Behavior of RC frames under quasi-static diagonal loads

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ABSTRACT

The aim of this investigation is to analyze the mechanical behavior of reinforced concrete frames under diagonal loads. The study provides a combination of analytical and experimental work related to the quasi-static diagonal loading of the reinforced concrete frames. The analytical modeling of the RC frames was performed in ETABS software on a real scale frame, whereas the experimental test was performed on a RC frame of a scale 1/3 of the analytical model. The load displacement curves were built from both the investigation methods and the maximum strength, yielding point, maximum displacement parallel and perpendicular to the loads, Modulus of Elasticity, and ductility factor (Rμ) of the RC frames were obtained and analyzed.

Keywords: experimental testing, ductility, masonry, infill walls, RC frame, ETABS

INTRODUCTION

Reinforced Concrete (RC) is a combination of concrete; a material with good compressive strength, but relatively low tensile strength and ductility, which are improved by using steel reinforcement bars that have good strength and ductility properties. RC structural members are generally designed to resist tensile stresses in special parts of the concrete that can cause unacceptable cracking or structural failure. Modern RC concrete can contain different RC materials made of steel, polymers or mixed composite material in conjunction with rebar or not [1].

Ductility may be defined as the ability of the structure to undergo big deformations without a substantial reduction in the flexural capacity of the structural members. This deformability is influenced by some factors such as the tensile reinforcement ratio, the amount of longitudinal compressive reinforcement, the number of lateral ties and the strength of concrete [2].

Ductile behavior in a structure can be achieved through the use of plastic hinges positioned at appropriate locations within the structural frames. These are designed to provide sufficient ductility to resist structural fall after the yield strength of the material has been achieved. The available ductility of plastic hinges in RC concrete is determined based on the shape of the moment-curvature connection [3].

The displacement ductility factor Rμ is defined by the ratio between failure displacements to yield displacement. The yield displacement (△y) is the lateral displacements at 80% from ultimate load at arise part of curve while the failure displacement (△f) is lateral displacement at 80% from ultimate load at subtracting part of the curve. The ductility factor and displacement ductility are computed using equation (1) below [4].

$$R\mu = \Delta f / \Delta y \qquad (1)$$

where: Rμ is the ductility factor, △f is the failure displacement and △y is the yield displacement

Pushover analysis is an approach analysis method in which the structure is subjected to monotonically increasing lateral forces with an invariant height-wise distribution until a displacement is reached. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure.

The lateral forces are increased up to some members will yield. The structure has been modified in push over analysis in order to decrease stiffness and then lateral forces will try to increase the yielding of members. The process of the putting lateral forces is continued in the structure until that the structure has reached a capacity and the deformation of the structure becomes unstable [5].

Assessment of the structural behavior of the RC frames has become an important topic especially in the earthquake prone countries. Tawfik, 2016, investigated the behavior and ductility of high strength frame concrete (HSFC). The experimental program was done on five specimens who have different dimensions. In the case of equal beam to column dimensions a plastic hinge was formed in the column, the plastic hinge was formed in the beam in case of stiffer column, the increase of inertia of beam for high strength RC frame increases the ultimate lateral load, energy distribution and stiffness by a small value while it decreases the ductility factor, increasing the inertia of column for H.S.R.C frame; the ultimate lateral load, energy distribution, and stiffness are increased by a significant value, while it decreases the ductility factor, increasing the stirrups at connections; the ultimate lateral load and displacement at ultimate lateral load are increased by a significant value [6].

Watson, 1989, carried out an experimental campaign to investigate the flexural strength and ductility of reinforced concrete columns under stimulated earthquake loading. Additionally, the behavior of columns with square and octagonal cross sections were also analyzed under simulated earthquake loading. For the columns, various amounts of shear reinforcement were applied [7].

Diagonal compression test as of ASTM E519-02 [8] is a widely used test to assess the shear resistance of masonry walls. Many researchers have used this method to assess the shear resistance of brick masonry panels [9,10] as well as stone masonry [11,12]. The obtained parameters provide good insights about the capacity of the wall to resist possible seismic forces.

The aim of this study is to investigate the mechanical behavior of reinforced concrete frames under quasi-static diagonal loading. And analyze the parameters such as maximum strength, yielding point, maximum displacement parallel and perpendicular to the loads, Modulus of Elasticity, and ductility factor (Rµ) of the RC frames.

METHODOLOGY

The methodology used in this study consists of modelling of a RC frame using ETABS software, as well as experimental testing of a reduced-size model of a scale 1/3 under diagonal compression. Prior to testing, all the materials mechanical characteristics were measured. The tests were conducted at the Civil Engineering Laboratory at EPOKA University.

Test set-up

The diagonal compression test is carried out by rotating the frame 45º, and application of the load exerted by a 50-tonne hydraulic jack, vertically. The frame edges sit on two loading shoes as seen in Figure 1a. The RC frame specimen was built by experienced worker and tested in the laboratory in order to avoid accidental stresses during transportation. In Figure 1 are presented the specimen ready to be tested and the CAD drawings for reinforcement. The frame has the following characteristics:

- frame dimensions:120 x 120 mm, reinforced with 4H12 and shear reinforcement of H6 @ 50 mm centers, 40 mm centers and 100 mm centers (depending upon the load distribution)
- concrete class C25/30
- steel grade B500C.

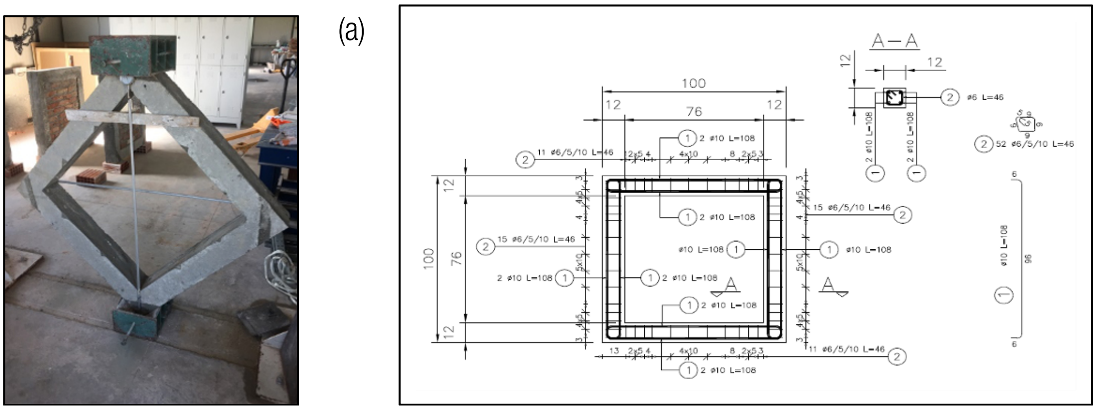
(a) (b)

Figure 1. (a) RC frame ready for testing; (b) CAD drawing of the reinforcement detailing of the frame.

Finite Element Modelling

The finite element model of the RC frame specimen consists of linear frame elements modelled using ETABS software. A very important step in modelling is defining correctly the restrains as well as plastic hinges (Figure 2).

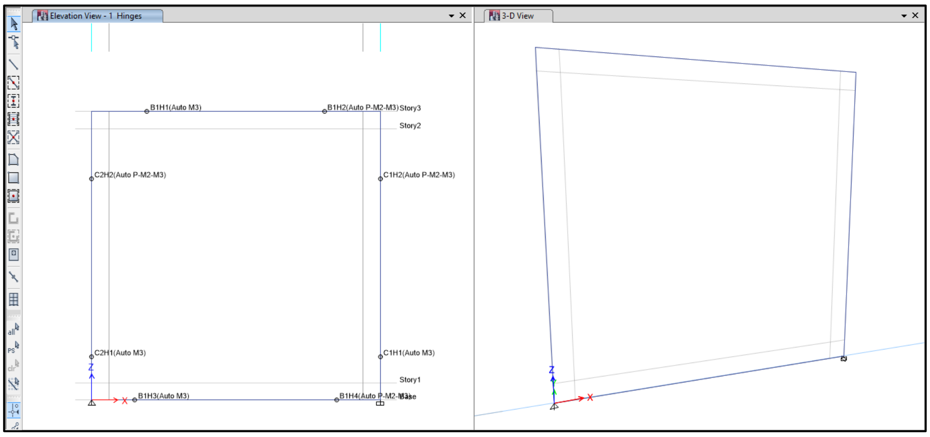

Figure 2. Frame model with hinges defined.

From the analysis output results, deformed shapes, joint displacements, base reactions, push over curves, etc. can be obtained.

RESULTS AND DISCUSSION

Experimental results

The exerted load was increased gradually. The first visible crack of the frame occurred at a load of 25 kN with a corresponding displacement in compression at 2.97 mm and a displacement in tension at 5.36 mm. The yielding stage of the RC frame occurred at a load of 45 kN. At this stage plastic behavior of the specimen is observed.

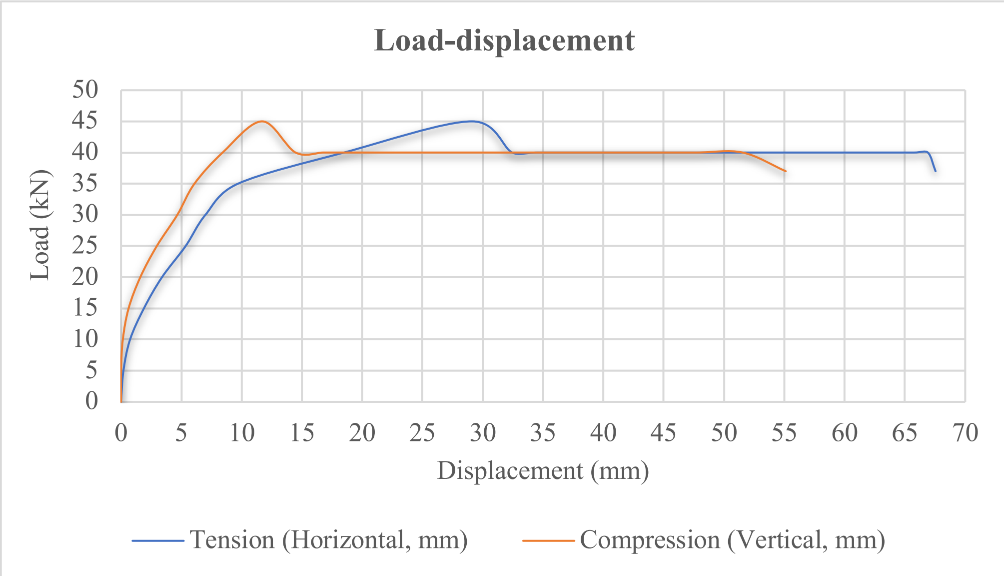

Figure 3. Load-displacement curve of RC frame

All the visible cracks in concrete occurred near the stirrups. The biggest crack width was observed near the top of the frame having a width of about 30 mm and had propagated along a length of 110 mm.

Figure 4. Deformed RC frame after the test and details of cracked joints.

Finite element analysis results

Finite element analysis results were obtained in terms of displacements, deformed shapes of the frames under dead load, P1 load, Combo load, P1 nonlinear load, G+P load; push over curve, FEMA 440 Displacements, effect of the hinges; etc.

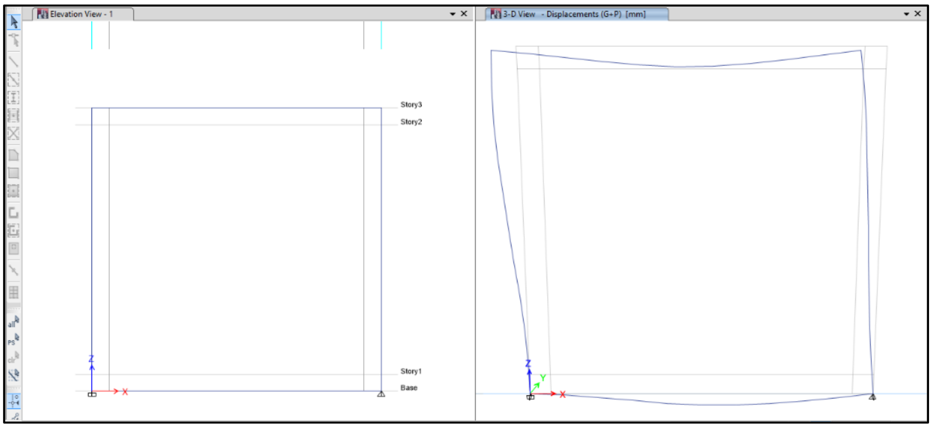

Figure 4. Deformed shaped under combination of applied load P and self-weight (P+G)

From the analysis results, three main cases were obtained from ETABS:

- Base shear vs. Monitored displacement - the intersection point of the base shear and the monitored displacement is at 47.00 kN and 120 mm.
- FEMA 440 Equivalent Linearization
- FEMA 440 Displacement Modification – the frame has base displacement of 2 mm and a base shear of 34.99 kN.

In Table 8 are presented the results of the base reactions of the frame under various load combinations of self-weight, G, the applied load P.

Table 8. Reaction of RC frame.

Load Case/Combo	F_x (kN)	F_z (kN)	My (kNm)
Dead (G)	0	38.8685	58.303
P1 Load	0.7	0.7	0
Combo Max	0	38.8685	58.303
Combo Min	0	38.8685	58.303
P1 Nonlinear Max	49.6242	49.6242	2.8505
P1 Nonlinear Min	0	0	0
G+P	0.7	39.5685	58.303

In Figure 5 is presented the monitored displacement and the base shear of the frame. In 2.8 mm displacement has a base force of 43.67 kN. The displacement and base shear continue to increase with the increase of the force on RC frame.

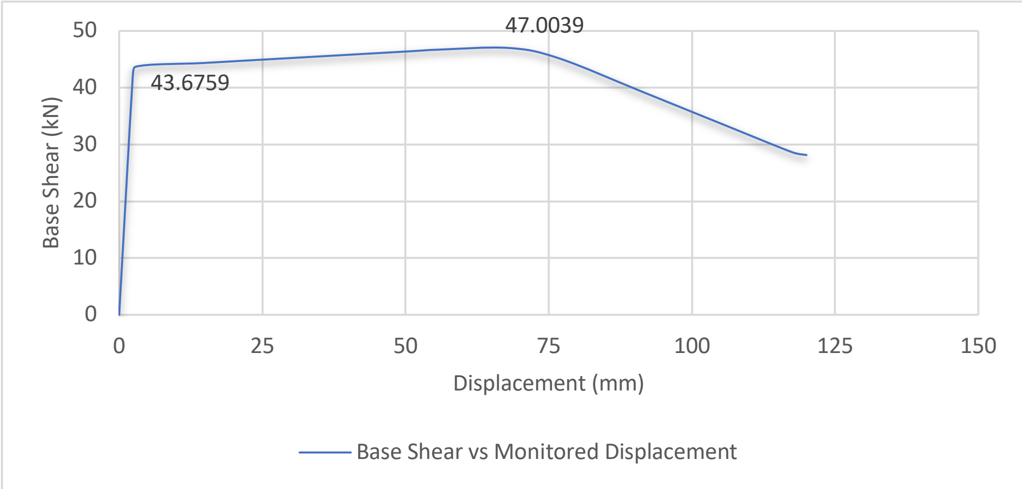

Figure 5. Base Shear versus Monitored displacement for RC frame.

Ductility of RC Frames

Calculation of the ductility factor for the frame was done using the equation 1. It was calculated taking into consideration horizontal and vertical directions.

- The ductility factor for RC frame in compression (y-direction):

$$R\mu = \frac{\Delta f}{\Delta y} = \frac{55.12\ \text{mm}}{11.7\ \text{mm}} = 4.71$$

- Ductility factor for RC frame in tension (x-direction).

$$R\mu = \frac{\Delta f}{\Delta y} = \frac{67.54\ \text{mm}}{5.36\ \text{mm}} = 12.60$$

- Ductility factor for RC frame from the numerical analysis.

$$R\mu = \frac{\Delta f}{\Delta y} = \frac{120\ \text{mm}}{2.8\ \text{mm}} = 42.85$$

CONCLUSION

In this study RC frame under diagonal quasi-static loading was investigated both experimentally and numerically. The numerical results obtained from ETABS software show that RC frame has a displacement of 2 mm and a base shear of 34.99 kN. On the other hand, from the laboratory results, it was seen that the RC frame has a displacement of 2.97 mm in compression and 5.36 mm in tension and a base shear of 25 kN.

The maximum displacement was recorded as 26.54 mm, whereas from the ETABS results, a maximum displacement of 120 mm was obtained.

The difference in the results is attributed the size difference between the specimen and the model. Nevertheless, the experimental results and the numerical results show a similar performance of the frames in both cases.

Yielding points on the frames that are tested in laboratory passes in five points beginning from the elastic zone, yielding point, strain hardening, ultimate strength, necking, and fracture stress

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