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EFFECT OF SEISMIC INCIDENCE ANGLE ON THE RESPONSES OF REINFORCED CONCRETE STRUCTURE USING MULTI-COMPONENT INCREMENTAL DYNAMIC ANALYSIS

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ABSTRACT

This article evaluates the seismic response of reinforced concrete structure using MIDA (multi-component incremental dynamic analysis) method. A numerical model examines the effect of the seismic incidence angle used for this aim. The incident angle varies from 0 to 360 degrees with an increment of 10 degrees. The obtained results indicate that the influence of seismic incidence angle should be considered sufficiently in the structural response assessment. Additionally, the maximum inter-story drift of structure behaves from in the elastic to the inelastic range depending on the difference of incidence angle.

Keywords: Multi-component incremental dynamic analysis, reinforced concrete structure, seismics incidence angle.

TÓM TẮT

Ảnh hưởng của góc tới động đất đến ứng xử của kết cấu bê tông cốt thép sử dụng phương pháp mida (multi-component incremental dynamic analysis)

Bài báo này đánh giá ứng xử động đất của kết cấu bê tông cốt thép sử dụng phương pháp MIDA (multi-component incremental dynamic analysis). Một mô hình số xem xét ảnh hưởng của góc tới của động đất được sử dụng cho mục đích này. Góc tới thay đổi từ 0 đến 360 độ với bước 10 độ. Kết quả của nghiên cứu chỉ ra rằng ảnh hưởng của góc tới động đất cần được xem xét một cách đầy đủ trong việc đánh giá ứng xử của kết cấu. Thêm vào đó, tỷ lệ trôi tầng lớn nhất của kết cấu ứng xử từ giai đoạn đàn hồi đến không đàn hồi phụ thuộc vào góc tới động đất khác nhau.

Từ khóa: Multi-component incremental dynamic analysis, kết cấu bê tông cốt thép, góc tới động đất.

1. Introduction

Evaluation of seismic response of reinforced concrete structure is one of the most important purposes in Performance Based Earthquake Engineering (PBEE). One of the basic factors of PBEE is to predict seismic capacity and demand on structures by taking into account their inelastic behavior [1]. The PBEE aims to make sure that the designed building satisfies specified performance criteria. Estimation of the performance of a structure requires a method that monitors the structural behavior from linear elastic region to yielding stage until its collapse. One of the methods commonly used to evaluate the performance of structures in recent years is Incremental Dynamic Analysis (IDA) [2, 3].

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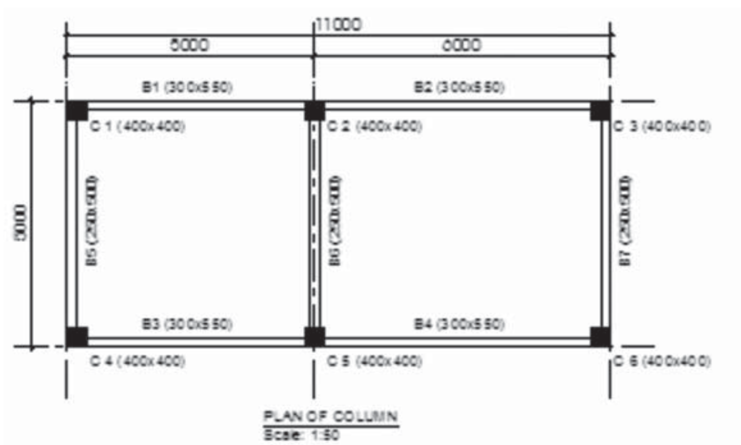
In this paper, the authors present the seismic inelastic response of three-dimensional reinforced concrete structure modelled in OpenSees subjected to a set of ground motions. This software is available online at www.opensees.berkeley.edu, which is one of the most powerful analytical platforms. In OpenSees software, material inelasticity of the elements is made of so called fiber modeling approach in which the element has been subdivided into many segments. The section is discretized in sufficient quantity of fibres and the response of sections are obtained through the integration single fiber's response of individual fibres.To examine all these aspects, a multi-component incremental dynamic analysis (MIDA) in the work by Lagaros [4] is used. This procedure conducts randomizations on the seismic excitation considering the effects of incidence angle.

2. Theoretical Process

2.1. The Structure Model

The structure used in this study is three-story reinforced concrete building. The building is similar in the plan and the same height of 3.3m in elevation. In layout plan, the building has 11m x 5m with 2 bays x 1 bay, shown in Figure 1. This building has been modeled using the OpenSees software [5]. The structure is modelled using nonlinear Beam Column elements. The cross sections are modelled using the Fiber Section approach, with rectangular concrete patches and layers of reinforcement. Details of section that presented the inelastic behavior of structure is displayed as follows:

```
section Fiber $secTag<-GJ $GJ> {
fiber...
patch...
layer...
...
}
```



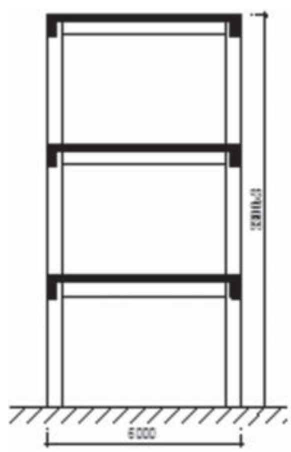


Figure 1. *Model of 3-story building*

2.2. Incident Angle of Earthquake

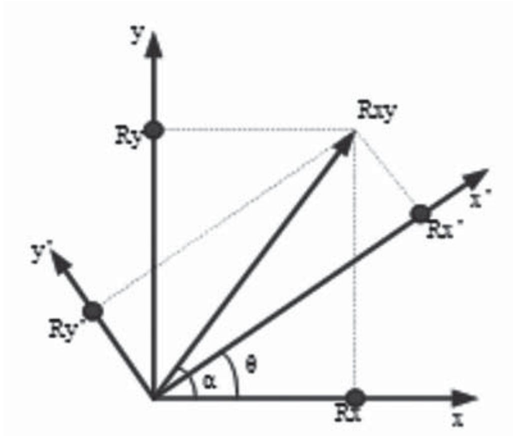


Figure 2. *Vectorial representation of* R_x *and* R_y

A structure subjected to the ground motion for pair of given ground motion, is a major and minor component. The one with the highest PGA corresponding the major component, while the other is minor component. Therefore, called *x* and *y* the structure axes of the structure, the major (p axis) and minor (w axis) component are additionally rotated θ away from the *x* axis as shown in Figure 2. The incident angle of the record θ is defined an orientation of the two horizontal excitation *x* and p axes.

In Fig. 2, called R_x and R_y are response quantities along the *x* and *y* excitations, respectively [6]. Therefore, R_0 is denoted the resultant response of R_x and R_y which is presented by Eqs. (1) – (2)

$$R_0(t) = R_x(t)\cos\alpha(t) + R_y(t)\sin\alpha(t) \tag{1}$$

$$\alpha(t) = \tan^{-1}\left(\frac{R_y(t)}{R_x(t)}\right) \tag{2}$$

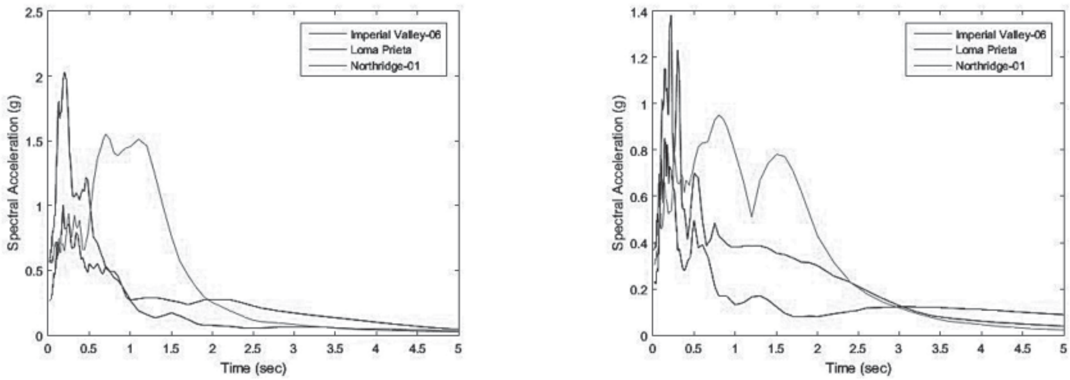
where $\alpha(t)$ is the angle between R_0 and R_x.

The response quantities of rotated components R_p and R_w are defined as Eqs. (3) – (4)

$$R_p(\theta, t) = R_0(t)\cos[\alpha(t) - \theta] \tag{3}$$

$$R_w(\theta, t) = R_0(t)\sin[\alpha(t) - \theta] \tag{4}$$

To evaluate the response of structure, the ground motion records must be chosen. All of the earthquakes records and data are downloaded from the PEER Ground Motion Databases, NGA-West2 [7], is one of the most comprehensive databases of earthquake records and data sets available in the world. The characterizations of records listed in Table 1 and Figure 3 show the acceleration spectral with 5% damping ratio.



H1-horizonal *H2-horizonal*

Figure 3. *Acceleration spectra of ground motions*

Table 1. *The set of ground motion records*

ID	Earthquake Name	Year	Station Name	Magnitude	R (km)
178	Imperial Valley-06	1979	El Centro Array #3	6.53	12.85
767	Loma Prieta	1989	Gilroy Array #3	6.93	12.82
1050	Northridge-01	1994	Pardee - SCE	6.69	7.46

2.3. Multi-Component Incremental Dynamic Analysis

IDA is an analysis method for evaluation of structure response (Vamvatsikos and Cornell, 2002). In this procedure, the curves showed the relation between the seismic intensity level and the maximum seismic structural response are drawn. The intensity measure (IM) and the damage measure (DM) are used as the intensity level and the structure response, respectively.

The MIDA proposed by Lagaros (2010), is based on the idea of IDA. However, herein both the earthquake records at all possible directions will be applied. In this study, the variable incident angle is also considered for assessment the response of 3D structure. A schematic representation of procedure is illustrated in Figure 4, where two components of seismic excitation of all accelerations are scaled to spectral accelerations at the fundamental natural periods of the buildings.

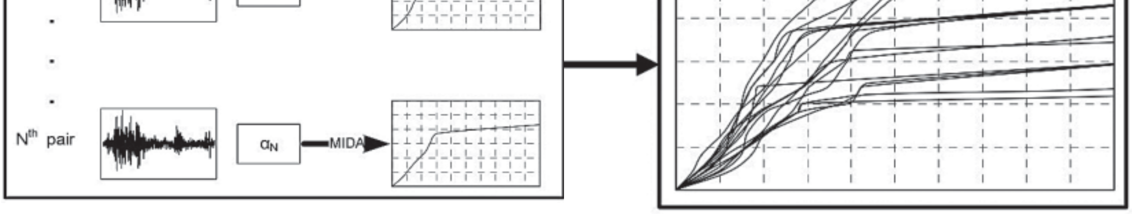


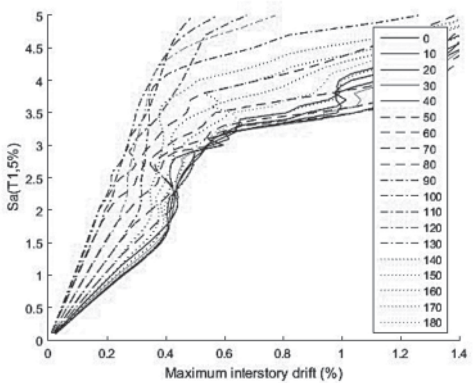
Figure 4. *The MIDA procedure [6]*

3. Results and Discussions

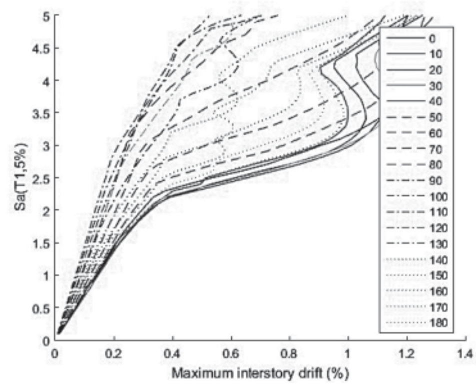
In this work, the spectral acceleration with 5% damping ration at the fundamental natural period, Sa (T_1, 5%) is selected as the IM parameter and the maximum inter-story drift (θ_{max}) is selected as DM. It should be noted that the inter-story drift is defined as the relative displacement of each story divided by the story height, which are expressed as percentages. To examine the effect of incidence angle to the response of the structure, all records shown in Table 1 are applied, which vary from 0 to 360 degrees, with the interval of 10 degrees.

3.1. Inter-Story Drift Ratio

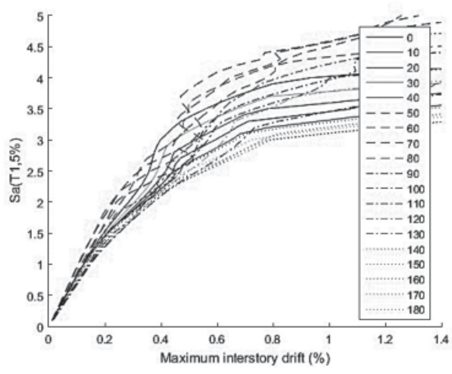
The MIDA curves from the nonlinear time history analysis for each record are displayed in Figure 5. As seen that the MIDA curves have a considerable dispersion for different ground motions although they have linear elastic response when the first signs of nonlinear occur. When increasing the intensity of the earthquakes, the maximum inter-story drift is also increasing from linear to nonlinear range. Considering about the closer examination of the linear elastic region of the curves, it can be concluded that the response of structure depends on the characteristic of ground motion. From the MIDA curve for each record, it is observed that the inter-story drift varies in a wide range when the difference of seismic incidence angle is applied.



a) Imperial Valley



b) Loma Prieta

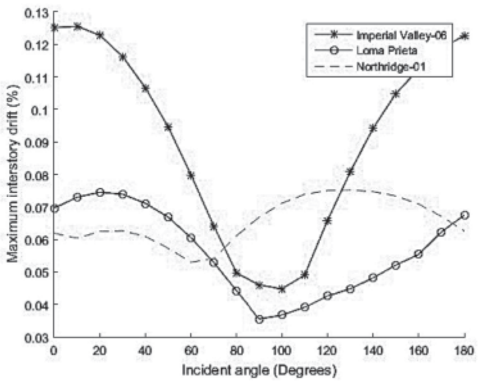


c) Northridge

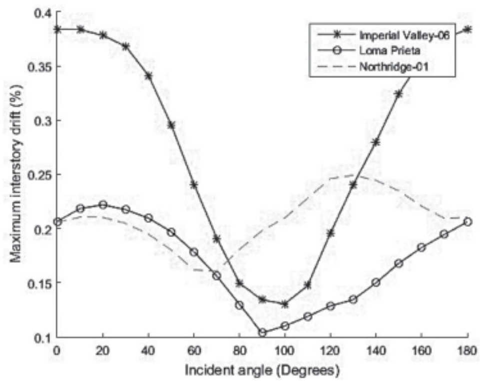
Figure 5. *The MIDA curves of the 3-story building*

3.2. Influence of Earthquake Incidence

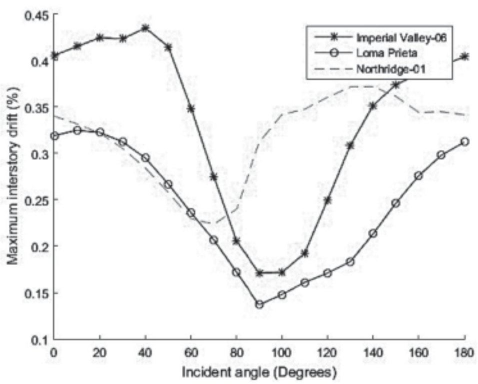
Herein, the effects of incidence angle respected with the changes of intensity level are examined. Figure 6 displays the maximum inter-story drift relating to incident angle and intensity level. As the responses from 190 to 360 degrees coincide with the result in range of 0 and 180 degrees, so the author only shows for later value. As seen in the figure, the maximum inter-story drift for the Imperial Valley varies from 0.045% to 0.126% for 0.5g intensity level while for the 3.5g intensity level the maximum inter-story drift for the same record varies from 0.299% to 1.047%. Similar results are also observed for other ground motions. Another significant observation is that the maximum seismic response is encountered for different incident angles when a different record is considered.



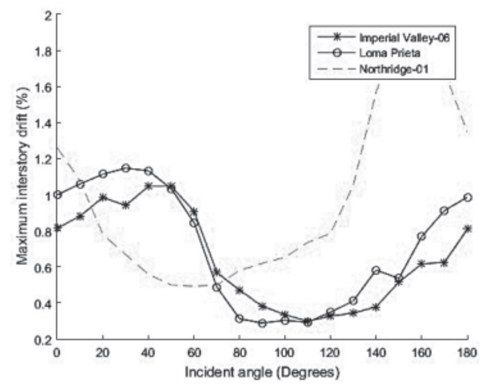
a) 0.5g



b) 1.5g



c) 2.0g



d) 3.5g

Figure 6. *Maximum story-drift ratio with respect to the incident angle of the record scaled to 0.5g, 1.5g, 2g and 3.5g*

4. Conclusions

The nonlinear seismic response of reinforced concrete structure has been studied to estimate the seismic response of structure considering the influence of incidence angle. The 3-story building modeled using the OpenSees software is applied using. The obtained results show that the effect of incident angles of horizontal component should be considered in seismic assessment, the performance of structural response will be dependent on the angle of incidence of the earthquake input. In addition, the critical angle under two ground motion components in structural behavior differs from one component, and performance assessment under bi-directional ground motions should be considered conservative.

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