THE EFFECTS OF MASS ECCENTRICITY SCENARIO ON THE SEISMIC TORSIONAL BEHAVIOR OF RC/MR BUILDINGS

Esmaeel IZADI Z.
Ph.D. Student, IIEES, Tehran, Iran
e.izadi@iiees.ac.ir

Abdolreza S. MOGHADAM
Assistant Professor, IIEES, Tehran, Iran
Moghadam@iiees.ac.ir

Keywords: Seismic, Torsional Response, Asymmetric, Mass Moment of Inertia, RC Building

ABSTRACT

In this study the effect of different mass eccentricity scenarios on the dynamic torsional behavior of an 8-story RC moment resistant building has been investigated. Firstly, to determine the range of the mass moment inertia (MMI) variation due to different mass distribution scenarios, three different scenarios which produce eccentricity were considered. These scenarios were applied to the plan of prototype structure and expressions were established to correlate MMI and mass eccentricity in each scenario. Result shows for slight eccentricities the variation of the MMI is negligible but as eccentricity is increased the range of the variation is extended.

At the second part of this study, 8-Story RC moment resistant building was designed according to the Iranian seismic code (Standard No. 2800, 3rd Edition). Sensitivity analyses based on finite element method and inelastic time history analysis have been carried out for determining the effects of MMI on the torsional response of the structure.The effects of the variation of MMI on the torsional response of the structure at 2 level of mass eccentricity including slight and severe is investigated and described in detail.

INTRODUCTION

For asymmetric structures subjected to seismic excitation, rotational response is expected to occur. As a result displacement demands on the elements at a particular floor level of structure is no longer uniform (Beyer, 2007). For this reason stress and strain concentration is happened at the edge element of the structures prone to torsion which causes sever damage due to seismic excitation. Different example of this type of damage has been reported during the past earthquakes. Torsional behavior of the asymmetric buildings due to inelastic response has been the focus of many different researches. In this regard, different design procedures have been developed for considering torsional response of asymmetric buildings. A large number of parameters affect inelasticresponse of asymmetric buildings. One of the most important ones which affects dynamic characteristics of the buildings is MMI. This parameter directly depends on the unbalanced mass distribution scenario which produces the eccentricity in layout. Considering constant mass, corresponding to a given mass eccentricity, probably there are infinite unbalanced mass distribution scenarios. Therefore for a known mass eccentricity a range of MMI is expected.The main objective of this study is to determine the variation range of MMI due to different unbalanced mass distribution scenarios and then investigate the effects of this variation on the dynamic torsional behavior of mass eccentricreinforced concrete moment resistant building.

DESCRIPTION OF THE CASE STUDY

In this study 8-story RC moment resistant frame with constant story heights 3 m is investigated. As shown in Fig.1 typical floor of the building has 3 spans with 5.0 m in width in each direction. Building has been placed in very high level of relative seismic hazard zone and relies on soil type III according to the Iranian Code of Practice for Seismic Resistant Design of Buildings (Standard No. 2800, 3rd Edition). Gravity load transfer system is RC two-way slab which is considered to be rigid. The buildings assumed to be residential and the non-factored gravity loads are: dead load equal to 7.5 KN/m2 and live load equal to 2 KN/m2. Seismic weight of each story considering dead load plus 20 percent of live load is equal to 1777.5 KN which typically assumed to be lamped at floor levels. Characteristic material strengths taken as concrete compression strength equal to 40 MPa and the reinforcing steel yield strength equal to 400 MPa. Dynamic characteristics and design base shear of the building frame under study based on the provisions and recommendations provided in Iranian seismic code shown in Table 1.

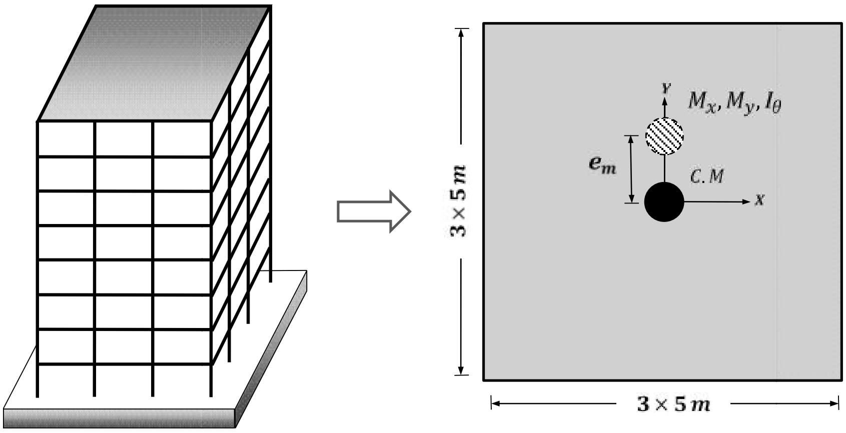


Figure1. Typical 8-story mass eccentric building considered (Izadi-Z, 2014)

Table 1. Dynamic characteristics and design base shear of the building frame under study

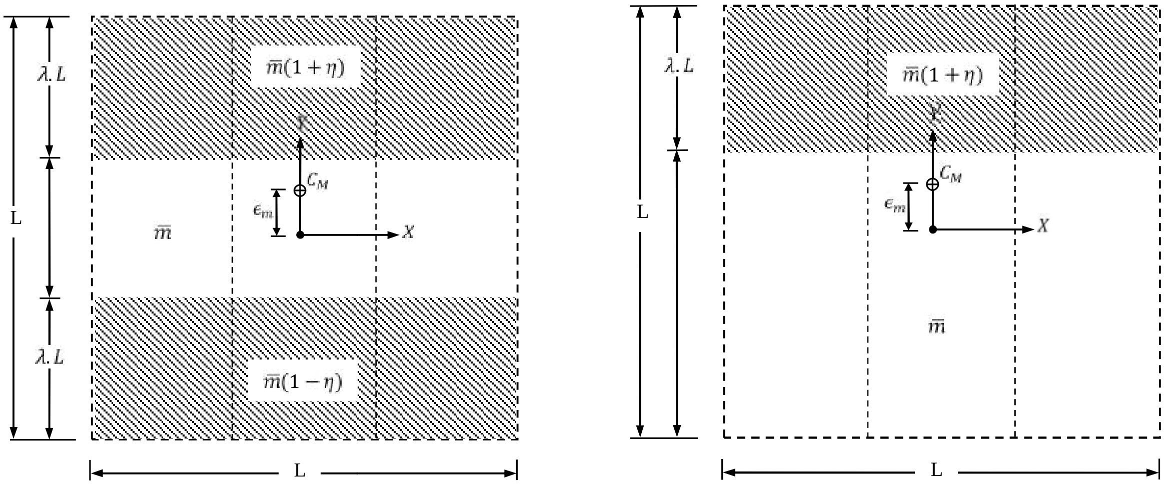
Story	**A** (g)	**H** (m)	**T_0**	**T_s**	**S**	**T** (Sec)	**1.25 T** (Sec)	**T** Analytical	**B**	**R**	**C**	**V** (KN)	**F_t** (KN)
8	0.35	24	0.15	0.7	1.75	0.76	0.950	1.19	2.24	7	0.112	1592	104

UNBALANCED MASS ECCENTRICITY SCENARIOS

In this study, three different unbalanced mass distribution scenarios which produce mass eccentricity is considered. With reference to symmetric structure, total seismic mass in each scenario iskept constant. These scenarios are including:

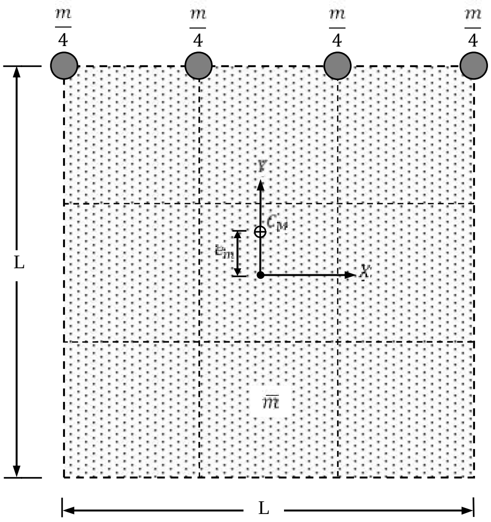
1. Unbalanced double-band mass scenario as shown in Fig.2.a
2. Unbalanced single-band mass scenario as shown in Fig.2.b
3. Unbalanced concentrated mass scenario as shown in Fig.2.c

These scenarioswere applied to prototype structure under study (L=15 and λ=3) and expressions were established to correlate MMI and mass eccentricity (e_m)in each scenario. Correlation between mass eccentricityand normalized mass momentinertia(NMMI) with reference to corresponding symmetric structure is shown in Fig.3. For slight eccentricitiesthe variation of the NMMI (ϕ) is negligible but as eccentricity is increased the range of the variation is extended.As shown in the Fig.3 variation range of the NMMI is less than 40% minus and plus even in the case of severe eccentricity, Consequently NMMI is taken 0.6, 0.8, 1.0, 1.2 and 1.4 for sensitivity analysis.



(a): Unbalanced double-band mass scenario

(b): Unbalanced single-band mass scenario



(c): Unbalanced concentrated mass scenario

Figure 2. Different unbalanced mass distribution scenarios being considered in this study

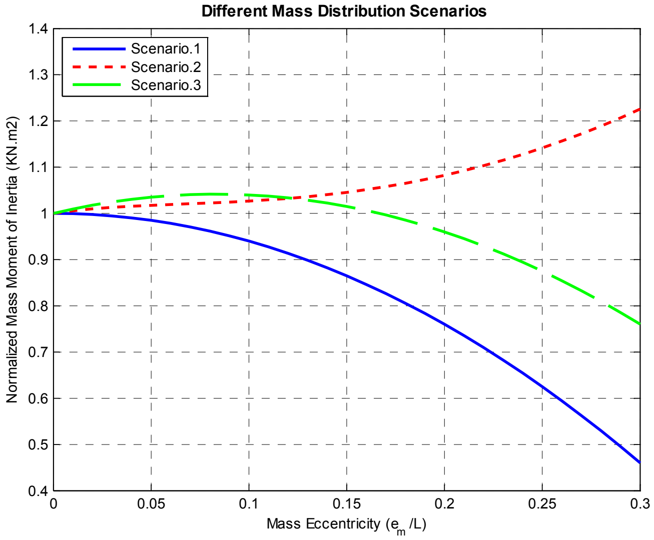


Figure 3. The effect of different mass eccentricity scenarios on the NMMI

INELASTIC TIME HISTORY ANALYSIS (ITHA)

For the purpose of seismic assessment, a series of ITHA have been carried out on the building frame under study. A suite of fifteen artificial accelerograms were generated to be matched with the design response spectrum of Iranian seismic code corresponding to the site being considered in this study. Matching procedure based on Wavelet transformation proposed by Suarez and Montejo [2007] was applied using program provided in Matlab environment. Acceleration response spectrum of artificially generated records in comparison to the design acceleration response spectrum has been demonstrated in Fig.4. ITHA of building frame is performed using Open Sees [2005] which is an object oriented framework for finite element analysis. The models are subjected to one-directional records and the excitation is along longitudinal axis. The structural elements are modelled as fiber elements which capable to consider plasticity along the elements and their cross sections. Separate stress-strain characteristics were used for the unconfined cover concrete and the confined core concrete as per Mander model [1988]. A 5% Rayleigh damping based on the linear combination of mass-proportional and tangent stiffness-proportional damping adopted to model initial elastic damping in ITHA.

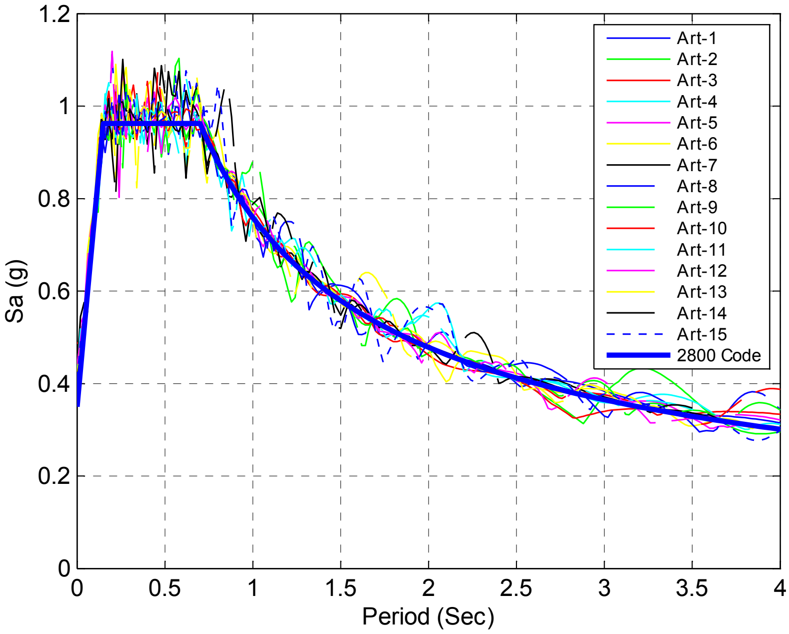


Figure 4. Comparison of artificially records spectra with design response spectrum (Standard 2800)

RESULTS

Sensitivity analysis based on ITHA was performed on the designed structure with slight (e_m/L=5%) and severe (e_m/L=15%) mass eccentricity model.NMMIwas changed gradually in each model and the effects of unbalanced mass distribution scenarios on the torsional behavior measured. Time history results are presented as mean value of the maximum responses under fifteenartificial records.Torsional responses in terms of maximum displacement demands, maximum diaphragm rotation,maximum nominal rotation and maximum nominal relative displacement are presented.

- **Maximum Displacement Demands**

Displacement demands at a particular floor level of eccentric structure due to torsional response is not uniform and demands should be addressed directly for each lateral load resistant element.Therefore maximum displacement demands of soft edge element, center of mass and stiff edge elementare presented and described separately. Fig.5 and Fig.6 shows the displacement demandsof soft edge element and center of mass for slight and severe mass eccentricity. Independent of the quantity of eccentricity, variation of displacement demands due to different NMMI is negligible. While as shown in Fig.7 variation of displacement demands of stiff edge elementdue to change of NMMI is considerable specially in the case of severe mass eccentric model.

- **Maximum Diaphragm Rotation**

Maximum diaphragm rotation is also taken as one of the response parameters which represent the severity of torsional behavior. Although maximum rotation is not among the common parameters used in torsional provisions of design codes, it is the fundamental response parameter of the eccentric structures which represent the torsional behavior. However maximum diaphragm rotation is not a practical parameter. Fig.8 shows the maximum diaphragm rotation for slight (e_m/L=5%) and severe (e_m/L=15%) mass eccentricity. Significant variation of the maximum rotation due to change of NMMI isimportant. This variation as shown in Fig.8 issignificant for both models with slight and severe eccentricity. Furthermore maximum diaphragm rotation is added as NMMI is increased.

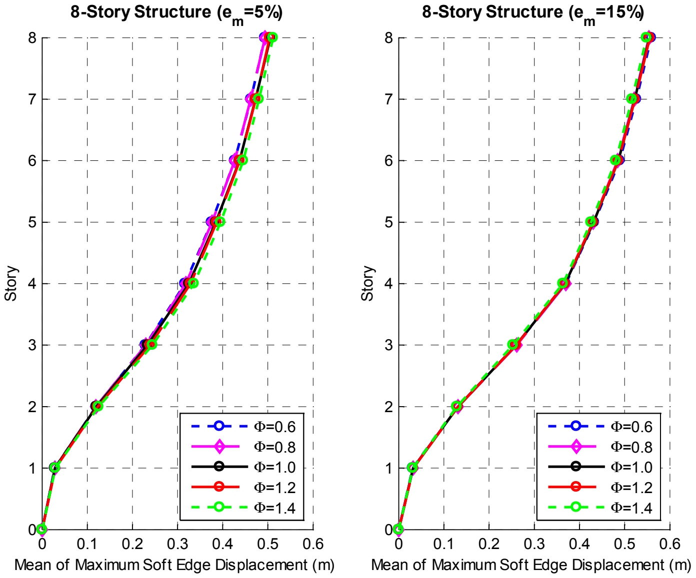


Figure 5. Maximum soft edge displacement for slight (e_m =5%) and severe (e_m =15%) mass eccentricity

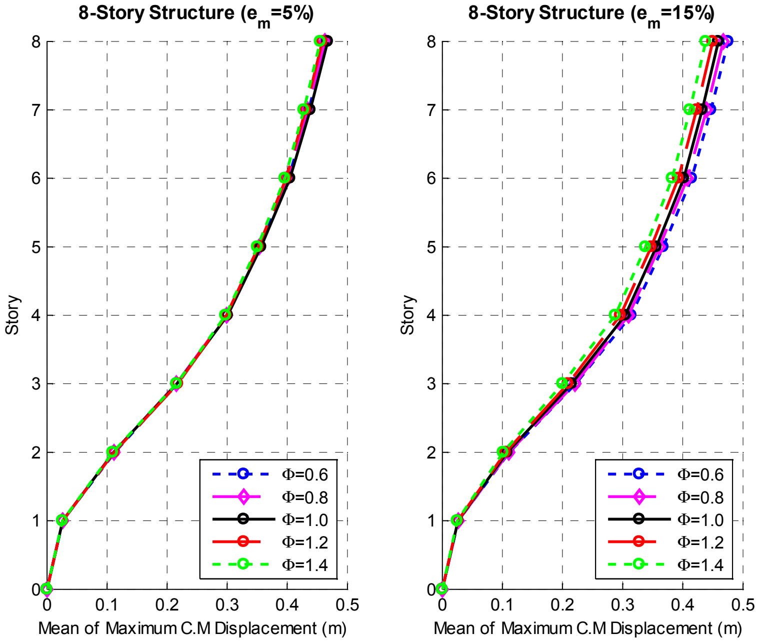


Figure 6. Maximum center of mass displacement for slight (e_m =5%) and severe (e_m =15%) mass eccentricity

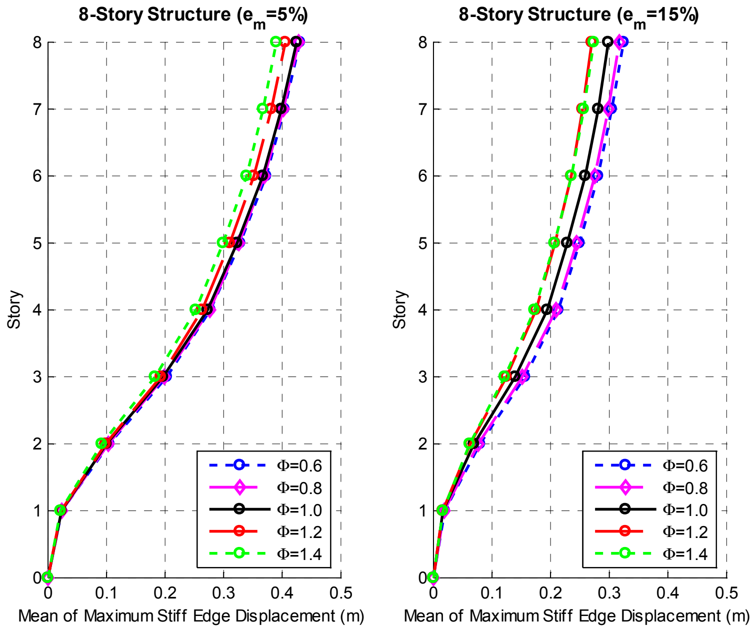


Figure 7. Maximum stiff edge displacement for slight (e_m =5%) and severe (e_m =15%) mass eccentricity

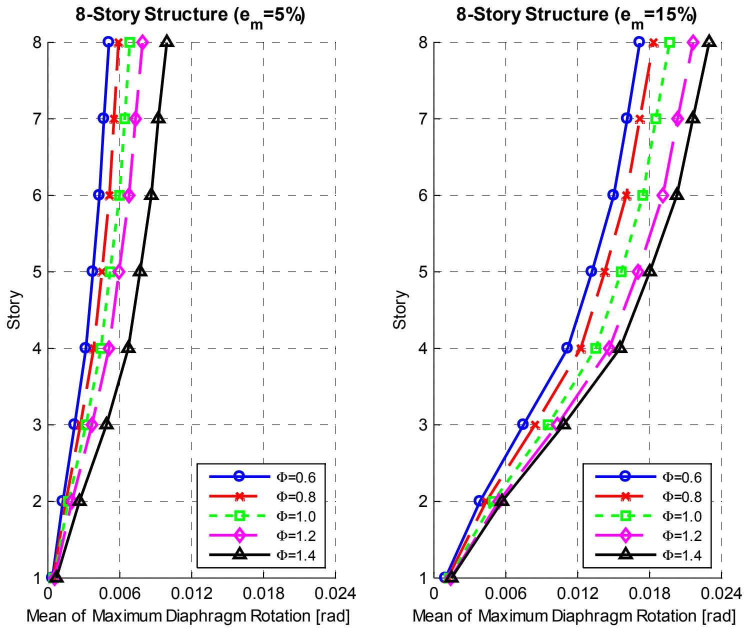


Figure 8. Maximum diaphragm rotation for slight (e_m =5%) and severe (e_m =15%) mass eccentricity

- **Maximum Nominal Rotation**

For asymmetric buildings subjected to seismic excitation, maximum translational and torsional responses do not occur simultaneously. Therefore it is not possible to directly associate the maximum displacement and rotation of the structure to the maximum displacement demands of the lateral load resisting elements. To overcome this problem, diaphragm nominal rotation has been suggested by Castillo (2004). Nominal rotation is widely used as one of the most common parameters in torsional provisions of some displacement based design codes.Maximum nominal rotation (θ_N)is defined as:

$$\theta_N = \frac{\Delta_{max} - \Delta_{c.m}}{X_{cp-cm}}$$

Where,Δ_{max} is the maximum displacement of critical lateral load resisting element, $\Delta_{c.m}$ is the maximum displacement at the center of mass and X_{cp-cm} is the distance between critical element and center of mass. Fig.9 plots the variation of the maximum nominal rotationfor slight and severe mass eccentricity. It is shown in Fig.9 that maximum nominal rotation for both models with slight and severe eccentricity is influenced significantly by the magnitude of NMMI. Fig.10 summarizes the effects of NMMI on the maximum diaphragm rotation and maximum nominal rotation of the models with slight and severe eccentricity.

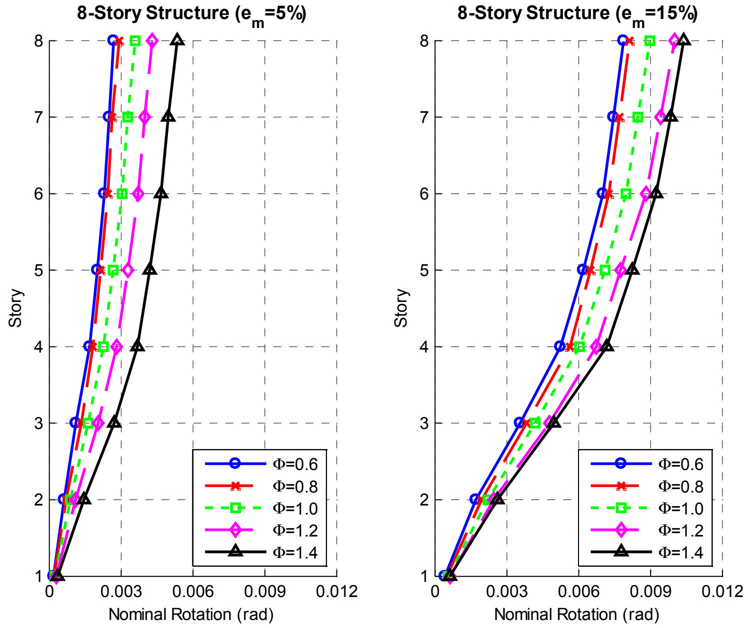


Figure 9. Maximum nominal rotation for slight (e_m =5%) and severe (e_m =15%) mass eccentricity

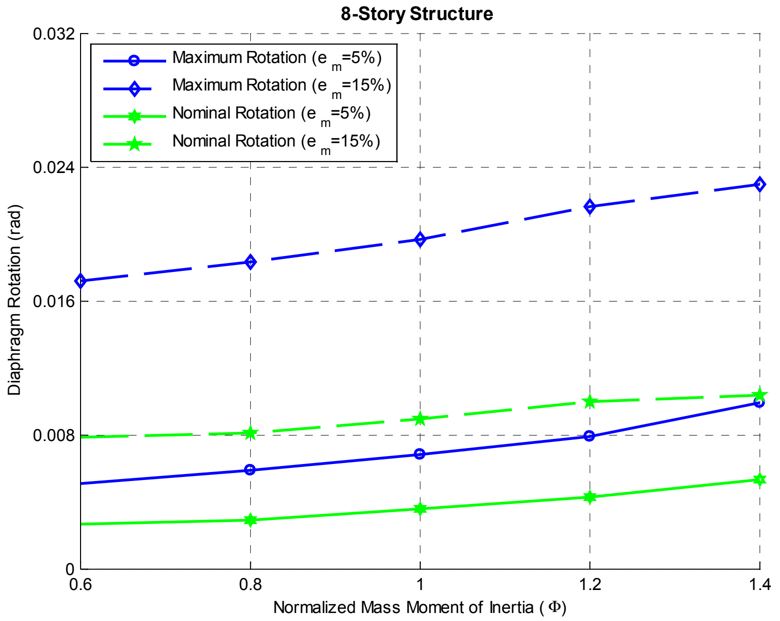


Figure 10. Correlation between normalized MMI and diaphragm rotation

- **Maximum Nominal Relative Displacement**

This parameter is another practical parameters used in torsional studies which represent the dynamic torsional behavior of eccentric structures. Nominal relative displacement is defined as:

$$\Delta_{rel}=\frac{\Delta_{max}}{\Delta_{c.m}}$$

Where Δ_{max} is maximum displacement at the story level and $\Delta_{c.m}$ is maximum center of mass displacement. Fig.11 shows maximum nominal relative displacement for slight and severe mass eccentricity. It is shown in this figure that nominal relative displacement at different story levels of each model is some how uniform. Furthermore this parameter is influenced significantly by NMMI for both models with slight and severe mass eccentricity.

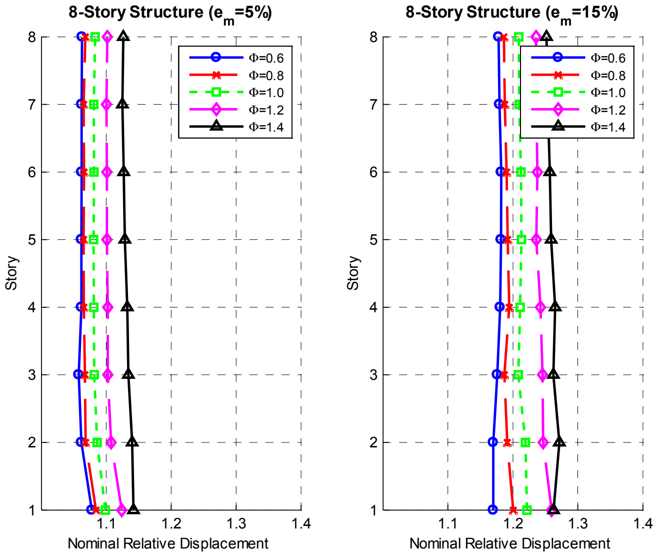


Figure 11. Maximum nominal relative displacement for slight (e_m =5%) and severe (e_m =15%) mass eccentricity

CONCLUSIONS

Based on a research conducted on the 8-story RC/MR building the following conclusions obtained:

- MMI directly depends on the unbalanced mass distribution scenario which produces the eccentricity. On the other hand for a known mass eccentricity a range of MMI is expected.
- The effect of MMI on soft edge and center of mass displacement demands is negligible. This negligible effect is not related to the magnitude of mass eccentricity.
- The effect of MMI on the stiff edge displacement demands is significant for both slight and severe mass eccentricity. By the growth of MMI, displacement demands of stiff edge are increased.
- Maximum diaphragm rotation, maximum nominal rotation and also nominal relative displacement as the most common dynamic torsional parameters are influenced significantly with the change in MMI. Gradual increment of MMI causes to increase of the foresaid torsional parameters.

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