IOP Conference Series: Materials Science and Engineering

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Evaluation of the Influence of Different Grades of Reinforcing Steel on the Seismic Performance of Concrete reinforced Frame Structures with Nonlinear Static Analysis

Evaluation of the Influence of Different Grades of Reinforcing Steel on the Seismic Performance of Concrete reinforced Frame Structures with Nonlinear Static Analysis

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Abstract. In this investigation, the elasto-plastic behavior and the seismic performance of concrete reinforced frame structures reinforced are evaluated by applying the Pushover method. This evaluation is done on several cases: with high ductility steel (Grade 40), conventional steel (Grade 60) and high strength steel (Grade 75). For the previous, the capacity curve graph obtained from the displacement coefficient method was used to measure the capacity of the structure. In addition, the performance of the structure for different levels of seismic design are evaluated with the resulting values of ductility and rigidity of each case. The results showed that reinforcing a structure with a Grade 40 reinforcing steel increases the energy dissipation capacity, and if reinforced with a Grade 75 reinforcing steel increases the strength capacity in the structure. Finally, the comparative result of the various cases are presented to demonstrate the influence of reinforcing steel on the plastic behavior of concrete reinforced frame structures.

1. Introduction

In the last 30 years, the disasters that have been happening due to strong seismic movements have left structures with severe damage and, in other cases, uninhabitable structures. Among the most devastating are the following: the earthquake in southern Peru of 2001 of magnitude 8.4, Sumatra-Andaman of 2004 of magnitude 9.1, the earthquake of 2007 Haiti of magnitude 7.0 and the one on the Pacific coast in the region of the 2011 Tohoku of magnitude 9.1 [1,2,3,4]. Despite the fact that these earthquakes occurred in different places, they all evidenced similar seismic activity.

With reference to the aforementioned in the previous paragraph, structures subjected to large magnitude seismic movements present problems of reduction of stiffness and resistance to shear, which causes an increase in the demand for ductility. This causes the columns at the base to fail before the beams and as a consequence the structures collapse [5]. Regarding the influence of the steel grade in the reinforced concrete structure for structures subjected to severe earthquakes, the columns on the ground floor must be capable of developing sufficient ductility since when its reach their elastic limit, the concrete stops working and the Inelastic deformation is assumed solely by the properties of the reinforcing steel. For this reason, it is necessary for structures to dissipate a large amount of energy, so it is better to carry out a structural design with high-strength steel instead of designing with high-strength concrete [6]. Also, since the reinforcing steel in the beams is in tension, the steel yields before the concrete reaches its maximum compressive stress; therefore, it is suggested to reinforce with high ductility steel [8,]. 9On the other hand, buildings with columns reinforced with steels higher than grade 60 provide greater resistance to lateral load and a lower repair cost, compared to conventional steel [5]. Likewise, the amount of longitudinal reinforcement in the columns, it can be decreased in direct proportion to an increase in the elastic limit of steel [7].

IOP Conf. Series: Materials Science and Engineering 1048 (2021) 012022 doi:10.1088/1757-899X/1048/1/012022

For nonlinear static analysis and evaluation of seismic performance, a fundamental reference is the ASCE 41-13 code. This analysis has shown that the structural response is more accurate with the displacement design method than with the force-based method, since inelastic deformation is the main cause of possible structural collapse [10].
In this sense, this research focuses on evaluating the influence of reinforcing steel on the capacity, ductility, and stiffness of buildings in the face of seismic forces with non-linear structural analysis and evaluating the performance of the structure for different levels of seismic design for a basic objective.

2. Investigation Methodology

The computational models are first evaluated with linear static and dynamic analysis and then nonlinear structural analysis is performed. An incremental triangular lateral load pattern is applied, which were defined by approximating the inertial forces that will occur in a seismic event according to the predominant mode of vibration of the structure. From all this analysis the graphs of the building's capacity curves are obtained. The evaluation of structural performance with the Coefficient Method is evaluated according to ASCE 41-13 considering 4 levels of seismic demand defined according to their probability of occurrence and return period for the basic performance objective level. The validation of the results is done with the ATC-40, FEMA 273, BERTERO and VISION 2000 standards. The characteristics of the structural models are described in Table 1.

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Table 1. Description of the case studies

Case	With reinforcing steel (Degree)		Number of floors	f'c (kg/cm^2)
	Columns	Beams		
1	40	40	4	280
2	60	60	4	280
3	75	75	4	280
4	75	40	4	280
5	75	75	4	210

4. Results

4.1. Evaluation of the capacity of the structure

Regardless of what grade of steel the structure is reinforced, the resistance and displacement capacity is the same up to a certain point in the linear range. However, when the structure reaches its yield point, the displacement and resistance begin to vary, thereby demonstrating that it is important to perform non-linear structural analysis to assess the capacity of the structure more accurately.

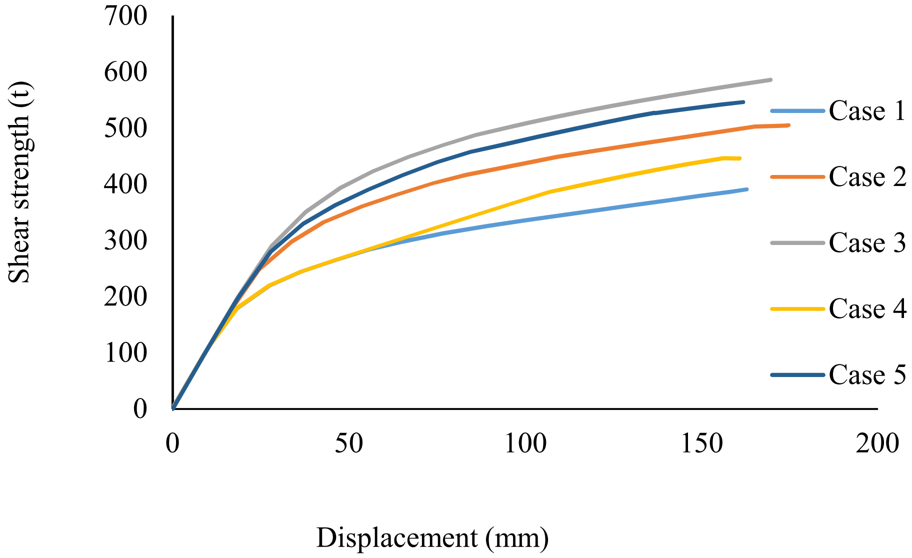


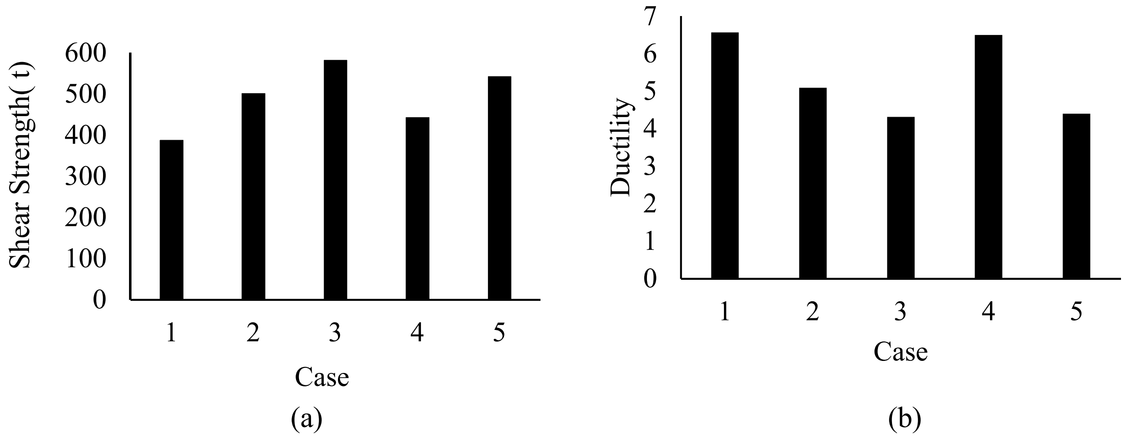
Figure. 1 Capacity curve of the 5 analysis cases

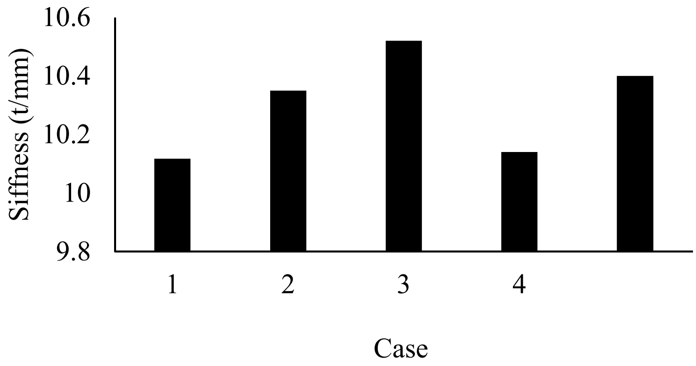
4.2. Evaluation of resistance capacity, stiffness and ductility

The conventional design of a structure reinforced with grade 60 reinforcing steel is 23% stronger, 29% less ductile and 2.3% more rigid compared to a structure reinforced with grade 40 steel. In contrast, it is 16% less resistant, 15% more ductile and 1.6% less rigid compared to a structure reinforced with grade 75 steel. This shows that the grade of the reinforcing steel influences the inelastic deformation of the structure.

The results of the investigation indicate that a structure with beams reinforced with grade 40 steel and columns with grade 75 steel is 16% less resistant, 28% more ductile and its rigidity is similar with respect to the structure reinforced with grade 60.

En cuanto a la estructura reforzada con acero de alta resistencia y con f´c=210kg/cm^2 es 7% menos resistente, y la ductilidad y rigidez son similares respecto a una estructura reforzada con el mismo grado de acero, pero con f´c =280 kg/cm^2. En cambio, es 8 % más resistente, 16 % menos dúctil y la rigidez es similar respecto a una estructura reforzada con acero de grado 60 y con f´c =280 kg/cm^2.





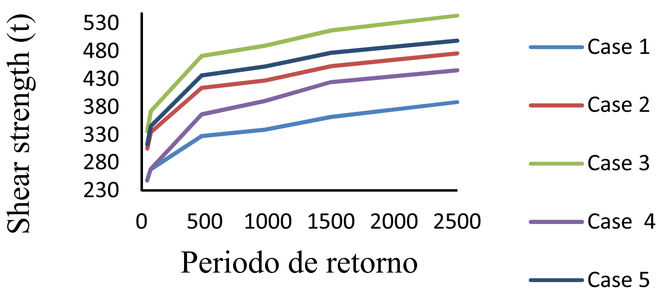
(c)

Figure. 2 Evaluation of resistance capacity, stiffness and ductility

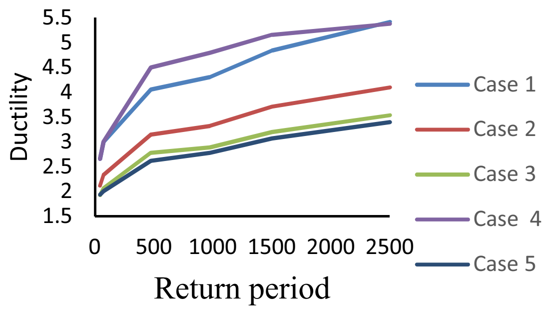
4.3. Evaluation of seismic performance

The results indicate that the demand for resistance and ductility increases; however, the demand for stiffness decreases when the severity increases or the payback period is longer.

Buildings reinforced with high-strength steel (cases 3 and 5) tend to withstand higher strength demands and structures reinforced with high-ductility reinforcing steel in the beams and with high-strength reinforcing steel in the columns (case 4) it tends to resist the demand for stiffness more.



(a)



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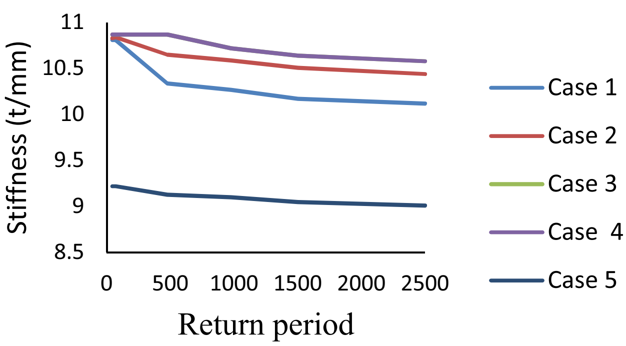

(c)

Figure. 3 Demand for shear strength, ductility and stiffness *a. Verification of lateral drift.*

The lateral drift presented by the structural models for a level of collapse prevention seismic performance indicates that they are lower than the limits proposed by the ATC-40, FEMA 273, and BERTERO and VISION 2000 standards.

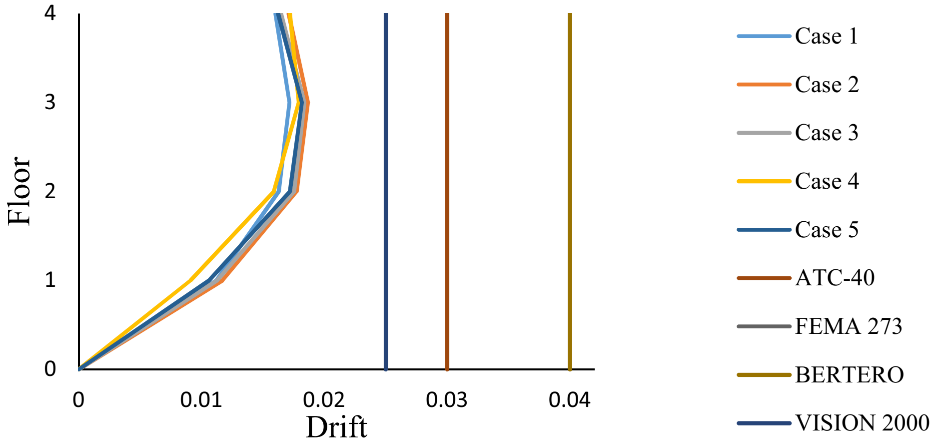

Figure. 4 Lateral drift demand and limits according to ATC-40, FEMA 273, BERTERO AND VISION 2000

5. Conclusions

Based on the results of the evaluation of the influence of reinforcing steel on the seismic performance of concrete reinforced frame structures, the following conclusions are made:

It is advisable to carry out the structural design combining different degrees of reinforcement in the structural elements, since each element supports different types of efforts, while some elements require more ductility, others require more resistance.

The beams that are subjected to traction must be reinforced with high ductility steel, since it provides the element with greater ductility. On the other hand, in the columns they need to be reinforced with high-strength steel in order to increase their resistance capacity to axial forces and lateral forces.

It is better to increase the resistance of steel than of concrete, because by reducing its f'c, the same ductility and resistance capacity of the structure is obtained.

For future research, the influence of reinforcing steel in tall reinforced concrete buildings can be studied with nonlinear static analysis.

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