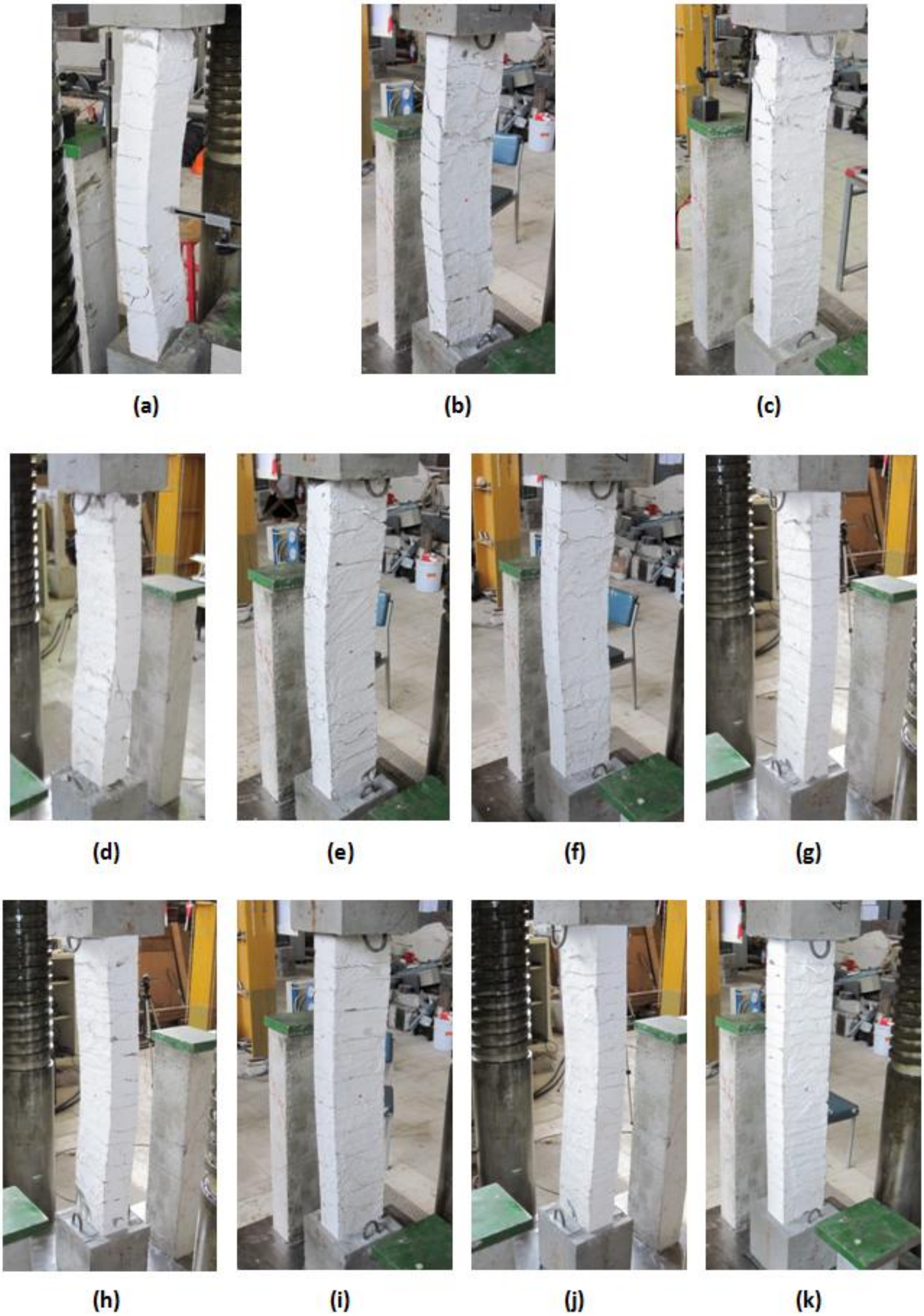

Figure 4.3. Modes of failure of specimens after the experiment of compression: (a) Y-4Ø8-179-30-1, (b) Y-6Ø8-268-30-2, (c) Y-4Ø8+2Ø10-319-30-3, (d) Y-4Ø10+2Ø8-368-30-4, (e) Y-4Ø12-402-30-5, (f) Y-6Ø10-419-30-6, (g) Y-4Ø14-547-30-7, (h) Y-6Ø12-603-30-8, (i) Y-4Ø16-715-30-9, (j) Y-6Ø14-821-30-10, (k) Y-6Ø16-1072-30-11

5. ANALYSIS OF RESULTS

From the conduct of experimental investigation and the evaluation and analysis of test results of specimens, observations arise with regard to the behaviour of test specimens and are the following:

1. Firstly, it is observed that the increase of longitudinal reinforcement ratio does not innovate any change in the way of failure of specimens even for very big reinforcement ratios of the order of 11%. Failure of all specimens (it is reminded that they have undergone the same degree of tension 30‰) is owed to lateral instability.

2. Very important and appreciable observation is that the increase of reinforcement ratio does not always imply an increase of the maximum failure load of specimens which fail due to transverse instability. It becomes obvious that specimens that have bigger reinforcement ratio, e.g. 7.15%, fail at smaller load (240 kN) compared to specimens with smaller reinforcement ratio, e.g. 6.03%, that fail at bigger load (255 kN). This fact is owed in the way that this increase of reinforcement ratio is achieved, that is to say with 4 or with 6 bars of longitudinal reinforcement. In any case, by comparing the results of maximum failure loads for specimens with the same number of bars (hence with the same reinforcement setup), it is observed that specimens with bigger reinforcement ratio fail at bigger loads. It appears, consequently, the large and important influence of reinforcement ratio in the failure load due to transverse instability.

Figure 5.1. Diagram of maximum failure load [P(kN), $P_u/P_{u,1.79\%}$] - ratio and area of longitudinal reinforcement [ρ_{long}(%), A_{long}(cm^2)].

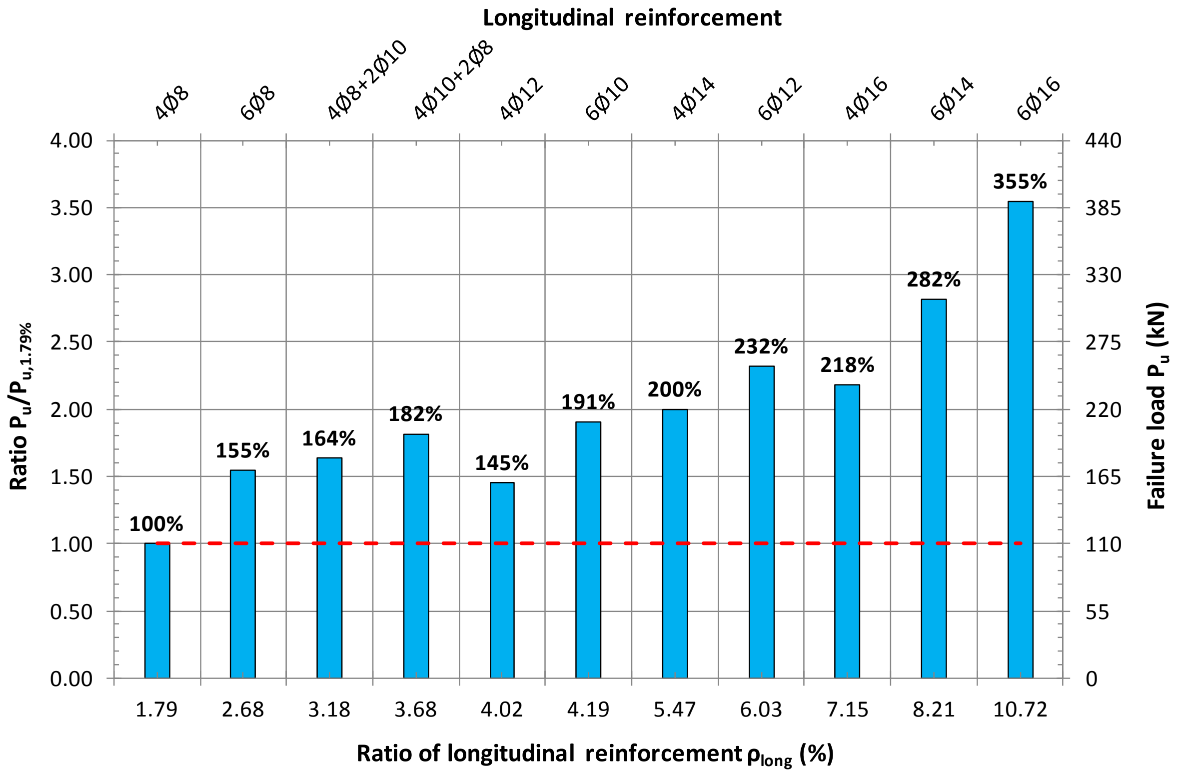

Figure 5.2. Column diagram of failure load [$P_u/P_{u,1.79\%}$, P(kN)] - ratio and type of longitudinal reinforcement [ρ_{long}(%)].

6. CONCLUSIONS

Based on the preceded test investigation and analysis and evaluation of its results, the following conclusions arise:

1. The main conclusion of the present study is that transverse instability of walls is a complicated phenomenon, which does not depend only on the height of ground floor (as implied by the vast majority of modern international codes) but also on other mechanical parameters, as it is e.g. the longitudinal reinforcement ratio.

2. Generally, the increase of longitudinal reinforcement ratio of extreme regions of walls has important influence in the halt of lateral buckling (moving the final critical failure load to bigger values) and consequently, it is possible to lead to avoidance of extreme enlargement of cross-section of seismic walls, under the term that this increase of reinforcement ratio is realized with proper setup of reinforcement bars.

3. With regard to the minimum thickness of seismic walls, which varies depending on the applied code, important additional investigation is required and in any event, it does not constitute the unique parameter of influence in the problem of undesirable transverse instability of structural elements, which ensure the seismic shielding of multistorey constructions.

4. It is experimentally argued that the final mode of failure of specimens remains the same (failure because of buckling in the weak direction) and is not influenced by the increase of longitudinal reinforcement ratio provided that the degree of elongation is constant.

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