Modelling of reinforced concrete RC frame using a simplified approach

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Abstract
The intent of this paper is to use a simplified finite element model to simulate the reinforced concrete frame by using Timoshenko beam elements for columns and beams and the modified Takeda model for the sectional behavior. The model takes into account the non-linear behavior of a reinforced concrete by introducing laws behavior that reflects the real behavior. A failure criterion that is based on the ultimate rotations of the element is associated with finite element model to study the local failure that occur in the frame at any point of the model. The FEMA 273 has given these ultimate rotations. In order to validate the model, the RC frame tested by Vecchio was simulated and therefore, the numerical results have been compared to those of the experiment

***KEYWORDS*:** RC/frame, moment curvature, plastic rotation, pushover analysis, global models.

1. Introduction

Recent earthquakes (Japan, 2011, Pakistan, 2013 and Nepal, 2015) have shown that existing structures, in particular those consisting of reinforced concrete frames, exhibit a lack of strength, compromising the safety of people during earthquakes. The most sensitive parts in structures, which are most likely to alter the performance of these, under a seismic load, are generally the nodal zones (Areas in the nodes vicinity) [Eduardo Carvalho Jr 2012]. It has been found that these nodal zones are the places where load transfer occurs, located at the intersection of the beams and the columns [D. Brancherie 2011]. The progressive plasticization of the zones in the nodes vicinity in the beams leads to the appearance of plastic hinges, thereby turning the structure into a mechanism that causes the whole collapse , [Miha Jukic 2014]. During this study, the experimental RC frame of Vecchio [Vecchio F 1992] is modeled through a CASTEM2000 finite element code, using Timoshenko beam elements for columns and beams with the modified Takeda model [Priestley 1987].The obtained results have been compared to the experiment in order to validate the finite element model.

2. Presentation of the experimental model

The experimental model stems from Vecchio F works [Eduardo Carvalho Jr 2012], [J. Faleiro 2005], where a two story's RC frame structure is considered and tested experimentally. The size and the reinforcement of the structure are presented in figure 1. In order to represent the constant live loads, two vertical constant forces of 700 KN each are applied on top of the RC frame structure. A lateral displacement is imposed and the corresponding load is measured until the failure of the structure.

3. Finite element model and Tekeda Model

As mentioned in the introduction, the global approach is used in the current study, where the columns and beams of Vecchio RC frame (figure 1) are modeled by the Timoshenko beam element and the sectional behavior is modeled with the Modified Takeda model. It found that this Takeda model has enough ability to reproduce the response of the RC frame structures under lateral and seismic loads [A.Aréde 1997].

This model is assumed to be a bending model, which is characterized by a tri-linear moment curvature law of RC cross section, for more details, see [A.Aréde 1997]. The moment curvature characteristics of a given cross section can represent the deformation properties of an RC section as shown in figure 2.

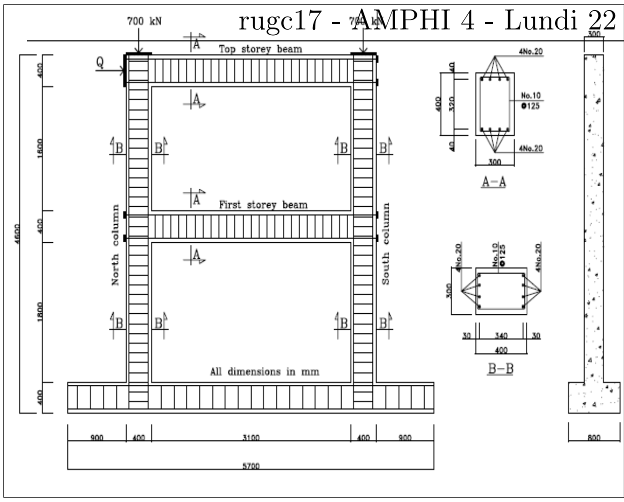


Figure 1. Geometry and reinforcement of the experimental RC frame

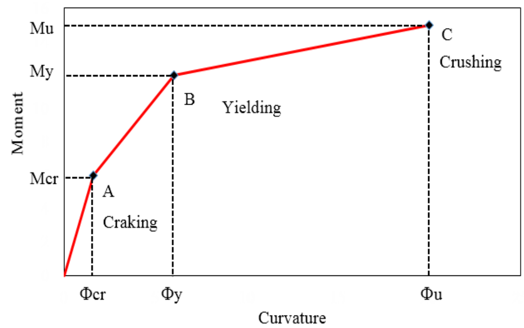


Figure 2. Quantitative moment-curvature relationship

4. Proposed failure criterion

This criterion is based on the failure of the plastic hinge, which can be evaluated by the curvature or rotation developed at each section along the length of the considered element. The developed curvatures or rotations are compared to those defined by the FEMA 273. When the plastic rotations found by the finite element model equal or exceed those given by FEMA 273, we consider that the section is failing, and when a sufficient number of sections fail, it can be considered that the entire RC frame collapses (appearance of failure mechanism).

5. Plastic rotation calculation

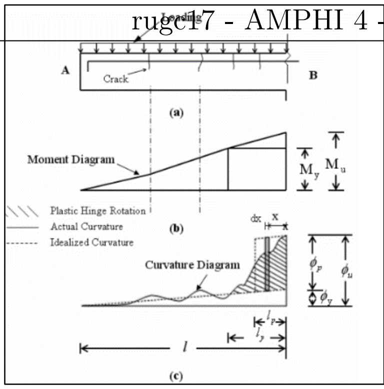
The strain energy in the structure is dissipated by the formation of plastic hinges in the end zones of an element without affecting the rest of the structure. Several analytical models such as [Baker 1964] [Bayrak 1998] [Berry 2008] [Corley 1966] [Kheyroddin 2008] [Mattock 1967] [Mortezaei 2012] [Mortezaei 2012] [Park 1982] [Paulay 1992] [Riva 1990] [Sheikh 1993] [Sheikh 1994] [Herbert 1964] have developed semi-empirical formulae (analytical models) in order to estimate the plastic rotation θp [ATC 1996]. The rotation of an element can be determined from the curvature dtistribution along the length of the element [Bae 2008] [Kheyroddin 2008]. Therefore, the rotation between two points, A and B (figure 3.c), is equal to the area under the curve between these two points, analytically it is given by $\theta_{AB}=\int_A^B \emptyset(x)\,dx$. Where θ is the rotation of an element, x is the distance of the elementary element dx from B, and ∅ is the curvature between points A and B (see figure 3.c).

6. Provisions for plastic hinge rotation capacities of RC members by FEMA 273

The nonlinear procedures of FEMA require definition of the nonlinear load deformation relation. Such a curve is given in figure 4. In this study, we consider that the failure is reported to the points : Immediate Occupancy (IO), Life Safety (LS) and Collapse Prevention(CP), are used to define the damage level for the plastic hinge [FEMA 1997]. Figure 1 represents the damage level (IO, LS, and CP) of the plastic hinge according to the developed rotation on the element. In this study, we consider that the failure is occurred when the CP damage is reached.

1. Simulation results of the Vecchio RC frame

The figure 5 represents the comparison between the numerical and the experimental results. In global manner, the numerical model can predict in acceptable way on the elastic and the plastic response of the RC frame. This figure shows also that, the numerical model predict very well the load and the displacement corresponding to the failure of the beams, as it is shown if the figure 5.



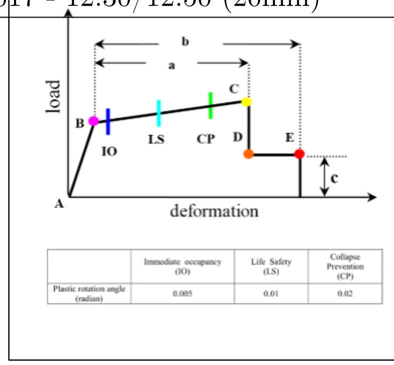


Figure 3. Curvature and bending moment distribution along the length of an element performance levels

Figure 4. Typical load deformation relation and target given by FEMA 273

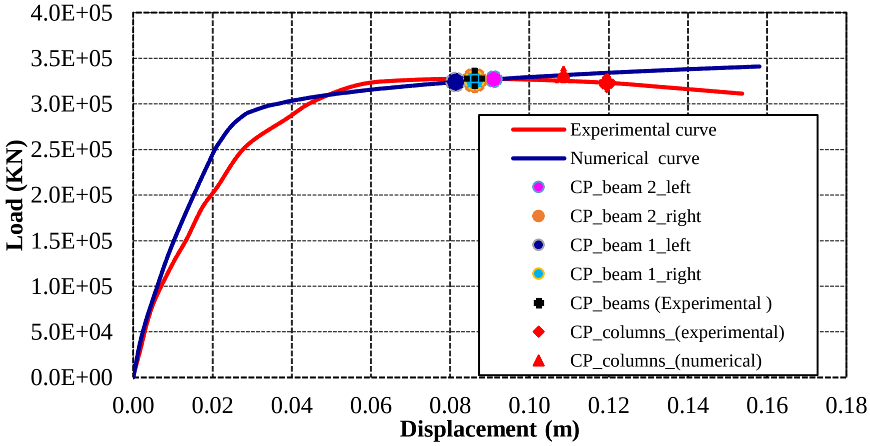


Figure 5. Numerical model versusexperimental resultsand failure criterion for beams.

The figure 5 presents the local obtained results of the simulated RC frame in terms of damage level with its corresponding load and displacement for each beam. The beam of the first level undergoes a damage level of IO (immediate occupancy) at the left and right zones, near the two nodes of the RC frame, for loads of 271.194 KN and 278.969KN, respectively. With load increasing, the damage level of IO passes to damage level of LS (life safety) for loads of 300.284KN and 301.981KN at the left and right zones of the beam, respectively. After reaching the two mentioned damage level, the failure of this first beam appears in the left and right zones for loads of 324.017KN and 325.569KN, respectively. At those loads, the plastic rotation developed in the finite element model in the left and right zones of the beam are greater than 0.02 rad (those calculated by FEMA 273), so the beam is considered as fail.

The beam of the second level follows the same damage path as the first beam and the failure is occurred in the same way as the first beam. The failure load on the left and right zones are 327.004 KN and 325.569 KN, respectively. As indicated in figure 5, the load and the displacement corresponding to the failure of the beam of the first and the second level in the experiment are 327.716 KN and 0.08617m, respectively, and in the numerical is around 327KN and 0.08618 m, respectively. From theses loads and displacements values corresponding to the failure, it can be concluded that the numerical model can predict very well the experimental response of the RC frame structures. Regarding the columns, no failure is observed in the experiment as well as in the numerical results. However, the columns underwent only damage at the base for the failure load of beams (see figure 5). It is also interesting to mention that only the failure of the beams leads the failure of the whole RC frame.

2. Conclusion

This paper presented a simplified finite element model under CASTEM2000 code that is capable to reproduce satisfactorily the global response of reinforced concrete frame under static load. The failure criterion associated to the model showed very interesting results that allowed predicting the failure at the local level such as the failure of the plastic hinge (nodal zones).

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