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# Experimental and Numerical Study of Strain Degree of Medium-Reinforced Prism Specimens

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***Abstract*** **-** Lateral instability of seismic walls is a catastrophic phenomenon which can affect severely the seismic behaviour of reinforced concrete multi-story buildings. It can even lead to the total collapse of multi-story buildings affecting human safety and having socioeconomical consequences, too. In the framework of this work, the influence of the degree of tension on the phenomenon of transverse instability of reinforced concrete seismic walls is examined. This investigation is both experimental and analytical and includes 4 test specimens. These specimens model the edges at the end of seismic walls. All columns simulate only the extreme reinforced areas of the walls, in order to study the basic mechanism of the phenomenon. The detailing of the specimens includes of 4 rebars with 8 mm diameter and 2 rebars with 10 mm diameter. The geometric dimensions are the same for all specimens. What differentiates the specimens from each other is the degree of tension they have sustained. More specifically, the tensile degrees used are 1%, 2%, 3% and 5%. Extreme earthquake action needs to be considered and that is the reason for using in the work herein large elongation degrees, e.g., 3% and 5%. The numerical investigation follows the experimental investigation using appropriate statistical software and finite elements. The resulting load-strain diagrams prove the very good correlation that exists between the test results and the analyses. The elastic branch, the yielding point and the plastic branch coincide very good for all four test specimens. Basic conclusion is that the degree of elongation is a very crucial mechanical parameter that affects tremendously the behavior of the boundary edges of structural walls.

***Keywords*****:** Analytical Study, Elongation Degree, Lateral Buckling, Medium Reinforced

## 1. Introduction

Structural behavior and soil-structure interaction has troubled engineers worldwide for various types of structures [1]–[3]. One crucial failure mode of reinforced concrete structural walls is the transverse instability [4], [5]. In international bibliography, it can be found either as lateral buckling or transverse buckling or out-of-plane buckling. The terminology instability is used sometimes, too, instead of buckling. Several researchers worldwide have investigated this particular phenomenon and the mechanical parameters influencing it [6]–[23]. The basic parameters examined were degree of elongation, longitudinal reinforcement ratio and slenderness [6], [24]–[27].

The probability of failure regarding lateral instability is minimized greatly when choosing a specific wall thickness given as a ratio of the bottom floor height [28], [29]. The utilization of an appropriate number of R/C seismic walls is a usual practice nowadays and this fact has led the modern concrete regulations to include such provisions [21], [22], [30]. It is essential that relative researches have made well-known that the utilization of a satisfactory number of structural wall comes about into an extraordinary resistance against the seismic [9]. It is vital to note that the out-of-plane instability is a phenomenon which has troubled researchers around the world, as well as for R/C walls and for walls constructed by other kinds of materials [31].

Despite the efforts conducted internationally, there is a knowledge gap, as far as researches combining experimental with analytical results using 3D finite element analysis software are concerned. There is also a gap when it comes to tensile strains deep inside the yield region. The present study uses experimental tests performed in the past by the first author trying to investigate the mechanical parameters affecting the transverse instability [32], [33]. These specimens were subjected to low, medium and high tensile strains equal to 1%, 2%, 3% and 5%. Such high tensile strains are rare to be used going deep inside the yield region. In this work, the four specimens subjected to tensile loading are modelled using finite element analysis and afterwards, a comparison takes place between the analytical investigation and the existing results of the experimental investigation concerning the tensile loading stage.

## 2. Experimental Research

### 2.1. Test Specimen Characteristics

The experimental investigation for the four test specimens has been described in detail by the first author in the past [16]. Figure 1a shows the geometrical characteristics of the four test specimens, while Figure 1b displays the load test setup used for the application of the tensile loading. It is noted that the tensile loading is the first stage of the two loading stages. In the framework of the present study, only the experimental results of the tensile loading stage are compared to the analytical ones. Table 1 shows the test specimens' characteristics. The number at the column labelling represents the degree of elongation that each specimen has sustained; meaning 1%, 2%, 3% and 5%.

Table 1: Dimensions of the test specimens

| **N/A** | **Specimen** | **Dimensions (cm)** | **Longitudinal reinforcement** |
|---|---|---|---|
| **1** | COLUMN-1 | 15x7.5x76 | 4xD8 + 2xD10 |
| **2** | COLUMN-2 | 15x7.5x76 | 4xD8 + 2xD10 |
| **3** | COLUMN-3 | 15x7.5x76 | 4xD8 + 2xD10 |
| **4** | COLUMN-5 | 15x7.5x76 | 4xD8 + 2xD10 |
| **N/A** | **Transverse reinforcement** | **Longitudinal rebar ratio (%)** | **Elongation Degree (%)** |
| **1** | D4.2@33 mm | 3.19 | 1.00 |
| **2** | D4.2@33 mm | 3.19 | 2.00 |
| **3** | D4.2@33 mm | 3.19 | 3.00 |
| **4** | D4.2@33 mm | 3.19 | 5.00 |

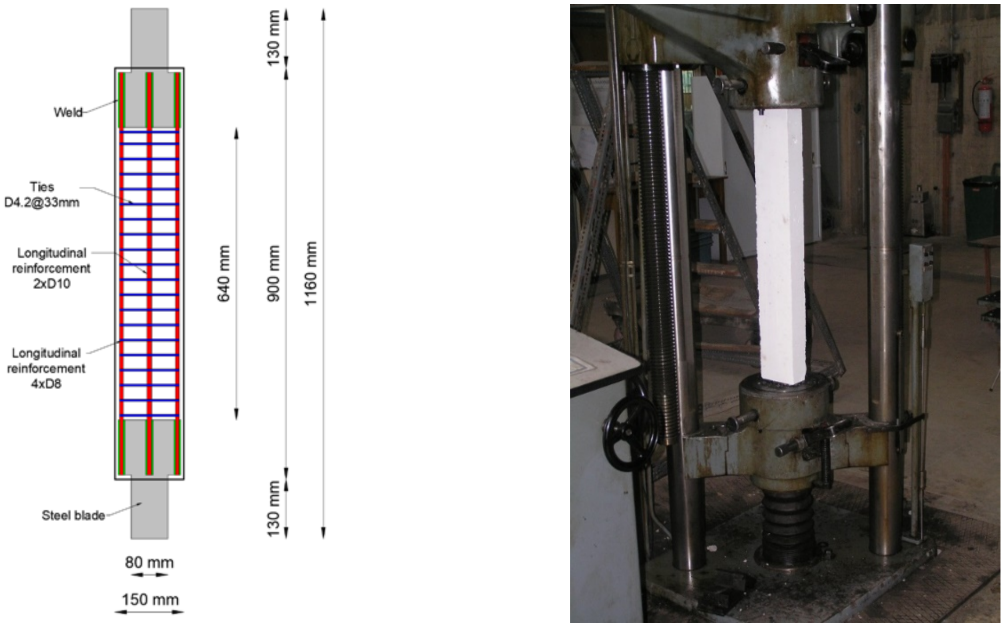


Figure 1: (a) Detailing of test specimens, (b) Tensile loading test setup

## 2.2. Materials

For all specimens, materials used for their construction and their characteristics were also described in the past [16]. Table 2 displays the concrete resistance for all specimens at 28 days while Table 3 shows the mechanical properties for the longitudinal steel and the transverse ties.

Table 2: Concrete mechanical properties

| N/A | Specimen | Cube resistance (28 days) (MPa) |
|---|---|---|
| **1** | COLUMN-1 | 22.82 |
| **2** | COLUMN-2 | 22.82 |
| **3** | COLUMN-3 | 22.82 |
| **4** | COLUMN-5 | 22.82 |

Table 3: Reinforcement mechanical properties

| Reinforcement | Yield strength (MPa) | Ultimate strength (MPa) |
|---|---|---|
| D8 (Used for longitudinal rebars) | 603.77 | 743.10 |
| D10 (Used for longitudinal rebars) | 552.02 | 670.91 |
| D4.2 (Used for transverse stirrups) | 674.01 | 674.01 |

### 2.3. Experimental Results

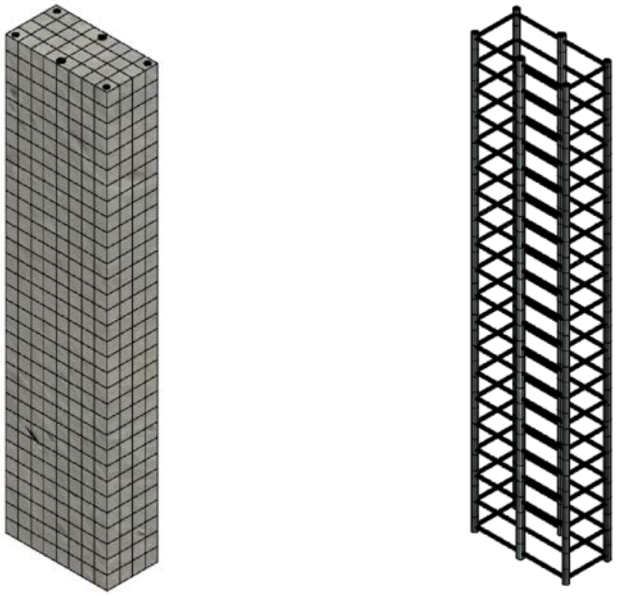
Each one of the four test specimens has been subjected to a different degree of elongation [16]. Figure 2 displays shape of specimens after the uniaxial tensile test has taken place. It is obvious that several cracks of different width have formed, as it has happened in other similar experiments [34], [35].

Figure 2: Shape of specimens tensile strain: (a) COLUMN-1, (b) COLUMN-2, (c) COLUMN-3, (d) COLUMN-5

## 3. Analytical Research

### 3.1. Modelling of Test Specimens

The analytical research has taken place using a finite element software. 3D elements were used to model all four test specimens subjected to tensile loading. It is noted, as it has been mentioned before, that the present work focuses on modelling only the first stage of loading; meaning the tensile loading path till certain preselected and different degrees of elongation. For the concrete material, the inelastic concrete model of isotropic plasticity from the software library has been chosen. For the reinforcement bar material, the properties derived from experiments are implemented in the software in order to model the inelastic behavior of reinforcement steel. A bilinear isotropic model has been chosen for the behavior of rebar steel. The bilinear isotropic model was chosen because this is the model used for the steel stress-strain relationship according to Eurocode 2 [36]. It is also a kind of model that takes into account the hardening behavior of reinforcement steel. The same inelastic model has been selected to model the behavior of the steel used for the transverse ties. 3D finite elements having an edge of 2 cm are used for the modelling of the concrete column section. Both the longitudinal reinforcement and the transverse ties are modelled using 3D finite elements having a length equal to 1 cm. Figure 3 shows the 3D model of the column both for the whole column section and the reinforcement steel. The column model is considered fixed at its base.



**(a)** **(b)**

Figure 3: (a) 3D model for column, (b) 3D model for the column reinforcement

### 3.2. Analytical Results

Figure 4 displays the displacement along the column height after the end of the tensile loading test.

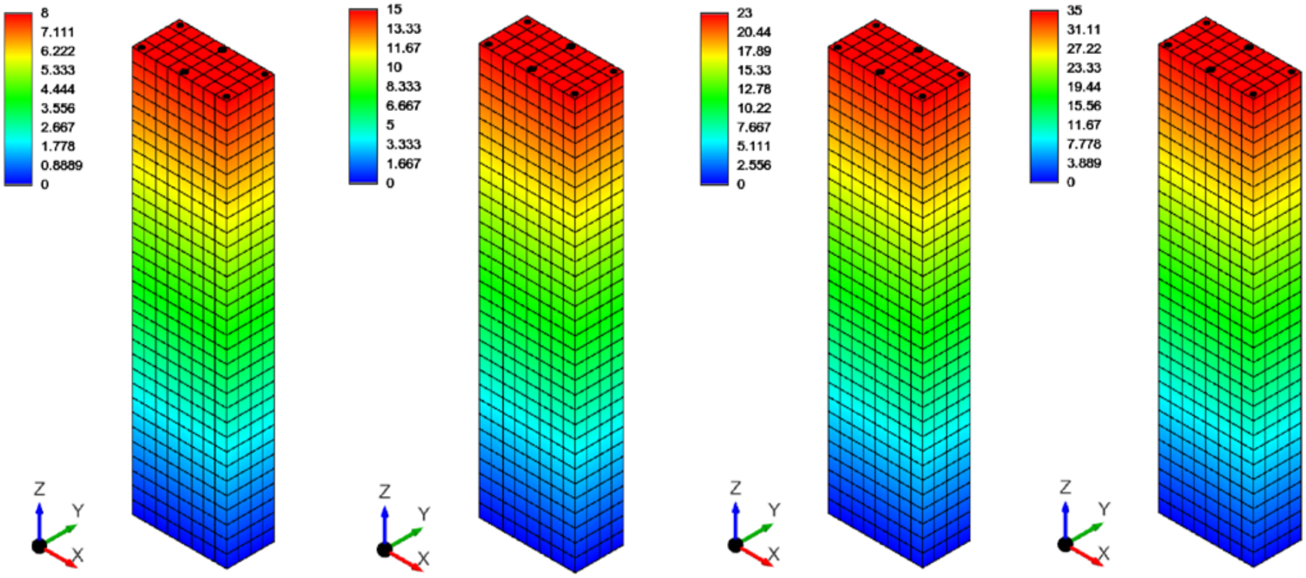


Figure 4: Tensile displacements along the column height per change of degree of elongation

# 4. Results and Discussion

## 4.1. Analytical versus Experimental Results

A comparison takes place between the load versus elongation diagrams which have resulted from the experimental tensile tests and the numerical tensile tests (Figure 5 - Figure 8).

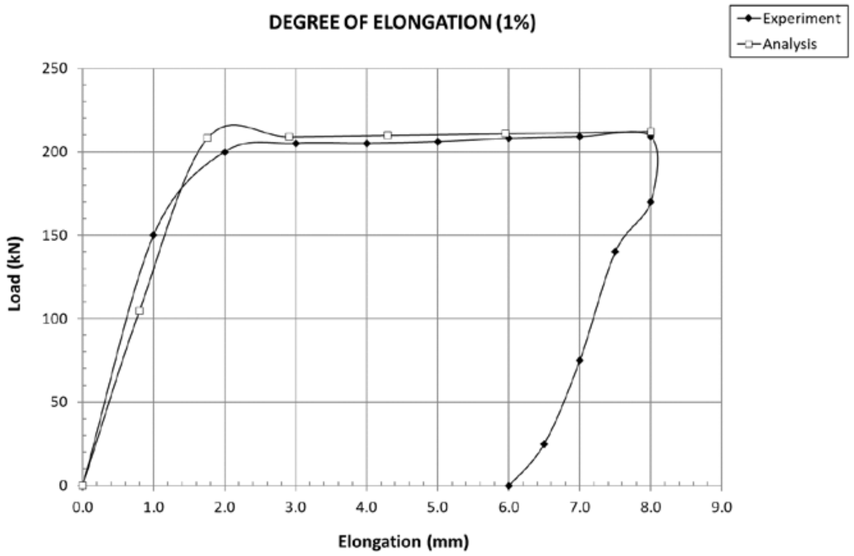


Figure 5: Load versus elongation diagram for specimen COLUMN-1

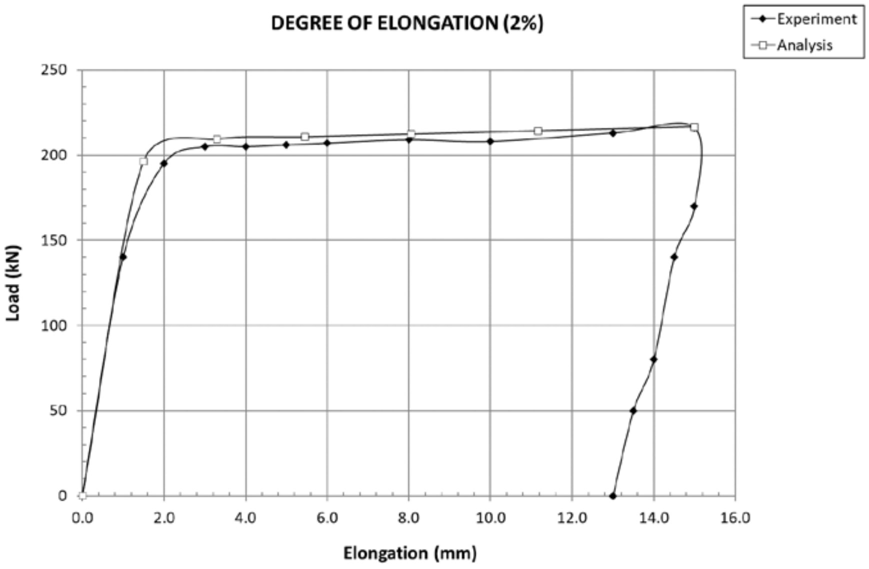


Figure 6: Load versus elongation diagram for specimen COLUMN-2

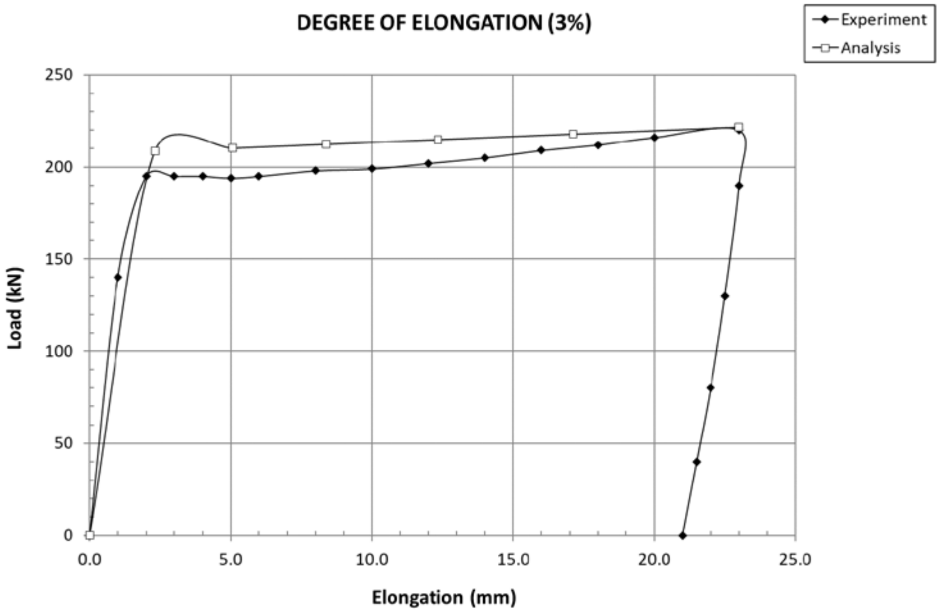


Figure 7: Load versus elongation diagram for specimen COLUMN-3

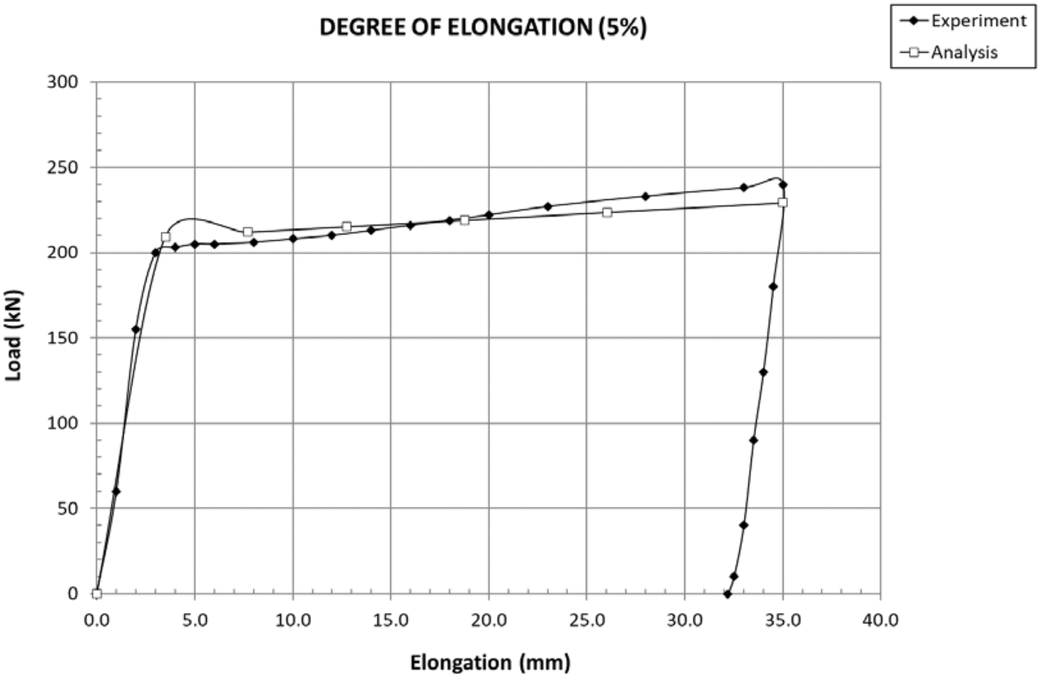


Figure 8: Load versus elongation diagram for specimen COLUMN-5

### 4.2. Discussion

The analysis of the previous results leads to the following:

1. Figure 4 displays the displacement along the Z-axis which coincides with the height of the prism specimens modelling the boundaries of seismic walls. All specimens are subjected to tensile strain till the preselected displacement according to the preselected tensile degree.
2. The vertical displacement is zero at the base of the prisms since the base is fixed (Figure 4). The maximum vertical displacement is found towards the upper part of the specimens where the tensile load is applied. The same phenomenon takes place in the tensile experiments where the tensile load is applied at the upper part of the test specimens while at the bottom part the test specimens are held rigidly by the grapples of the tensile machine.
3. It is obvious that the test results correlate very good with the analytical results for all test specimens (Figure 5 - Figure 8). Both the elastic and the plastic branch coincide very well between the experiments and the analyses.
4. It is noteworthy that yielding takes place almost at the same load both for the tests and the analyses for all test specimens.
5. Only the effective length of the specimens has been modelled, since this is the length within which the tensile elongation appears (Figure 1). The effective length is equal to 640 mm (Figure 1).

## 5. Conclusions

In the framework of the current research, an analytical investigation has taken place including numerical analyses of four test specimens modelling the extreme ends of R/C seismic walls. The numerical analyses have taken place using 3D finite elements. The results from the numerical analyses are compared to the relevant experimental results from the same test specimens found in a previous publication of the first author. The following conclusions should be noted:

1. The results from the tests converge very good with the results from the analyses performed concerning the load-displacement diagrams of the tensile loading.
2. The elastic branch, the yielding point and the plastic branch coincide very good for all four test specimens.
3. The degree of elongation is a very crucial mechanical parameter that affects tremendously the behavior of the boundary edges of structural walls and its investigation has to be applied in the proper and right way following a correct procedure. The convergence between the experimental and the numerical results proves that the procedure applied, in the present work, follows the right path.
4. Future research could and should model the whole test specimen and not only the effective length in order to simulate even more precisely the experimental behavior. Then this more precise analytical behavior could be compared again with the relevant experimental results.

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