COMPARISON OF INCREMENTAL DYNAMIC ANALYSIS CURVE WITH PUSHOVER CURVE

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ABSTRACT

During the past earthquakes, different low ductile failure modes are observed in the gravity design structures and thus, the most of existing damage indices may fail to assess the damage of gravity design structures accurately in referring to the two main performance levels: serviceability and ultimate limit state.
In order to estimate the ultimate inter-storey drift, either the incremental dynamic analysis (IDA) or static push over analysis has been performed in the literature. Since the pushover analysis is a static analysis it cannot take into account the effects of energy content, duration and frequency content of an accelerogramme while IDA analysis perform a dynamic analysis of structure under input accelerograme and then the effect of those parameters to the ultimate drift can be estimated. Therefore, this study investigate the effect of energy content, duration and frequency content of an accelerogramme in estimation of ultimate drift ratio by comparing the ultimate drifts obtained from IDA analysis and the pushover analysis.
For this purpose, IDA and pushover analysis are performed for selected two storey school bulding and compare the results.

***Keywords*:** Incremental dynamic analysis, pushover curve, inter-storey drift ratio

1. INTRODUCTION

During past earthquakes, different low ductile failure modes were observed in gravity design concrete frame structures. Joint failures, flexural failures, shear failures and combined failure of shear and flexure of mostly the column elements are common types of failure modes (Saatcioglu et al. [4]. In particular, shear failures are observed in short columns as shown in Figure 1. Such short columns are formed due to the openings placed to accommodate windows. Therefore, the challenge is which damage index proposed in the literature is suitable to quantify the damage state of such structures more accurately. In the following text, it is briefly discussed the proposed damage indices in the literature.
A various damage indices have been proposed in the literature to assess the damage state of a structure subjected to a seismic excitation. The studies by Cosenza et al. [2] and Bozorgnia and Bertero [3] have summarized the many of the damage indices proposed in the literature.
Out of damage those indices, the inter-storey drift damage index is commonly used as a better non-modal parameter based damage index to quantify the damage of a structure due to its simplicity. It is defined as the ratio of maximum inter-storey drift at the center of mass to the ultimate inter-storey drift, which usually corresponds to the 30% strength drop of the whole storey, as given in Eq 2.

$$DI = \left(\frac{ID_m}{ID_u} \right) \qquad (02)$$

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2. BULDING DESCRIPTION AND MODELLING

The building is 27.9 m long and 9 m wide. It has 9 bays of 3.1 m span along its length. The storey height is 3.3 m and comprises of 8 class rooms besides the stair void and store room. In-fill brick walls 1.5 m wide corridor in front of the building and in between each other bay make a space of 7.5 m 6.1 m for each class room as shown in Figure 1.

Figure 1: Selected school building

When consider the structural configuration of the building, all the elements cast with reinforced concrete. There are 20 columns of 375 x 300 mm supporting 300 x 650 mm and 115 mm thick floor slab at first floor level. 225 x 450 mm roof beams and 225 x 225 mm tie beams are supported at the roof level. In both first floor level and roof levels of the building the tie beams of 225 x x225 mm have been used to connect the super structural elements together.
To performe the IDA analysis, 3–dimensional model was developed using "Opensees" Finite element program published by the University of Berkeley [3].
The model comprises of frame elements to represent columns and beams while rigid diaphragms represent the floor slab and roof. The in-fill brick walls are ignored as we are going to evaluate the building performance applying earthquake along global "X" direction (along the building length) as the worst case for analysis.
The material for the development of finite element model, were defined following in-built uniaxial materials taking the material non-linearity in to account.

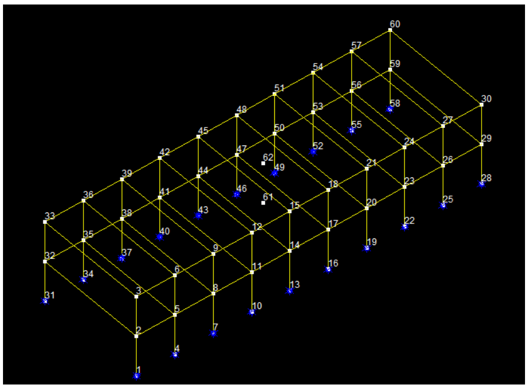

Figure 2: Numerical model develpoed in OPENSEES

All the frame elements (Beam & Columns) are inelastic beam-column elements based on forced formulation which is available within the "Opensees" framework [3]. Each in-elastic beam-column element is assigned five integration points.
The fibre section assigned to an element is constructed using a patch and reinforcement layers. The size of the patch and the number of reinforcement layers vary depending on the cross sectional size and the reinforcement detailing of the element, respectively. The material nonlinearity of the concrete represents a uniaxial Kent-Scott-Park concrete material model with degraded linear unloading/reloading stiffness according to the work of Karsan-Jirsa and no tensile strength. Since there are no adequate shear reinforcements provided in the columns and the beams in all three buildings, the confinement effect of the core concrete is minimized.
The connectivity of beam and column elements defined according to co rotational theory to represent moderate and large deformations of in-elastic rotations. The floor slab represent by a rigid diaphragm ignoring the flexibility. All the degrees of freedom are restrained at the base nodes.

3. RESULTS

3.1 Incremental Dynamic Analysis

Incremental dynamic analysis (IDA) has been developed by Vamvatsikos and Cornell (2002). IDA involves nonlinear dynamic analysis of a structural modal under a selected set of ground motions. For this study, 30 real ground motions are selected from the PEER data base. IDA is performed for several scaling levels of each a structure to behave all the way from elasticity to its global failure. Subsequently, the IDA curves of structural response are generated as measured by a damage parameter versus the scale factor of the ground motion. The serviceability limit state is defined in the elastic limit of a structure while the ultimate limit state is defined based on the type of the failure mode observed in the critical elements in which larger plastic deformation is expected. . It is clear from Figure 3 that IDA curves start as straight line in the elastic range and then shows the softening by displaying a tangent slop less than the elastic and also indicate the significant softening displaying the effect of yielding. They also display the record-to-record variability.

The serviceability limit state of each structure is defined as the end of the elastic limit. For the building, serviceability limit point on each IDA curve is defined corresponding to the flexural yielding at the first storey columns.

According to the study by Vamvatsikos and Cornell (2002), the ultimate limit state point on an IDA curve is defined as a point where the IDA slope is equal to 20% of the elastic while it also belongs to a softening branch.

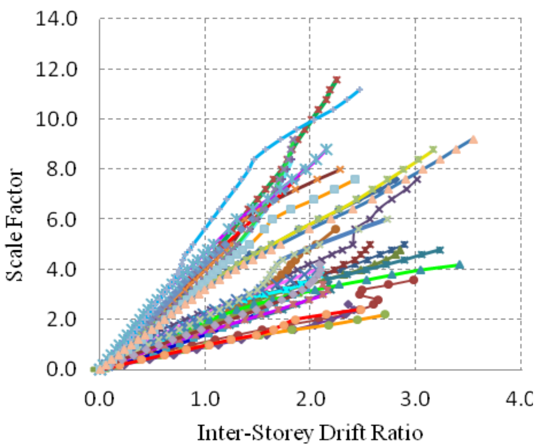

Figure 3: Incremental dynamic analysis curves for 30 earthquakes

However, this study incorporates the element performance to define the ultimate limit state point of a structure on the IDA curve. From the numerical investigation, it is evidenced that the global failure of the first building results in the failure of first storey column elements in flexure due to the formation of soft-storey mechanism. As the result of the gravity design of the frames, effective depths of the beams are higher than the columns and, in turns, this results beam sections have more strength and stiffness than the corresponding column sections. Therefore, plastic deformations are concentrated at the first storey columns forming the soft storey mechanism. As a consequence of this, the global failure points on IDA curves of the buildings corresponds to the 30% drop from the moment capacity of frame element at first storey level as shown in Figure 4. Table 1 summarizes the average values of inter-storey drift ratio for the serviceable limit state and ultimate limit state.

Table 1: Inter-storey drift ratios- Incremental dynamic analysis

Building No.	SLS	ULS
	Inter-storey ratio (%)	Inter-storey ratio (%)
1	1.2	1.9

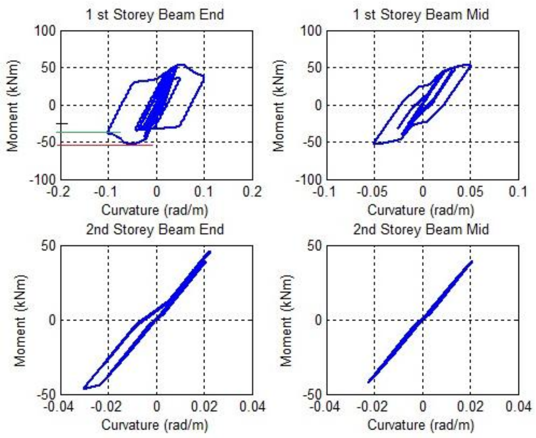

Figure 4: Moment-curvature diagrams

3.2 Pushover Analysis

Pushover analysis is performed using a triangular load distribution with the effect of gravity load acting on the structure. The blue curve in the Figure 5 shows the resultant pushover curve while the red line represents the equivalent bi-linear approximation to the pushover curve to define the yield drift or the inter-storey drift corresponding to the serviceability limit state.

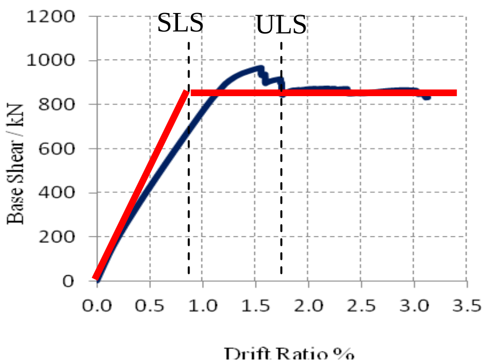

Figure 5: Pushover curve and equivalent bi-linear curve

It is clear from Figure 5 the corresponding inter-storey drifts for serviceability limit state (SLS) and ultimate limit state (ULS) are 0.8% and 1.75%, respectively.

Table 2: Inter-storey drift ratios- Pushover analysis

Building No.	SLS	ULS
	Inter-storey ratio (%)	Inter-storey ratio (%)
1	0.8	1.75

4. CONCLUSION

From the results of dynamic analysis of the structure, following conclusions can be drawn.
The gravity design school building forms unfavorable soft storey mechanism under the moderate earthquake loading.
By comparison of inter-storey drift ratios corresponding to the serviceability and ultimate limit states obtained from incremental dynamic analysis curve with those obtained from pushover curve, it can be concluded that pushover curve under estimate the inter-storey drift demands. This could be due to the fact that static pushover analysis cannot take into account the effects of energy content, duration and the frequency content of a accelerograme.

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