Assessing Seismic Fragility of Low-Rise RC Buildings by means of Incremental Dynamic Analysis (IDA)

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Abstract. The modern era witnessed an urbanization and economic growth concentrated in urban areas. Despite an increase in welfare, this receives a greater threat when an earthquake occurs. This research aims to assess the structural risk of low to medium-rise reinforced concrete building structures, commonly built in developing countries. This research was carried out by performing an incremental dynamic analysis (IDA) od an existing building model. In this analysis, the structural model was given a set of dynamic earthquake loads which were increased in magnitude according to certain scale rules until the structure experienced nonlinear behavior and reached a near collapse condition. Five artificial accelerogram recordings were applied on the structure after matching with the spectral response of the target location of the structure. From the analysis, the IDA curves were obtained which describes the global dynamic behavior of the structure, namely displacement due to earthquake lateral loads. Then the damage limits were determined on the IDA curve based on the HAZUS criteria. Then the seismic risk was expressed by constructing a seismic fragility curve. This curve states the probability of exceeding certain damage limits due to variation in earthquake intensity during the service life of the structure.

1 Introduction

Increased economic activity and production are made possible by infrastructure. hence fostering employment growth and societal wellbeing. As a result, many nations are working to improve and sustain economic growth through infrastructure development. Numerous construction and infrastructure projects are centered in metropolitan areas, along with population increase and the faster pace of urbanization.

However, many earthquake-prone locations continue to face a major threat from earthquakes. Earthquakes can result in significant losses, such as injuries, disability, and fatalities, especially urban areas regions with high population density and economic activity.

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A building's infrastructure damage can cause business interruption and a loss in terms of replacement expenses even though contemporary building design and construction standards have been able to lower the risk of fatalities.

This study aims to assess the risk of reinforced concrete structures of medium-rise buildings due to earthquake loads. These are typical buildings and are widely built and operated in urban areas in developing countries. The seismic risk of a building is expressed by a fragility curve which shows how far the damage might exceed the limit for various earthquake scenarios [1–3].

2 Methods

An existing government building in Pacitan, East Java Province, was used as the case study in this study. The city of Pacitan is near to the subduction zone in the south of Java Island because of its location at the extreme point of the southwest of East Java Province and the Indian Ocean to the south. It is apparent that the building play vital role to have continues service to the people of the city after an earthquake.

This building consists of two floors and was built of reinforced concrete moment resisting frame system. The Compressive strength of concrete is fc' 30 MPa. Meanwhile the ultimate tensile strength of deformed reinforcement steel is f_u 340 MPa and the yield strength is f_y 240 MPa. The finite element model of the structures is shown in the Figure 1.

The analyses were performed by advanced finite element software; SeismoStruct. It is capable of performing large deformations and nonlinear materials structural analysis under static or dynamic forces. Analyzing structural performance, incremental dynamic curves representing nonlinear displacement due to seismic forces, were obtained. eventually, with a set of data, fragility curves are developed and discussed.

2.1 Structural Modelling

The finite element model of the structures is shown in the figure 1.

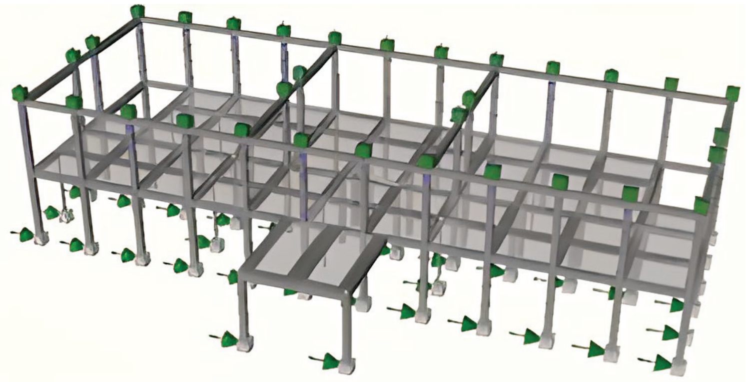

Fig. 1. Structural model.

The constitutive behavior of the cross-section can be either formulated according to the classical plasticity theory in terms of stress and strain resultants, or explicitly derived by discretizing the cross section into fibers. In this study the material model follows fiber element model illustrated in the figure 2. The fiber model is used to simulate the behavior of cross-sections, and each fiber is connected to a single uniaxial stress-strain relationship. The nonlinear uniaxial material response of the individual fibers into which the section has been divided is integrated to produce the sectional stress-strain state of the beam-column elements, fully accounting for the spread of inelasticity along the member length and across the section depth.

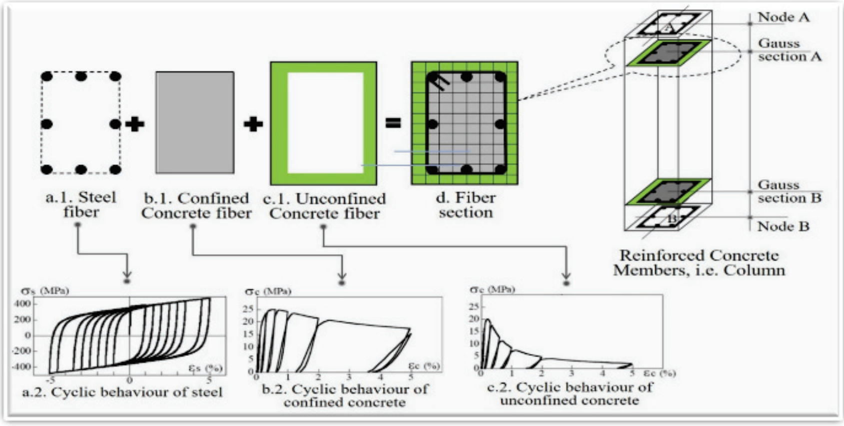

Fig. 2. Fiber element model.

2.2 Seismic Input

Eleven earthquake records recapitulated in the table 1 were selected as seismic input at the base of the structures, all of them would be base line corrected, in order to provide sufficient seismic demand accuracy.

Table 1. Earthquake records.

Earthqukes	Location	Year	Magnitude
Coalinga	California, The US	1983	6.2
El Alamo	California, The US	1956	6.8
Imperial Valley	California, The US	1979	6.5
Kern County	California, The US	1952	7.3
Kobe	Hyōgo, Japan	1995	6.9
Loma Prieta	California, The US	1989	6.9
Mammoth Lakes	California, The US	2004	6.0
Morgan Hill	California, The US	1984	6.2
Northwest China	Xinjiang, China	2008	5.1
Parkfield	California, The US	1966	6.0
San Fernando	California, The US	1971	6.5

Then spectral matching has been carried out to these earthquake records approaching a target response spectrum of the structure's location. The matched response spectra of the suite of the records are depicted in the Figure 3.

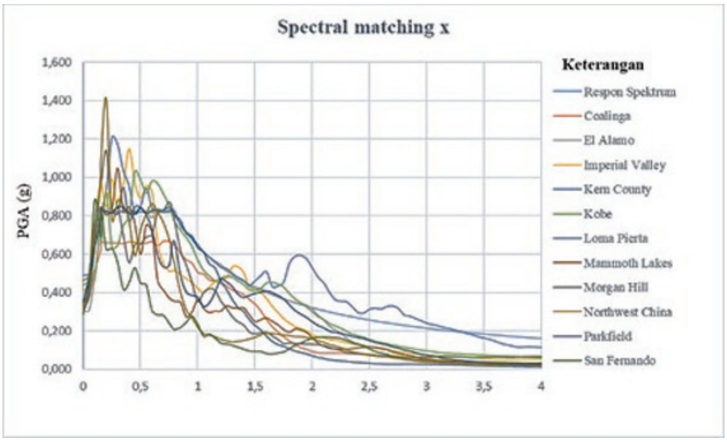

Fig. 3. Matched response spectra.

2.3 Incremental Dynamic Analysis (IDA)

A constant push toward more precise but also more complex analytical methods in structural analysis has been made feasible by the increase in computer processing capacity. Hence, the state of the art has evolved over time from elastic static analysis through dynamic elastic, non-linear static, and eventually non-linear dynamic analysis.

In the most recent instance, it was customary to run one to several records once each to produce one to several "single-point" analyses, which were mostly used to verify the designed structure. However, techniques like the non-linear static pushover (SPO) or the capacity spectrum method provide a "continuous" picture as the full range of structural behavior is investigated, from elasticity to yielding and finally collapse, by appropriately scaling the static force pattern. This greatly facilitates our understanding of the complex behavior of the structure under seismic forces. Then, the incremental dynamic analysis (IDA) was established as the state-of-the art method to determine the structural collapse capacity under earthquake ground motion [4].

In order to thoroughly examine the behavior of structures under seismic loading, earthquake engineers use incremental dynamic analysis (IDA), a computational analytical tool. With IDA, a structural model is subjected to a variety of nonlinear dynamic studies using suites of earthquake ground motion, each of which is scaled to a different level of seismic intensity [5,6]. The scaling levels are carefully chosen to push the structure through all possible states of behavior, from elastic to inelastic to global dynamic instability, when the structure effectively experiences collapse.

In this study, IDA is conducted once the model and ground motion recordings have been selected. Thus, it is necessary to create a nonlinear computer model of the prototype structural system as depicted in figure 1. The selected earthquake recordings must be scaled from a low Intensity Measure (IM) to a number of higher IM levels until structural collapse occurs in order to begin the study [7–10].

A nonlinear dynamic time history analysis is carried out for each IM increment. Higher IM analyses are conducted repeatedly until a structural collapse takes place. Finding the highest drift recorded during a study yields one point in the PGA vs. drift (IM vs. Engineering Demand Parameters [EDP] domain.

2.4 Fragility Function and Limit States

Once IDA curves have been generated, the predicted drift for an earthquake with a specific intensity may be calculated. Then, the created IDA curves can specify a number of damage limit states. In this study, the definitions of damage limit states were determined by adopting HAZUS criteria with the result of assigning slight damage, moderate damage, extensive damage, dan near collapse to the IDA curves [11].

Thereafter, curves may be developed expressing the fragility function of the structure. Fragility is defined as conditional probability of damage exceeding prescribed limit given seismic intensity. It is expressed as

$$P(ds|S_a) = \Phi\left(\frac{1}{\beta_{ds}}\right) \ln \ln \left(\frac{S_a}{S_{a,ds}}\right) \tag{1}$$

where *ds* is damage limit states, S_a is spectral acceleration, β_{ds} is uncertainty comprises of aleatoric and epistemic uncertainty.

3 Result and discussion

3.1 Incremental Dynamic Curves

The accelerogram and structural model are particular to the IDA investigation. A model will frequently provide highly distinct reactions that are hard to anticipate beforehand when subjected to various ground movements.

The analysis performed with multiple records[12] in this study yielded suites of IDA curves depicted in the figure 4 and figure 5. Each graph shows the demands that each ground motion record places on the structure at various intensities [13], and they are rather fascinating in both their parallels and differences.

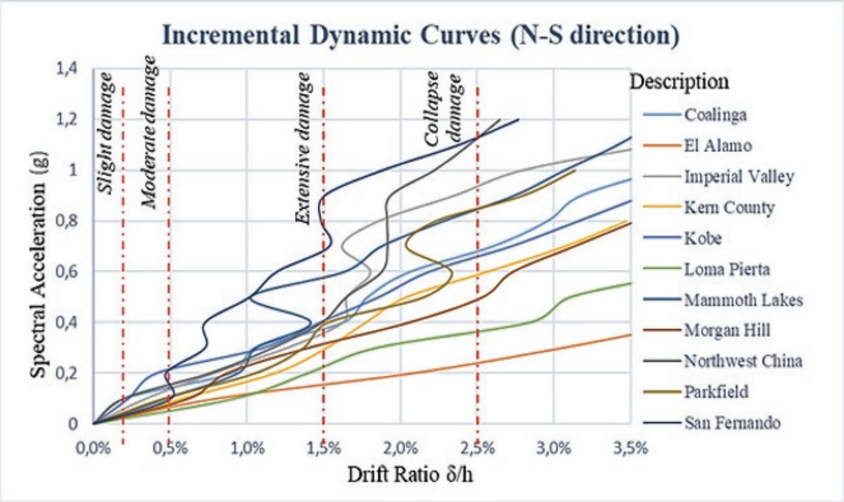

Fig. 4. Incremental dynamic curves of the building (North – South direction),

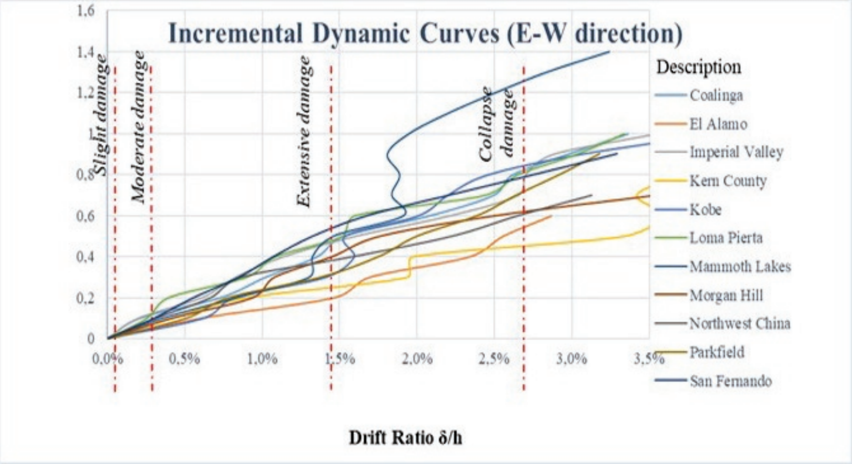

Fig. 5. Incremental dynamic curves of the building (East – West direction).

There is a separate elastic linear area on every curve. When any element approaches the limit of its elasticity, a structural model with initially linearly elastic parts will exhibit this behavior, which ends when the first nonlinearity enters the picture.

3.2 Fragility Curve

The IDA curve may be further evaluated probabilistically by applying the fragility function and presented in the form of a fragility curve. As a function of an engineering demand parameter that depicts the ground motion (spectral acceleration or spectral displacement at a specific frequency), fragility curves are a statistical tool used to indicate the likelihood of surpassing (probability of exceeding) a given damage state (or performance).

From the analysis, fragility curves are depicted in the figure 6 and figure 7. Together with the ground motion parameter on the x-axis(abscissa), the fragility probability value is shown on the y-axis (ordinate). The fragility curve exhibits the likelihood of structural damage when an earthquake load of a given intensity is applied to it at its service limit.

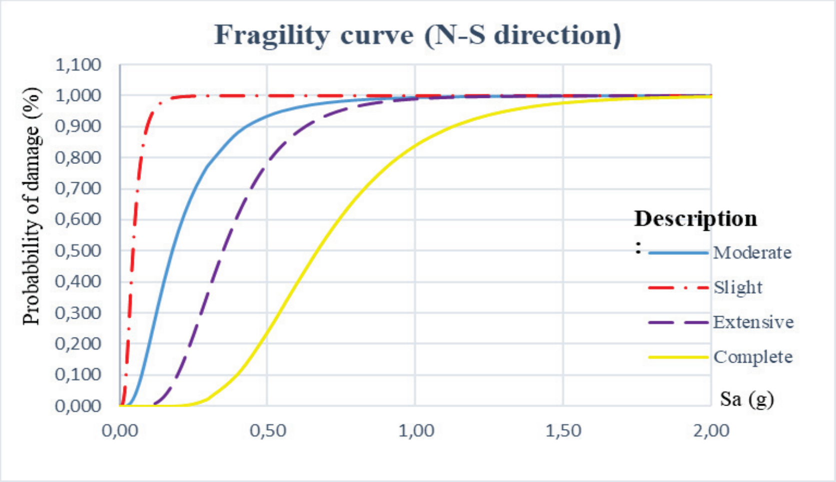

Fig. 6. Incremental dynamic curves of the building (North – South direction).

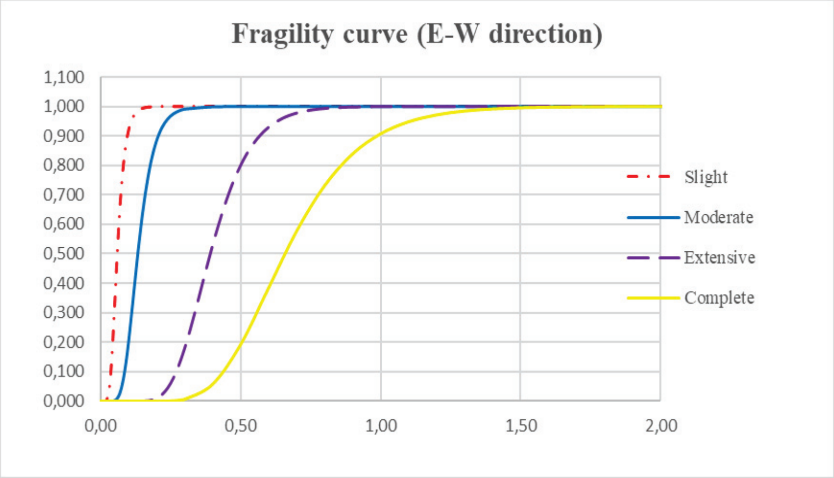

Fig. 7. Incremental dynamic curves of the building (East– West direction).

Interpretation of the fragility curve might be carried out by setting the value of spectral acceleration of the location of the building and then read the probability of the damage state of the structure given the intensity predicted. For example, when viewed from the N-S direction the building's fragility curve, at 0.5 g PGA there is a probability of 100% the structure will experience slight damage, 97% for moderate damage, 75% for extensive damage, 20% for complete damage.

With the use of this curve, it is possible to mathematically and logically assess the likelihood that existing building structures would sustain damage owing to fluctuations in the intensity of earthquake loads throughout the course of their useful lives [1].

4 Conclusion

The paper has shown the procedure of developing fragility curve based on the incremental dynamic curves. The following findings might be drawn from evaluating the fragility curves shown in figure 6 and Figure 7.

Reviewing the results of the fragility curve in the E-W direction, if the building is subjected to an earthquake with a PGA of 0.5 g, the building has a possibility of slight damage of 100%, moderate damage of 100%, extensive damage of 80%, and for complete damage by 19%.

With the predicted intensity of the earthquake that occurred at the location of 0.5 g, but if the direction of the earthquake is different, the structure will also experience a difference in performance in the face of an earthquake even though the results are not much different.

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