Non-linear time history analysis of building connected with a walkway

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Abstract
The popularity of walkway bridges is increasing rapidly due to their aesthetics and needs; they set out a bridge for easy access, an evacuation alternative during an hour of disaster. This study mainly focuses on the response of the building connected with a walkway for various lateral loads. To cater that need, two buildings 5m apart are analyzed by providing the walkway of various width at various locations to find the maximum response of the building such as drift and displacements.

In this research, the effect of seismic behaviour and the response of two 5 storey buildings connected by a walkway are studied. The non-linear time history analysis is performed using SAP2000. The various storey drift and displacement are studied by varying the location and width of the walkway bridge. It is observed that the structure has better seismic performance if the walkway is placed on other location than centre.

Keywords: Non-linear time history analysis, walkway bridge, ground motion, seismic behaviour, lateral displacement, inter-storey drift, SAP2000.

Introduction

The multi-storey buildings connected with the walkway are the new trends in construction which do not follow the traditional structural design concept. For such structures, the complexity has increased. This has led to identifying the new approach in construction which will satisfy the aesthetic and structural needs. Hence, their effects on structural behaviour and design must be studied and understood well by the structural engineers to ensure the safety of such structures. The walkway bridges increase the area for horizontal movement and congestion at ground floor levels and lower levels are relatively reduced.

The connecting bridge for two buildings can be constructed using various approach i.e. using the column-beam system with a masonry wall and using a deep beam. The behaviour of deep beam was relatively effective to reduce shear force, axial force and bending moment in bridge beam compared to column-beam system with masonry wall. The interpretation of non-linear time history analysis of two linked buildings performed using the Malaysian earthquake having PGA of 0.15g indicates that the link could effectively change the structural responses of such buildings i.e. response has been increased attributing to the additional mass of the link. To omit the undesired structural responses, the properties of the link i.e. mass, stiffness, location, as well as strength, must be optimized.

A set of ground motion records with varying peak ground acceleration was used to excite the building configuration in two orthogonal directions. The dynamic-load induced response of the structure is affected dramatically when the connecting sky-bridge is at the top floor and the response for the location of sky-bridge in other location was affected slightly. The examples of buildings connected with sky-bridge are Petronas tower, American Cooper building, Sky habitat, Linked hybrid etc.

The multi-tower structures connected with long-span truss elevation with large floor slab opening have more complexities. When the experimental and analytical studies were performed on such structure, it was concluded that the stiffness and strength of long-span connecting truss should be improved to improve the overall response of the building to meet the requirement of Codal provision during potentially large vertical acceleration under strong earthquake.[10]

Modelling: The plan of two buildings each having size of 14m x 17m having storey height of 3m, connected by a walkway bridge of 5m is modelled as shown in Figure. Altogether 12 models (MI, MO and MC type) are generated by varying the width of the walkway bridge (2m, 3m, 4m) and location i.e. on first, second, third and fourth floor. The models, analysis and design of buildings connected with a walkway bridge are performed using SAP2000 using the design data as shown in table 1.

Analysis: SAP 2000 is used for the analysis of the structure and the response of the structure is carried out in both X and Y direction for equivalent static and response spectrum analysis. Figure 2 shows the plot of the variation of inter-storey drift for equivalent static analysis and response spectrum analysis. The seismic response of the structure under dynamic loading is determined using non-linear time history analysis using the various scaled ground motion data.

In this study, we have selected eight ground motion data of different PGA from the PEER NGA database having the magnitude of the earthquake in the range of 6 to 8, shear velocity in the range of 360 to 720 m/s. The selected ground motion data are scaled using SeismoMatch according to the target spectrum of IS 1893:2016 by maintaining the tolerance of less than 30%. The target spectrum is characterized by considering the seismic zone V having medium soil conditions. The range of time period is selected between 0.05 to 2 and the response spectra of scaled ground motion are shown in figure 3.

Table 1
Design data for structure.

Modelling Data		Analysis Data	
Particular	**Information**	**Particular**	**Information**
Model Height	G+4	Seismic Load	Using IS 1893(Part-1)-2016
Walkway length	5 m	Zone Factor	0.36 (Seismic Zone-V)
Floor Height	3 m	Soil type	Type-II, Medium Soil
Plan Size	33 m x 17 m	Wall Load	10 kN/m^2
Size of Beam	0.23 m x 0.35 m	Partition wall	4.72 kN/m^2
	0.3 m x 0.4 m	Parapet wall	2.85 kN/m^2
Size of column	0.4 m x 0.4 m	Floor Finish	1 kN/m^2
	0.4 m x 0.35 m	Live Load	4 kN/m^2
Materials Used	M-30 grade concrete and Fe 500 HYSD reinforcement	Analysis Performed	Response Spectra and Non-linear time history analysis

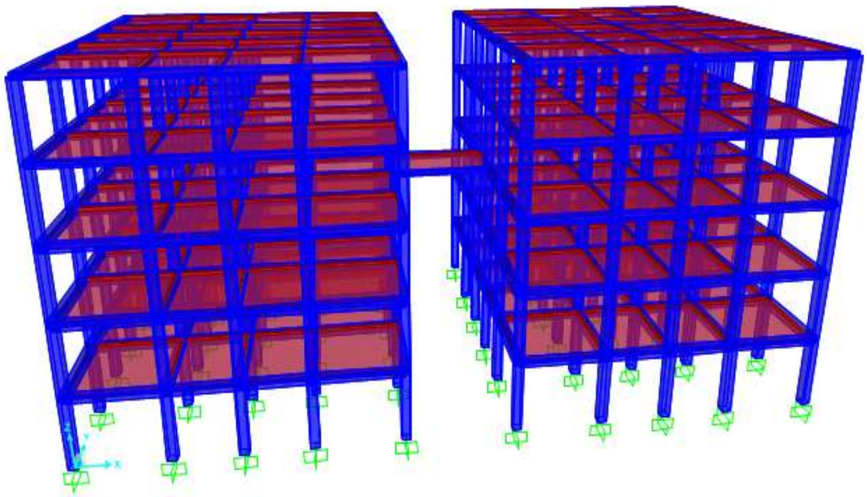


Figure 1: Sample 3-D rendered view of multi-storey building connected with a walkway

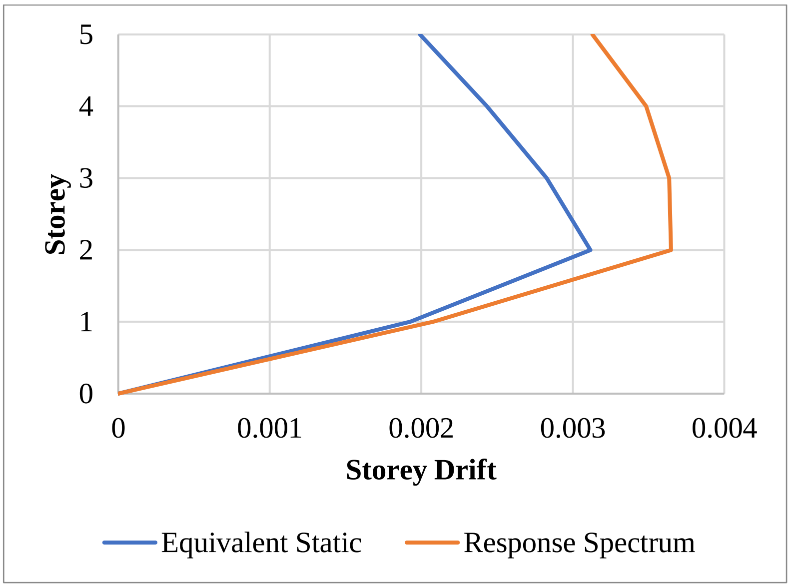


Figure 2: Average inter-storey drift plot for equivalent static and response spectrum analysis.

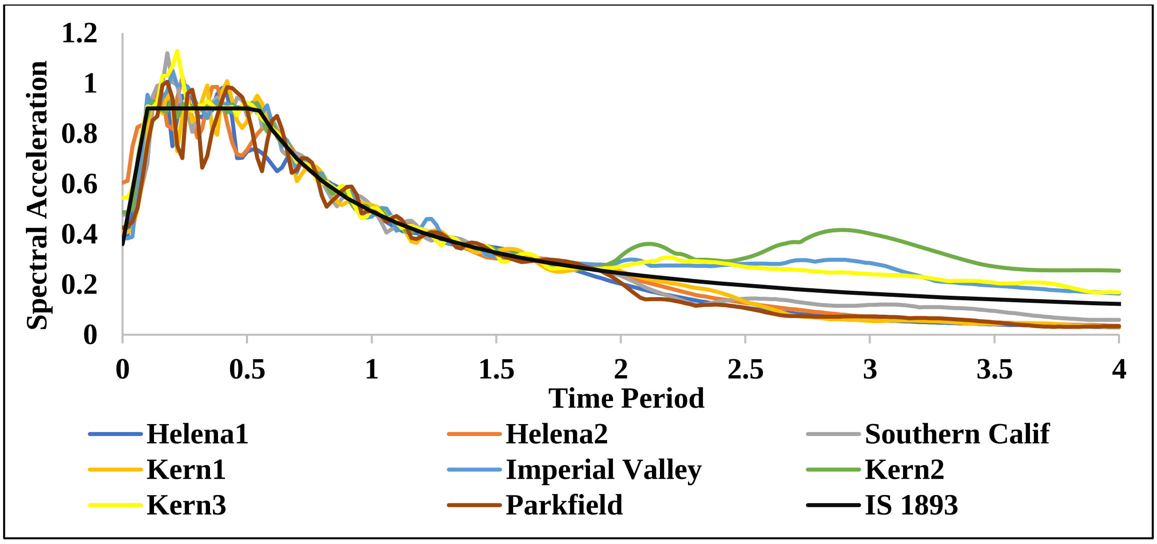
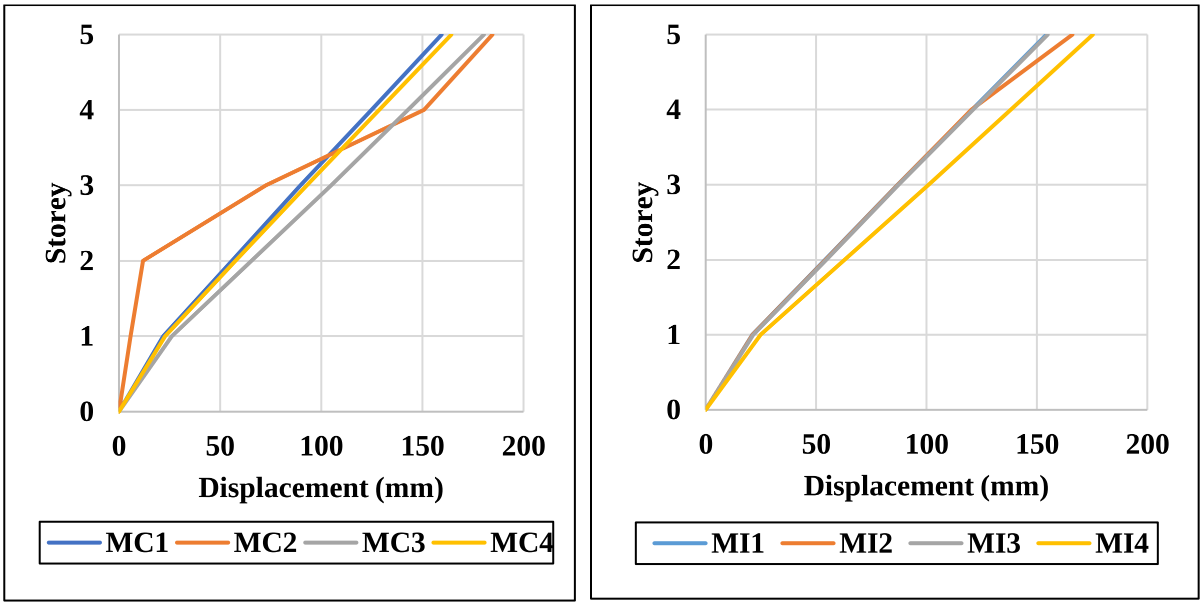
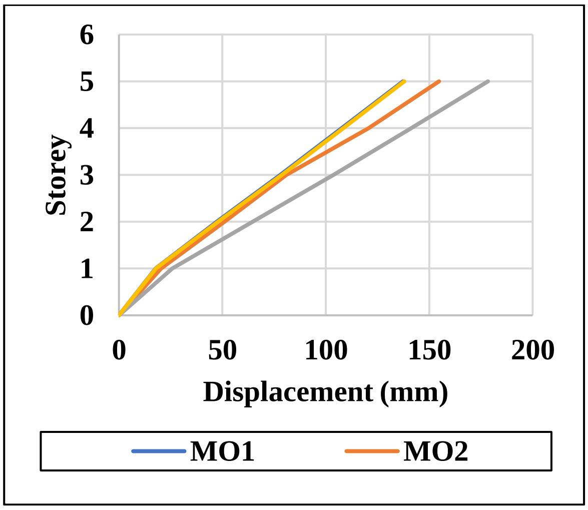


Figure 3: Response spectra of scaled ground motions





(c)

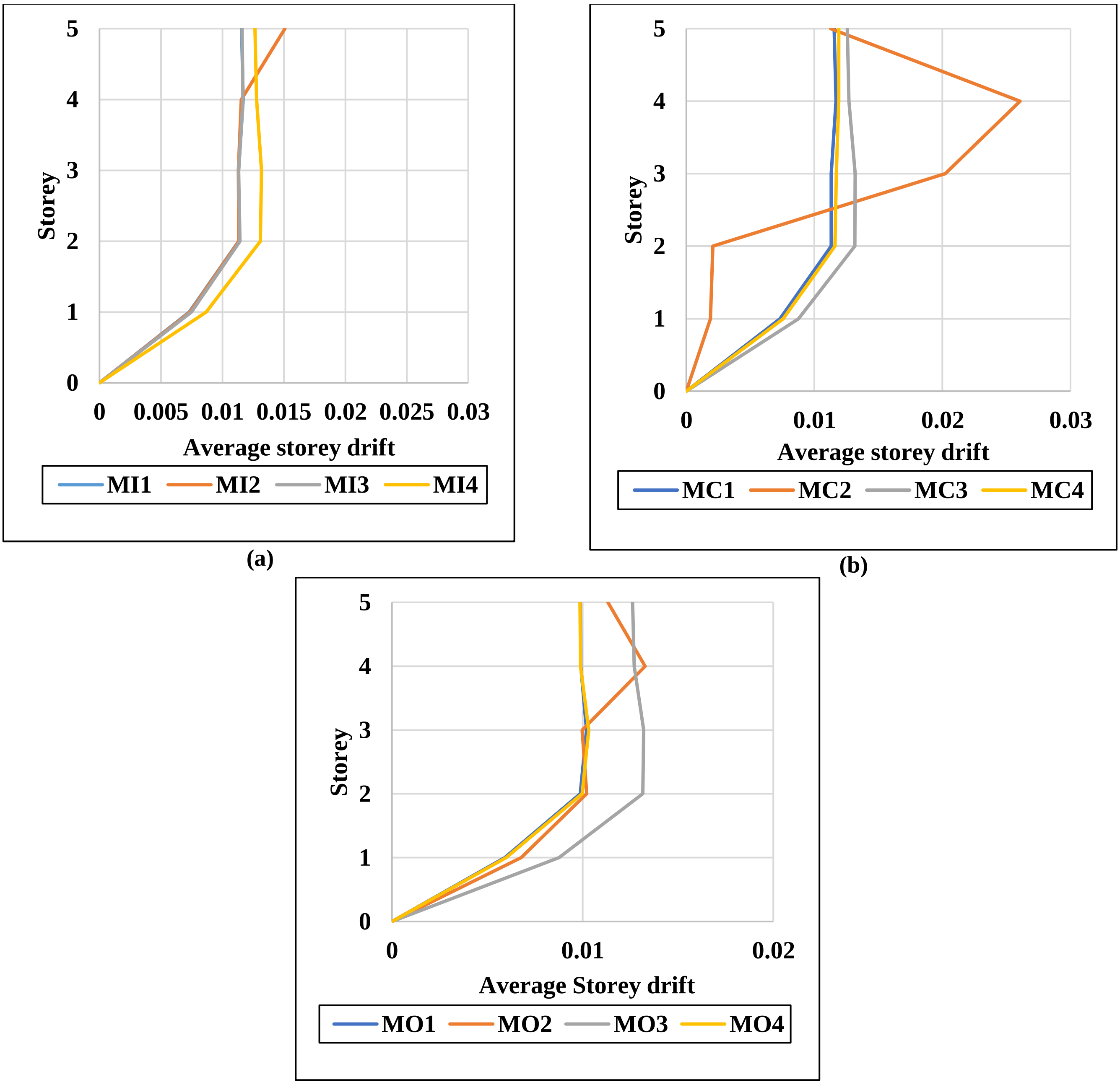
Figure 4: Storey lateral displacement for all ground motions (a) When walkway width is 2m (MI type), (b) When the walk way width is 3m (MC type) and (c) When the walkway width is 4m (MO type)

Results and Discussion

The non-linear time history analysis was performed on all the models using the eight scaled ground motion data. The response of the structure is then interpreted in terms of lateral displacement and inter-storey drift. Figure shows the average lateral displacement of the structure by varying the location of the walkway bridge. The average lateral displacement is observed in the top floor for the all scaled ground motion i.e. 175.341 mm for MI4, 184.636 mm for MC2 and 178.4096 mm for MO3.

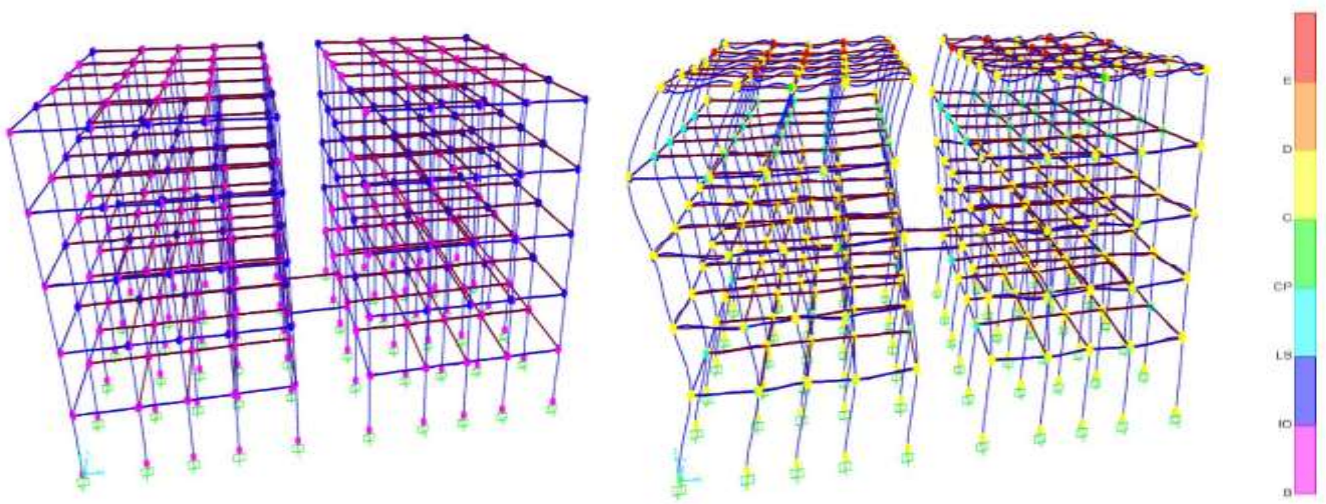
It shows that percentage variation in average lateral displacement for MI4 and MO3 in comparison to MC2 is 4.891% and 3.038% respectively which clearly shows that maximum displacement is experienced at the top floor.

Similarly, the relative displacement of successive storey level per storey height i.e. inter-storey drift is calculated for all the models. The average inter-storey drift is as shown in figure 5. The average inter-storey drifts observed for the scaled ground motion are: 1.5% on the top floor for MI2, 2.6% on the fourth floor for MC2 and 1.32% on the fourth floor for MO2. As per IS Codal provision, the maximum inter-storey drift is limited to 0.4%. It is observed that the inter-storey drift is exceeding the permissible limit which suggests that the structure is susceptible to collapse under strong ground motions.



(c)

Figure 5: Inter-storey drift for all ground motions (a) When walkway width is 2m (MI type), (b) When the walk way width is 3m (MC type) and (c) When the walkway width is 4m (MO type)



(a) (b)

Figure 6 Plastic hinge formation (a) For MO1 model for Parkfield ground motion (b) For MC2 model for Helena 2 ground motion

Table 2
Properties of Scaled Data

Ground Motion	Scale Factor	T_{min}	T_{max}	Tolerance (%)	PGA (g)
Helena1	1	0.05	2	22.40	0.387
Helena2	5.45	0.05	2	24.90	0.604
Southern Calif	14.665	0.05	2	24.80	0.373
Kern 1	1.672	0.05	2	28.40	0.336
Imperial Valley	2.765	0.05	2	18.60	0.383
Kern 2	8	0.05	2	27.00	0.271
Kern 3	6.03	0.05	2	25.00	0.408
Parkfield	6.03	0.05	2	23.10	0.425

The yielding zones of a structural element developed at the point of maximum bending or deformation are generally termed as plastic hinge. Plastic hinges help to predict the potential weak areas in the structure by keeping the path of the sequence of damages of each and every member in structure. The hinges represent localized force-displacement relation of member through its elastic and inelastic phases under seismic load and have non-linear stages i.e. immediate occupancy (IO), life safety (LS) and collapse prevention (CP) which lie within ductile range.

In immediate occupancy, the structural parts experience considerable changes. In life safety stage the damage is moderate but the structure remains stable. In collapse prevention, the structure is on the verge of experiencing local or total collapse. Beyond this range, the structure shows sudden and reduced resistance to load. The minimum deformation is observed in MO1 (Figure a) for the Parkfield ground motion in which the structure is in the stage of immediate occupancy i.e. this model experiences minor structural damages with limited fracture in connection due to certain localized yielding. Similarly, the maximum deformation is observed in MC2 (Figure 6b) for Helena 2 ground motion in which the structure collapses due to total loss of resistance.

Conclusion

The following conclusions are drawn from the seismic performance of the buildings connected by a walkway in terms of displacement and inter-storey drift using non linear time history analysis.

- The maximum storey displacement and inter-storey drift are observed in MC2 model for Helena 2 earthquake ground motion.
- The minimum storey displacement and inter-storey drift are observed in MO1 model for Parkfield earthquake ground motion.
- Since, the maximum and minimum response are shown by different ground motion, it signifies that the selection of type of ground motion has vital role in non-linear time history analysis.
- The model having a walkway width of 4m (MO type) provides more lateral resistance in comparison to that of having width of 2m (MI type) and 3m (MC type).

Hence, the seismic performance of the structure depends on the selection of type of ground motion as well as the positioning of the walkway. It is notable that the positioning of the walkway bridge is better if placed other than at the beam-column joints (i.e. at centre).

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