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Effect of Earthquake Components on Seismic Response of RC Moment Resisting Frames

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Abstract

When an earthquake occurs, it is recorded in three particular direction by the seismic instruments viz. X, Y and Z. The coupled response due to multiple components of an earthquake on reinforced concrete structures can be different compared to single component only. In this research, the coupled inelastic behavior of RC structure is studied under multiple earthquake excitation. A 3 stories RC frame is taken into consideration and uni-directional, bi-directional and tri-directional analysis is done. Global and local response parameters are then studied. In global response parameter , base shear is studied and in local response parameter, axial force variation is studied. The results show that transverse component of an earthquake have significant impact in increasing the base shear and the vertical component of an earthquake is associated with increase in the axial force variation in columns.

Keywords

RC structure; nonlinear time history; earthquake components; fiber section; distributed plasticity

1. Introduction

Earthquake is a random and complex phenomenon. The combined effect of all the components of an earthquake can cause a structure to behave very differently compared to a single component. Simultaneous action of multiple components of an earthquake may cause considerable increase in the inelastic demand of the structures. Furthermore, the effects due to the horizontal component has been extensively studied but the effect due to vertical component of an earthquake has been largely underestimated in analysis and design Kim et al[1]. Most of the seismic codes around the world compensate the effect of vertical shaking by a simple V/H ratio varying from a range of 1/2-2/3. Many past earthquakes have shown that the vertical component of an earthquake can be larger than the horizontal components. V/H ratio is not a constant value and is a strong function of natural period, source to site distance and soil condition as suggested by Bozorgnia & Campbell[2]. Many seismic codes around the world require that the maximum value of each orthogonal component of ground motion be calculated separately and then appropriately combined using the square root of sum of square rule to determine the maximum value of response during combined loading instead of considering the simultaneous action of multiple components of an earthquake. Many analytical studies have been conducted to study the multicomponent effect of earthquake on structures.

Dutta & Kunnath[3] studied the bidirectional effect of ground motion on the response to RC structure and hightlighted on the importance of bidirectional analysis. Faella et al[4] studied the effect of unidirectional and bidirectional excitation on symmetric 3D RC frame structure and concluded that bidirectional analysis have significant impact on the global and local behaviour of the structure. Mwafy[5] studied the effect of bidirectional (HGM and VGM, respectively) interaction on RC structures. The outcome of this research clearly demonstrated that the effect of vertical component of the ground motion was highly significant. Because of this the interstory drift collapse limit state was reached at lower PGA. Papazoglou & Elnashai[6] studied analytical and field evidence for damage due to vertical ground shaking. The research concluded that certain failure modes are more attributable to high vertical earthquake forces and hence consideration for this vertical forces for structural design is necessary.

Table 1: List of Selected Earthquakes

SN	Earthquake	Year	Station	Mw	Hyp	H1(g)	H2(g)	V(g)	V/H-SR
1	Imperial Valley-06	1979	Bonds Corner	6.53	11.72	0.777	0.599	0.532	0.494
2	San Fernando	1971	Pacoima Dam	6.61	17.6	1.238	1.219	0.687	0.842
3	Landers	1992	Lucerne	7.28	44.58	0.789	0.725	0.823	0.931
4	Kocaeli, Turkey	1999	Yarimca	7.51	25.07	0.322	0.228	0.241	1.085
5	Kobe, Japan	1995	Kobe University	6.9	31.08	0.312	0.276	0.452	1.689

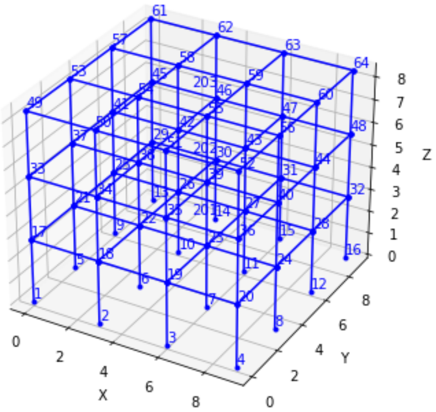

Figure 1: 3 Storey Model in OpenSees

Table 2: Finite Element Model Parameters and structural Properties

Parameters	Value	Units
Beam	230x350 mm	
Column	300x300 mm	
Slab	127 mm	
Bay size	3x3	
Bay Length	3mx3m	
Live Load	1	kN/m^2
Floor Finish	1	kN/m^2
Yield Strength of Steel(fy)	415	MPa
Ultimate Strength of Steel(fu)	485	MPa
Yield Strain of Steel(εu)	0.0021	-
Ultimate Strain of Steel(εu)	0.144	-
Modulus of Elasticity,Steel(Es)	$2*10^5$	MPa
Modulus of Elasticity,Concrete	22360	MPa
Poisson's ratio,Concrete	0.2	-
Shear Modulus	9316.95	MPa
Unit weight of Concrete	25	kN/m^3
Concrete Ultimate Strain	0.02	-

Table 3: Base Shear Variation along Global X-direction compared to X-only Loading

Model Type	3 Storey Model	
Load Case	XY (%)	XYZ (%)
Imperial Valley-06	29.15	29.44
San Fernando	30.12	30.39
Landers	37.75	42.40
Kocaeli, Turkey	33.35	35.57
Kobe, Japan	27.92	26.25

2. Selection of Earthquake Time History

The result of time history analysis is significantly impacted by the selection of earthquake ground motions. A total of 5 earthquake records are selected for analysis purpose. The selected earthquake time history is listed in Table 1. The ground motions are selected representing a varying range of peak vertical to horizontal spectral ratios (V/H1-SR). The selected earthquake motions also have variation in magnitude, frequency content and duration.

3. Building Model and Modelling of its Non-linearity

For this study, a 3 storey RC Frame, modelled in OpenSees[7], is taken into consideration as shown in Figure 1. It has three bays in x and y direction respectively. Structural properties and the finite element model parameters adopted for the model is listed in Table 2. OpenSees is used for performing the nonlinear time history analysis. Distributed plasticity approach is used for modelling the nonlinearity in beams and columns. Fiber sections are created for beams and columns. A total of 6 integration points or 6 number of fibers are created per element(Beams and Columns) and Gauss lobatto type of integration scheme is followed. Concrete is divided into core and cover concrete. The effect brought about by the confining reinforcement is also taken into consideration[8].When fiber sections are created, nonlinear stress-strain behaviour need to be assigned to the created fibers. Concrete is modelled using Concrete02 element in OpenSees where as steel is modelled using the hysteretic material as shown in Figure 2 and Figure 3 respectively. For 3 storey model adopted, reinforcement bar of 16mm diameter is used for the beams and columns. Geometric nonlinearity (P-Δ effect) has not been considered in the analysis.

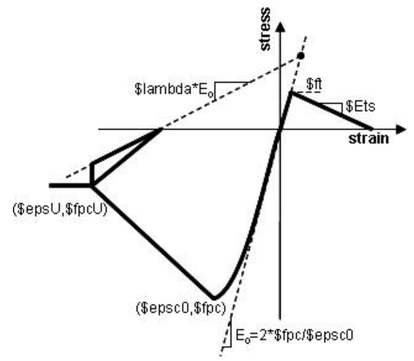

Figure 2: Concrete02 Cyclic Behaviour

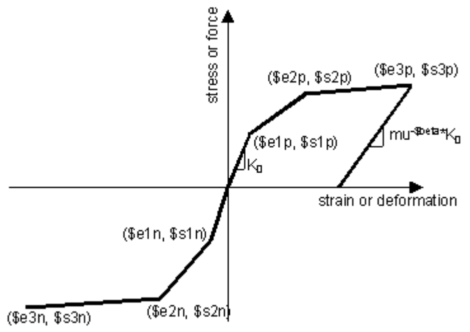

Figure 3: Hysteretic Material Cyclic Behaviour

4. Results and Discussion

Table 4: Variation in Maximum Axial Force in comparison to X-only Loading

Model Type	3 Storey Model	
Load Case	XZ (%)	XYZ (%)
Imperial Valley-06	5.34	6.26
San Fernando	1.39	2.92
Landers	51.62	55.25
Kocaeli, Turkey	3.93	2.39
Kobe, Japan	22.00	21.19

Effect of earthquake components were studied for global and local variable. The outputs obtained are discussed in the subsequent section. On a global level, base shear was studied whereas on a local level, axial force variation in columns was studied.

4.1 Global Response

Table 3 shows percentage variation in the base shear along global x direction obtained for “xy” and “xyz” loading case for all the selected earthquakes. For comparison, x-only loading case is considered as the base case. Transverse (y) component has caused significant variation in base shear along x-direction. In case of bidirectional shaking (xy), on an average, the base shear along x-direction was increased by 29.15%, 30.12% 37.75%, 33.35% and 27.92% for Imperial Valley, San Fernando, Landers, Kocaeli and Kobe earthquake respectively. The average percentage increase in base shear along the global x direction due to bidirectional and tridirectional shaking was almost same which shows that the z component of an earthquake has almost no effect in the base shear variation along the global x direction.

4.2 Local Response

For the local responses, axial force variation in column was studied.The vertical component of a ground motion caused increase in the maximum axial force in the columns of all the storey. For each ground motion record, an increase in the maximum axial force was observed in the column. Table 4 shows the percentage increase in maximum axial force for “xz” and “xyz” loading for each earthquake record with respect to the x-only loading case. On an average, the increase in maximum axial force was 5.34%, 1.39%, 51.62%, 3.93%and 22.00% respectively for Imperial Valley, San Fernando, Landers, Kocaeli and Kobe earthquake. The percentage increase due to “xz” loading case and “xyz” loading case is almost same which shows that transverse (y) component has very little role to play in increasing the axial force in column.

5. Conclusion

This study is solely focused on studying the effect of earthquake components on global and local response of a reinforced concrete frame structure. Unidirectional, bidirectional and tridirectional time history analysis of the structures were performed for the 5 selected time history. The results were then properly analyzed to study the multicomponent effect of earthquake on the global and local response of a reinforced concrete frame structure. Based on the analytical results obtained from the study, following conclusions can be inferred:

1. The effect of transverse (y) component of an earthquake causes an increase in the maximum base shear along the global x-direction. In other words, the base shear obtained along the global x-direction during the bidirectional (xy) shaking is higher that obtained from the unidirectional

(x-only) shaking. The vertical component of an earthquake has little effect in the base shear variation.

2. The vertical component of an earthquake causes significant effect in increasing the maximum axial force in the column. The transverse (y) component on the other hand, has negligible effect in the axial force variation in columns.

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