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Estimation of the Park-Ang Damage Index for Floating Column Building with Infill Wall

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Abstract**—**Buildings with floating column are highly undesirable built in seismically active areas. Many urban multi-storey buildings today have floating column buildings which are adopted to accommodate parking at ground floor or reception lobbies in the first storey. The earthquake forces developed at different floor levels in a building need to be brought down along the height to the ground by the shortest path; any deviation or discontinuity in this load transfer path results in poor performance of the building. Floating column buildings are severely damaged during earthquake. Damage on this structure can be reduce by taking the effect of infill wall. This paper presents the effect of stiffness of infill wall to the damage occurred in floating column building when ground shakes. Modelling and analysis are carried out by non linear analysis programme IDARC-2D. Damage occurred in beams, columns, storey are studied by formulating modified Park & Ang model to evaluate damage indices. Overall structural damage indices in buildings due to shaking of ground are also obtained. Dynamic response parameters i.e. lateral floor displacement, storey drift, time period, base shear of buildings are obtained and results are compared with the ordinary moment resisting frame buildings. Formation of cracks, yield, plastic hinge, are also observed during analysis.

Keywords**—**Floating column, Infill Wall, Park-Ang Damage Index, Damage State.

I. Introduction

COLUMNS that float or hang on beams at an intermediate storey and do not go to the foundation have discontinuities in the load transfer path, are the floating column buildings. Many buildings with floating column adopted to get more space for parking or reception lobbies collapsed and were severely damaged in earthquake [1]. Earthquake load depends on seismic zones, types of soil, type of construction and plan geometry. Lateral load due to earthquake is highest in high seismic prone areas and its magnitude depends on the intensity of peak ground acceleration [2]. Floating column effect on structure can be reduced by infill wall which may not resist the gravity load but it contributes significant role during earthquake [3]. In general, stiffness of infill wall is not considered and so changes in dynamic behavior of structure are ignored [4].

The earthquakes are natural hazards which have tremendous potential for losses both social and economic. The quantification of damage of structures has been a growing concern for the Engineers though it has been widely used in the past two decades. Major contributions has led to significant development of damage assessment but no proper code has been established as there are many parameters governing the failure of structure. The quantification helps in assessing the seismic performance of the structure under any ground motion, thus the need of retrofitting of the structure arises [5]. The damage index is a response which measures the damage as well as degradation in a structure. The assessments of seismic vulnerability in these decades have broadened the area of seismic design. Still the safety against collapse is the main target; the performance of the structure is repeatedly analyzed to obtain the desired result. The damage index can be a function of maximum displacement, energy dissipated, fundamental frequency, loss in stiffness, etc. The damage criterion should include displacements as well as the effect of repeated cyclic loading. The Energy based Damage Index takes into account the maximum displacement as well as the energy dissipated by the structure due to repetitive cycles produced.

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II. Example Building Description

Each building has ground plus four storeys with floor height equal to 3m. Earthquake loads are considered to act only in the horizontal directions. The unit weight of reinforced concrete is taken as 25 kN/m^3 and that of masonry is taken as 19 kN/m^3.The floor finish load and the water proofing loads are taken as 1 kN/m^2 and 1.5 kN/m^2.Live loads on the roof and on the floor are taken as 1.5 kN/m^2 and 3 kN/m^2.

Elevation and square plan of 9m x 9m of floating column building is shown in Fig. 1. Plan for floating column building from section AA-BB, from section BB-CC and from section CC-DD are shown in Figs. 1 (b), (c), and (d) respectively.

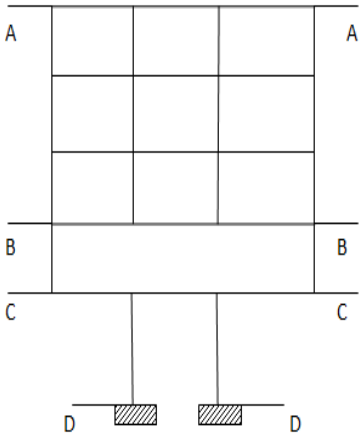

Fig. 1 (a) Building elevation

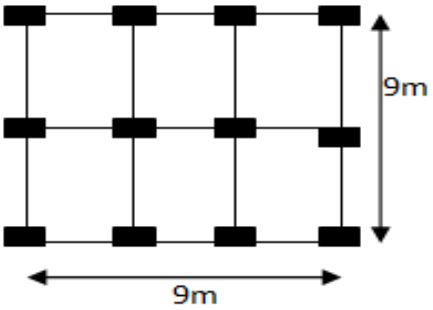

Fig. 1 (b) Plan of section AA-BB

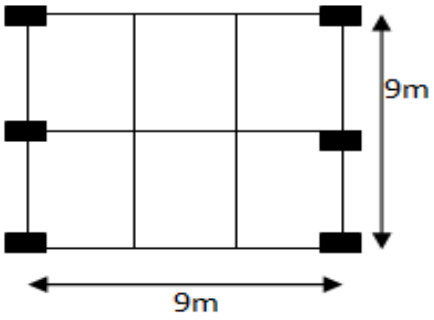

Fig. 1 (c) Plan of section BB-CC

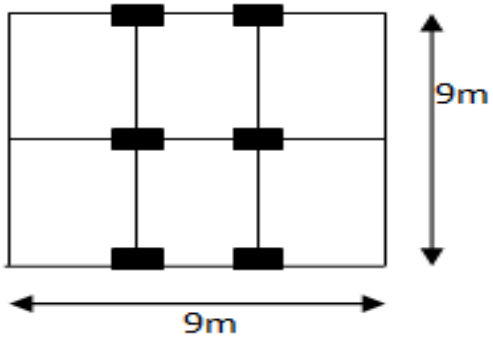

Fig. 1 (d) Plan of section CC-DD

Fig. 1 Elevation and plan of Floating column building

III. Analysis

All the buildings are analyzed as ordinary moment resisting frames. Structural analysis and design are carried out using STAAD-Pro [6]. M 20 grade concrete and Fe 415 steel are used. Inelastic damage analysis is carried out by a program for inelastic damage analysis IDARC V7.0 [7] for each type of building. Elcentro ground motion is taken with peak ground acceleration of 0.32g with duration of 26.5 sec. Table I shows the size of structural members for example buildings.

TABLE I
Properties of Beam and Column

Beam Size (m)	Column (m)
1st storey: 0.35x0.45	G.F to 1st floor: 0.45x0.45
2nd to 5th storey: 0.25x0.35	2nd floor to 4th floor 0.30x0.30

Infill wall is analyzed by assuming compression strut as shown in Fig. 2.

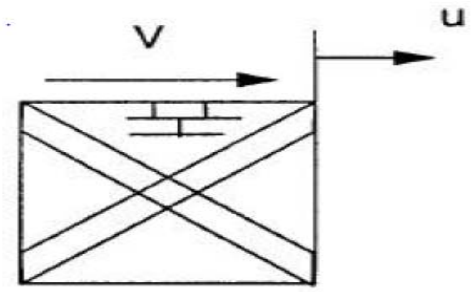

Fig. 2 Masonry infill panel: Compression struts

The struts are considered ineffective in tension; however, the combination of both struts provides resistance in both directions of loading.

IV. Results and Discussions

A. Fundamental Time Period

Fundamental time period for floating column building is 0.642sec. Floating column buildings are more flexible and its time period It is higher than 49.38% as compared to the ordinary moment resisting frame building.

B. Lateral Floor Displacement

Top floor displacement for floating column building is 81mm. It is higher by 74.07% as compared to the ordinary moment resisting building of same plan and geometric condition. Top floor displacement is reduced by providing infill wall which is shown in Fig. 3.

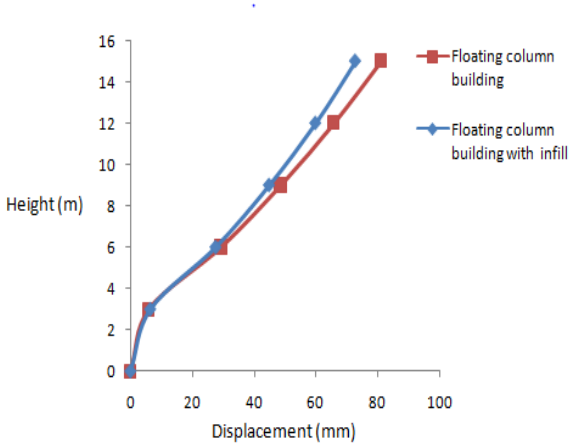

Fig. 3 Lateral floor displacement

Top floor displacement for floating column building with infill wall is 72.8213mm. It is reduced by 11.11% due to infill wall effect as compared to the floating column building without infill wall.

C. Storey Drift

The difference in the lateral displacement between two consecutive floor level is storey drift. Damage to non structural components of buildings depends on drift. Maximum storey drift for floating column building is 23.339 mm at height of 6m from the base of building. It is higher by 69.56% due to introducing floating column in building as compared to ordinary moment resisting frame building. Storey drift is reduced by providing infill wall and it is reduced by 10% as compared to the floating column building without infill.

D. Base Shear

Shear induced at the base of building during earthquake is called base shear which depends on the mass and stiffness of building. Base shear of floating column building is lower than the ordinary moment resisting frame building as the mass of concrete in column is less for floating column building structure.

TABLE II
BASE SHEAR

Building Type	Base Shear(kN)	% variation
Floating column building	277.22	Increased by 86%
Floating column building with infill	517.68	

Table II shows the value of base shear of floating column building with and without infill wall. Infill wall increase the stiffness of floating column building, as a result base shear is increased by 86% as compared to the floating column building without infill wall.

E. Damage Index

Analysis of damage occurred on structural component is carried out by Park & Ang model, i.e.

$$DI_{P\ \&\ A} = \left(\frac{\delta m}{\delta u}\right) + \left(\frac{\beta}{\delta u * P}\right) \int dE;$$

where δm and δu are the maximum and ultimate deformations respectively, yield strength of element denotes as P and $\int dE$ is absorbed hysteretic energy by element during response history.

To obtain overall structural damage index, following calculations are made:

$$DI_{story} = \sum (\lambda_i)_{component} (DI_i)_{component};\ (\lambda_i)_{component} = \left(\frac{Ei}{\sum Ei}\right)_{component}$$

$$DI_{overall} = \sum (\lambda_i)_{story} (DI_i)_{story};\ (\lambda_i)_{story} = \left(\frac{Ei}{\sum Ei}\right)_{story}$$

Damages on floating column building are more than ordinary moment resisting frame building due to structural irregularity introduced by floating column. Infill wall has significant role to the damages of the building. Damage index of structural component, storey and overall structure is represented in Table III.

TABLE III
DAMAGE INDEX

Item	Floating column building	Floating column building with Infill
Column Damage	0	0
Beam Damage	0.049	0.051
Beam-slab damage	0.048	0.051
Column-wall damage	0	0
Overall Structural Damage	0.046	0.049

Overall structural damage is increased by 6.5% due to infill wall effect. There are no damages on column and column-wall of the floating column building with and without infill wall.

F. Damaged State of Structure

Damaged state of structure helps to identify the condition of structure due to earthquake. Though damage index helps in quantifying the damage, the damage states adds more to the degree of retrofitting for the existing structures. The damage predication allows us to glean the nature and extent of physical damage of building type from damage predication. The result of damage estimation enables us to predict the risk involved in defining a damage model. It is also used to determine the casualties due to structural damage, monetary losses due to building damage and other social and economic impacts. Figs. 4 and 5 represent the damaged state of floating column building without and with infill wall respectively.

Fig. 4 Damaged state of floating column building

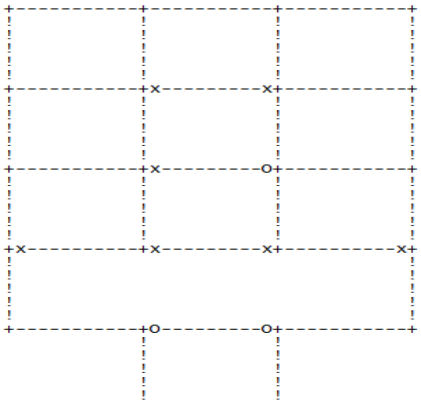

Fig. 5 Damaged state of floating column building with infill wall

Crack induced in structure is represented by "x" and developed plastic hinge on structure is indicated by "o". Due to infill wall effect, cracks are not developed on the top storey and plastic hinge is not developed on the 3rd storey of floating column building. But plastic hinge is formed on the 1st storey of the building in case of floating column building with infill.

V. Conclusion

Based on the analysis and design, following conclusions are made.

1. Floating column building shows poor performance during earthquake.
2. Time period, lateral floor displacement, storey drift are higher due to presence of floating column.
3. Base shear is least in case of this building as mass of column is less.
4. Infill wall provides seismic strengthening of floating column building. It helps to reduce the seismic parameters of this type of building.
5. Base shear is increased due to infill wall as it provides more stiffness on the structure.
6. Damage index is slightly more because of infill wall but it helps to minimize the formation of cracks on the upper storeys.
7. During earthquake, ground floor is damaged more and plastic hinge is formed in presence of infill wall.

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