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Influence of Slab System in Transfer of Lateral Loads to Reinforced Concrete Shear Wall

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Abstract: The function of the slab system in a building is mainly to carry the gravity load. There are different types of slab systems which will be selected based on gravity loading, length of loading span and requirement of the architecture. The structural engineers mainly concentrate on vertical loads while designing the slab system, even though slab systems provide a significant amount of lateral stiffness to the structures to resist the lateral loads. In some designs, the lateral stiffness of the slab system is taken into account while others do not. In this study, the influence of slab systems in the transfer of the lateral load to the lateral load resistance system is assessed. The target building type is a wall-frame system. To find out the influence of the slab system on the lateral stiffness of the wall-frame system, rectangular shape regular type buildings with different stories (5, 10 and 15 stories) are selected. Here, three different types of slab systems, such as slab and beam, flat slab and flat slab with drop panel, are selected. Next, the effect of structural response is investigated for the structures under seismic and wind forces, with and without lateral slab stiffness. In this study, the response (displacement, inter-storey drift, frequency and base shear distribution) obtained through modal response spectrum analysis, non-linear time history analysis and static wind analysis are used for comparison. From the responses, it is clear that the lateral stiffness of the slab system has a significant influence on the serviceability limit state design of a structure, but not to the ultimate limit state design. Considering the lateral stiffness of slab, the deformation of a structure is controlled by (5-15) %, (15-35) % and (30-55) % for SB, FS and FSDP, respectively, based on the structural height.

Keywords: Diaphragm action, Drop panel, Flat slab, Inter-storey drift, Lateral stiffness, Response spectrum analysis, Slab and beam

1. Introduction

The building height is increasing with the rapid growth of the human population and lack of land availability. Developing countries seek to gain more living spaces with increasingly taller buildings, concurrently trying to make the structures economically viable. The high-rise building concept was started in the 19th century based on economic equations [1]. High rise buildings are being built to accommodate the rapid growth of inhabitants and to be a landmark of a country. Due to technical and cost-effective benefits, tall buildings have become a unique feature of housing accommodation in densely inhabited town zones all over the world.

In structural design, optimization plays an important role in creating the best solution with the available resources. In high-rise buildings, it is very important to ensure that the adequacy of resistance of the building for the lateral forces. Lateral loads acting in the buildings are mainly due to earthquakes and wind. In a country like Sri Lanka, the wind force is the most dominant lateral load rather than earthquake loads, as Sri Lanka is less vulnerable to the earthquake hazards [2]. Most of the high-rise buildings are reinforced concrete buildings and the most generated lateral load resisting system is a shear wall-frame structure in Sri Lanka.

Structural optimization can be done based on structural performance and the weight of the buildings to bring an economical solution. There are two types of primary loads acting on high-rise buildings which are vertical (gravity) loads and lateral loads.

Columns, beams, slabs and shear walls are the

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main structural components to resist the loads on structures. The shear walls can be effectively used to resist the lateral loads [3].All gravity loads are applied on the slab and the slab transfers the vertical loads to the columns and the columns transfer the loads to the support. The wind loads are distributed to the frames from external cladding with a different method than gravity loads and seismic forces. Seismic forces are generated on the earth crest and transfer to the structure from the base. However, some additional structural system is needed to resist lateral loads. The slab element transfers the lateral loads to the specified lateral load resisting system through diaphragm action. While transferring the lateral load, slab components contribute a significant amount of stiffness to the structure. This study is carried out to evaluate the stiffness contribution of the slab in transferring lateral loads. In this study, six types of slab conditions were selected for the analyses: slab and beam, flat slab, flat slab with drop panel, slab panel with beam without slab stiffness, flat slab without slab stiffness and flat slab with drop panel without slab stiffness. A few studies on the behaviour of slabs with lateral loads have been conducted [4], [5], and [6]; however, the lateral stiffness of a structure's lateral load resistance has not been studied sufficiently. Different types of slabs at different heights, showing interesting behaviour under seismic and wind loading. The assessment of the behaviour of structural concrete slabs subjected to dynamic loading requires tools that can be used to analyse and design structural elements that will improve the state of the art of protective design.

The aim of this paper is to present the findings of the study on the influence of lateral stiffness of the slab system of RC multistorey structures for the lateral loads. For that purpose, RC wall structures are developed with selected slab panel systems (i.e., slab and beam, flat slab and flat slab with drop panel) with appropriate FE simulation packages. Non-linear time history analysis and linear static wind analysis are carried out using *ETABS* FE software. These different slab structures are modelled with and without slab lateral stiffness to calculate the stiffness contribution of the slab for a given configuration of the structure.

2. Structural Systems of High-Rise Building

The building structural systems can be classified into two types based on the load transmission mechanisms. They are gravity load resisting systems and lateral load resisting systems.

2.1 Gravity Load Resisting System

The gravity loads shall be resisted by the frame elements such as columns, beams and slabs. The gravity loads initially act on the slab, which transfers them to another vertical load resisting structural element. The slab analysis is essential for determining the forces on other structural elements. For this reason, slab design plays a very important role in building design [7]. Slab systems are used to create flat horizontal surfaces such as floors and roof decks. There are different types of economical slab systems for reinforced concrete buildings [8]. Several factors influence the economy of floor systems, such as building type, architectural layout, span length between columns and aesthetic features. Since floor system cost constitutes a major part of the structural cost, the selection of an economical floor system for given situation would affect the overall cost of the project [9]. Besides considering the cost, the structural performance is essential when designing a structure. Structural behaviour of slab and beam, flat slab, and flat slab with drop panel system, is discussed in detail.

2.1.1 Slab and Beam

The slab and beam system consists of frames with beams into columns and supports the slabs which span between the beams. It is a very traditional system (see Figure 1). The deep beams provide a stiff floor that is capable of long spans and able to resist lateral loads.

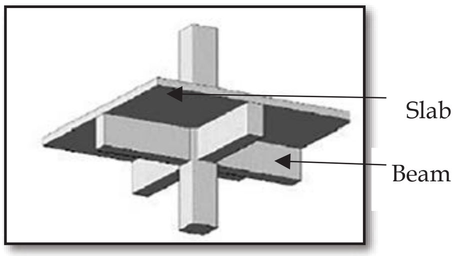


Figure 1 - Slab and Beam System (NTS)

2.1.2 Flat Slab

The flat slab (see Figure 2) is a beam-less slab having the load path in two-way directions. Flat-slab structures enable simple design, pure and clear space with the absence of beams, faster construction and time saving [10]. Engineers regard flat slab construction as having one advantage over other structural forms such as two-dimensional action and plate action, etc. [11].

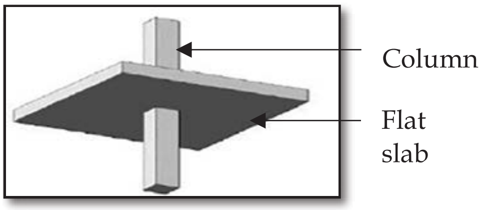


Figure 2 - Flat Slab (NTS)

2.1.3 Flat Slab with Drop Panel

The flat slabs are more critical for the punching shear at the connection with the column. To avoid that, the columns are designed with column heads/ drop panels with increased thickness from the slab. The flat slab with a drop panel is shown in Figure 3.

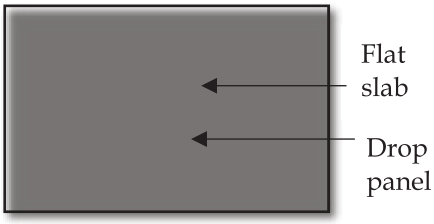


Figure 3 - Flat Slab with Drop Panel (NTS)

2.1.4 Load Transferring Mechanism through Slab System

In addition to the gravity load, a building needs to be stabilized for lateral loads. Most lateral loads vary in intensity which depend on the building's geographic location, structural materials, height and shape of the structure [12]. The floor diaphragms transfer the lateral loads to the vertical elements. The floor diaphragm should have sufficient strength to transfer the inertia forces to the lateral load resisting system. A large opening in the floor panels may restrain the continuity of the floor path [13].

The calculation methods and equations have been presented by Konstantinidis [14] for the floor diaphragmatic behaviours. The diaphragmatic behaviours of the slab can be a parallel translation of the diaphragm or rotation of the diaphragm. When a horizontal force (*H*) acts on a storey level, all the points of the slab in that particular level, including the column top points, move following the same rules due to the in-plane rigidity of the slab. These rules induce the diaphragm to develop a parallel (translational) displacement by δ_{xo} , δ_{yo} and a rotation θz about the centre of stiffness C_T (x_{CT}, y_{CT}) in xC_Ty coordinate system, which is parallel. Therefore, when the system of orthogonal columns is parallelly arranged then $K_X = K_x, K_Y = K_y, K_{XY} = K_{xy} = 0,$ where flexural stiffness expressed in terms of K_x, K_y in respective directions, meaning that a horizontal force H_x applied at the centre of stiffness in X direction results in a displacement only along X (the same applies for Y direction). A rotation of the diaphragm due to moment M_{CT} applied at centre of stiffness C_T to the initial coordinate system X, Y and has as origin the point C_T. Figures 4 denotes parallel translation of the diaphragm in both directions and rotation due to a force H applied to the centre of mass. Figure 5 designates the rotation of the diaphragm. Equations (1) to (4) represent the centre of stiffness and lateral stiffness. Equation 5 represents the torsional stiffness of the floor diaphragm. Equation (6) indicates the displacement of the centre of stiffness.

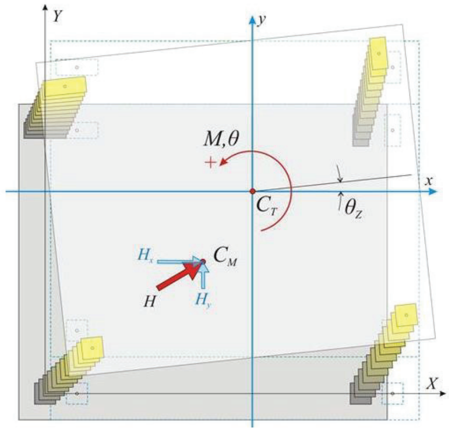


Figure 4 - Parallel Translation of the Diaphragm in Both Directions and Rotation

Centre of stiffness and lateral stiffnesses:

$$X_{CT} = \Sigma\,(K_{yi}\,X_i)/\Sigma\,(K_{yi}) \quad \text{... (1)}$$

$$H_x = K_x \cdot \delta_{xo} \quad \text{... (2)}$$

where $K_x = \Sigma\,(K_{xi})$

$$Y_{CT} = \Sigma\,(K_{xi} \cdot Y_i)/\Sigma\,(K_{xi}) \quad \text{... (3)}$$

$$H_y = K_y \cdot \delta_{yo} \quad \text{... (4)}$$

where $K_y = \Sigma\,(K_{yi})$

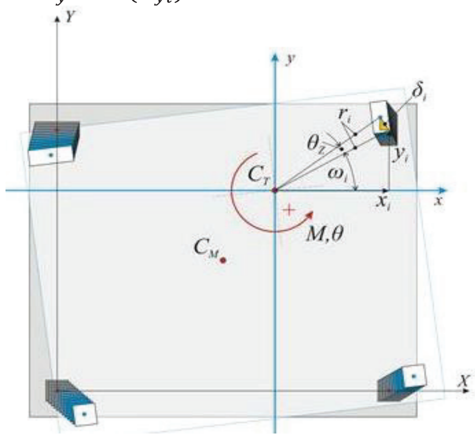


Figure 5 - Rotation of the Diaphragm

Torsional stiffness of the floor diaphragm:

$M_{CT} = K_\theta . \theta_z,$ ... (5)

where $K_\theta = \sum (K_{xi}.Y_i^2 + K_{yi}.X_i^2 + K_{zi})$

Displacements of the centre of stiffness:

$\delta_{xo} = \frac{H_x}{K_x}, \delta_{yo} = H_y/K_y, \theta_z = M_{CT}/K_\theta$ ... (6)

where $K_x = \sum (K_{xi}), K_y = \sum (K_{yi})$,

$K_\theta = \sum (K_{xi}.Y_i^2 + K_{yi}.X_i^2 + K_{zi})$

Where, K_{zi} denotes the torsional stiffness of the column i. Torsional stiffness of diaphragm K_θ denotes the moment required to cause relative rotation of the diaphragm by one unit.

2.2 Lateral Load Resisted System

Several structural systems are commonly used to resist the lateral loads, namely, moment resisting frame, shear wall, dual system (MRF+ shear wall), tube system, tube in tube, outrigger and belt truss, braced frame, diagrid system and exoskeleton structure, etc. When the number of storeys exceed four, shear wall-frame structures are broadly identified structural systems in Sri Lanka [15]. When a tall building has both shear wall and frame to resist lateral load, the shear wall deflects in bending mode under horizontal load. Shear walls and frames interacting is advantageous for tall buildings, since the connection and stiffness of the floor slab diaphragm and other stabilising elements improve the lateral load resistance.

3. FE modelling of Building Structures

3.1 Structural Details for the Analyses

For the analyses, initial member sizes of columns, beams and slabs are chosen based on the applied gravity load on the building. The thickness of the shear wall is calculated based on the static wind load of the building. The rectangular shape structure shown in Figure 6 is employed for the analyses. A shear core is located at the centre of the building to resist the effects of lateral loads from both directions.

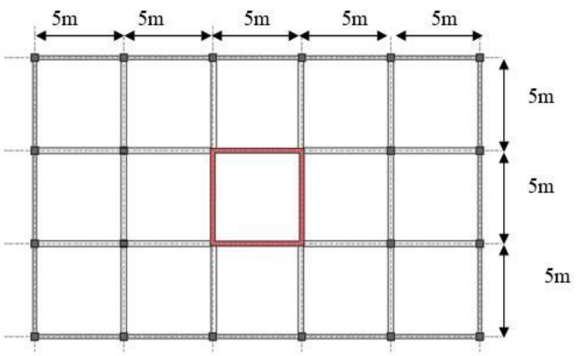


Figure 6 - Wall-Frame Arrangements

Shear walls are typically designed in different shapes on structural plans of a building [16]. However, this study is neither about the shape of the wall nor the location of the wall. Therefore, an internal core wall is provided as given in Table 1. The thickness of the shear wall is calculated based on the requirement of Eurocode (EN 1991 - 1-4: 2009) for the wind load and the deflection limit (H/500) is recommended, where H is the total height of the structure.

Table 1 - Shear Wall Detail with Height

Shear wall shape	Structure height(m)	Number of storeys	Wall thickness (mm)
C-type	17.5	5	200
C-type	35.0	10	200
Square	52.5	15	250

Figure 7 shows the c-type of shear wall used for 5 and 10 storey structures. Figure 8 shows the four side covered square shape shear wall without opening, used in the analysis as mentioned in Table 1.

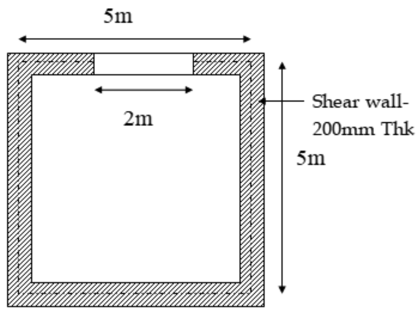


Figure 7 - C-Type Shear Wall

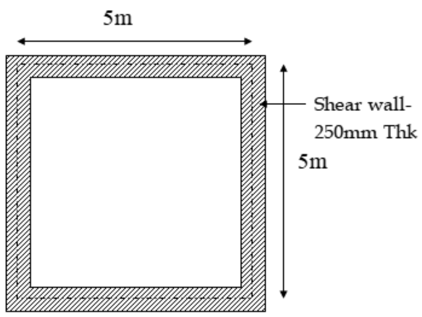


Figure 8 - Square Shape Shear Wall

Three different types of slab systems have been selected for the analyses with the same base area of the building. To study the effect of the lateral stiffness of the slab, each slab structure is virtually modelled with slab stiffness, in order to carry and transfer the lateral loads as well as without slab stiffness using the slab stiffness modifier. The stiffness modifier is provided not to carry the lateral loads by the slab itself. However, it transfers the lateral loads to the wall and frame. The slab details, which are considered in the analyses, are shown in Table 2.

Table 2 - Details of the Slab

Slab type	Slab thickness(mm)
Slab and beam	125
Flat slab	150
Flat slab with drop panel-slab	135
Drop panel (3mx3m)	250

Figure 9 shows the non-linear behaviour of concrete which is used to develop the hinge properties in the analyses as per FEMA 356 guidelines [17]. The material properties of the concrete used in the analysis: compressive strength of concrete= 25 N/mm², poison's ratio=0.2 and density of concrete=24 kN/m³.

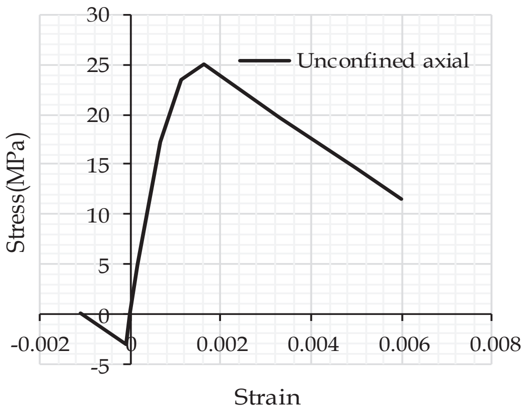


Figure 9 - Nonlinear Behaviour of Concrete

3.2 Selection of Loads

Gravity (dead + live), wind and earthquake loads are applied for each building. Gravity loads are calculated according to EN 1991-actions on the structure. The self-weight of the structure is included in the dead load and the structure is assumed to be a residential building. Therefore, 1.5kN/m² floor load is considered for the live load as per EN 1991- 1-1. The live load reduction factor is not considered in this study.

3.2.1 Selection of Wind Load

The main focus of this research is to study the effects of lateral loads on buildings. The wind load is computed based on EN 1991-1-4:2005 code. In Sri Lanka, there are three wind zones according to wind loading guidelines (see Figure 10). As the Colombo area is selected for this study, zone 3 has been adopted.

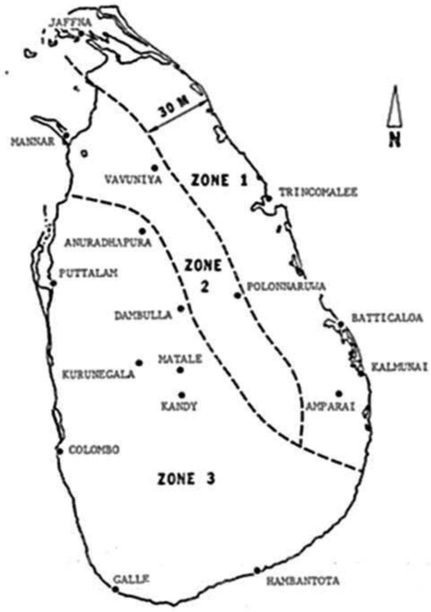


Figure 10 - Wind Zones in Sri Lanka

The wind pressure at the top is calculated for different heights of the structure and is shown in Table 3. 28 m/s ten-minute mean wind speed is selected for the wind pressure calculation for BS EN 1991-1-4:2005 [18].

Table 3 - Wind Pressure at the Top of the Building vs Height

Height of the structure (m)	Number of storeys	Wind pressure (kN/m²)
17.5	05	0.65
35.0	10	0.77
52.5	15	0.84

The wind force acting on the structure varies with the height of the building that is developed by the *ETABS* software. As an example, the 15 storey building's variation of wind profile with the number of storeys is shown in Figure 11.

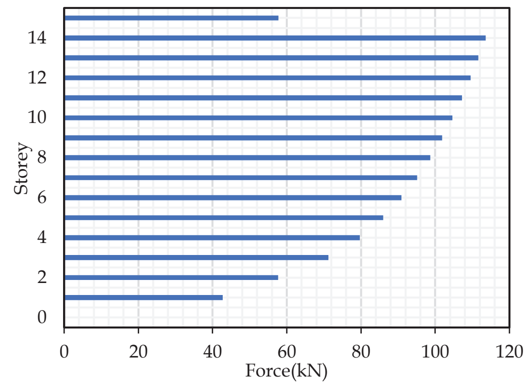


Figure 11 - Applied Wind Profile to the 15th Storey Building for X-Direction

3.2.2 Selection of Ground Motions

Non-linear dynamic analyses are performed to study the effect of seismic force on the building. Non-linear time history analysis is conducted with a selected ground motion. Hence, five sets of ground motion data (Taiwan, 1986; Leriss, 1983; Borah, 1983; Imperial Valley, 1979; Hollistar, 1969) are taken from the PEER database [19]. It is not feasible to use the site-specific/structure-specific ground motion which is taken from PEER directly to the Sri Lankan region. Therefore, scaling is done to suit Sri Lanka's expected ground acceleration spectrum. Consequently, five different earthquake records are selected from the databases which are recorded at different locations in the world.

The baseline correction is carried out first. In order to apply the baseline correction, the acceleration RAW data from PEER, whichever was shifted from zero baselines, are corrected [20]. Subsequently, the selected ground motion data is adjusted to Sri Lankan expected peak ground acceleration using Spectral matching software [21]. Design target spectrum is selected as 0.1g spectral acceleration for the Colombo area [22]. Figure 12 shows the seismic zonation map of Sri Lanka.

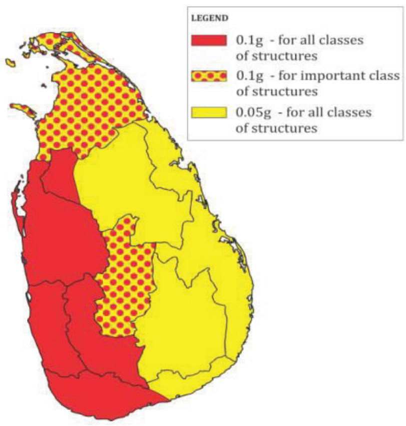


Figure 12 - Seismic Zonation Map (Sri Lanka) [23]

For these analyses, the SRSS (Square Root of Sum of Square) method is used to calculate the maximum structural response. Figure 13 shows the spectral curve is used for the modal response spectrum analyses.

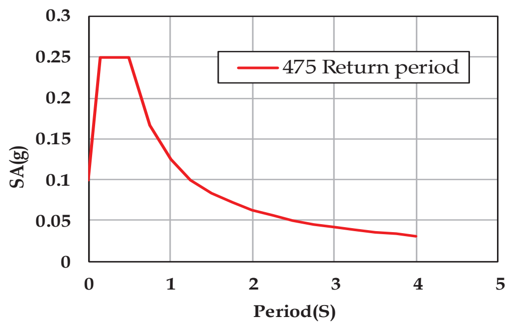


Figure 13 - Spectral Response Curve for Colombo (Sri Lanka) Region [23]

Figure 14 shows the selected unscaled ground motions and Figure 15 shows the matched ground motions which are used for the non-linear time history analyses. As the number of ground motion data selected for the analyses is less than seven, the most unfavourable structural response value is taken into account [24].

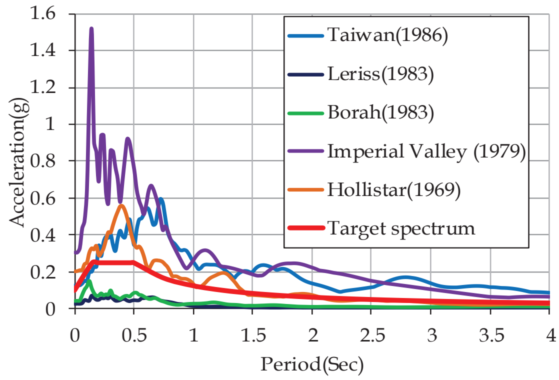


Figure 14 - Selected Unscaled Ground Motions

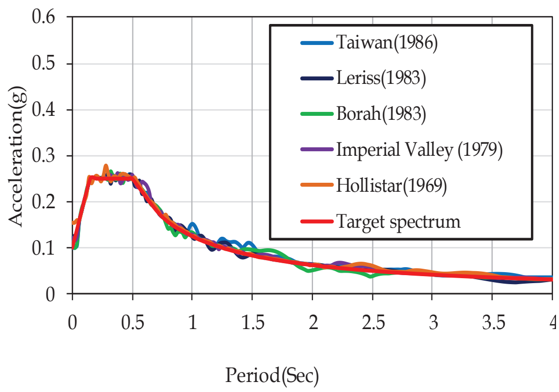


Figure 15 - Matched Ground Motions

3.3 Finite Element Modelling

The Finite Element Model of the structure is modelled in *ETABS* software. The columns and beams are modelled as a frame element whilst the slabs and shear walls are modelled as a thin shell element to account for their stiffness. A semi-rigid diaphragm constraint causes all of its constrained joints to move together as a planar diaphragm and also the stiffness of the slab has to be taken into account for the analyses. The slab and beam, flat slab and flat slab with drop panel floor models are developed. To obtain further effects of analyses, these three structures are modelled with stiffness modifiers where no lateral loads are carried by the slab and whole lateral loads are transferred to the shear wall and frames.

For the non-linear analyses, hinges are assigned for columns and beams (Figure 16) as per FEMA 356 guidelines [17]. Flexural hinges are assigned at the ends of the beam members. P-M-M interaction hinges are set at the ends of the columns to represent the axial force-moment capacity of the columns [25].

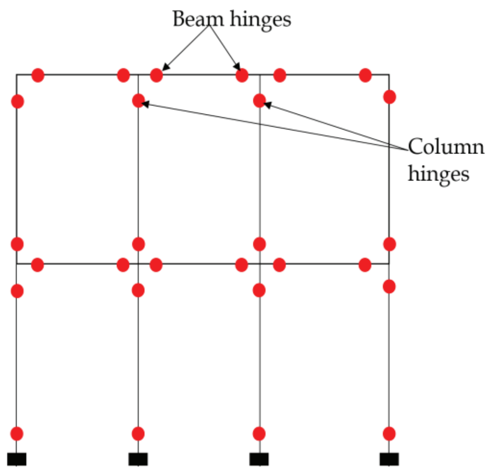


Figure 16 - Non-Linear Hinge Location

4. Numerical Results of Building Structures

To identify the slab lateral stiffness contribution for the lateral loads, four different types (i.e., modal, wind, response spectrum and non-linear time history) of analyses are carried out for slab and beam (SB), slab & beam without slab stiffness (SBWS), flat slab (FS), flat slab without slab stiffness (FSWS), flat slab with drop panel (FSDP), flat slab with drop panel without slab stiffness (FSDPWS), and the structural responses are compared and discussed.

4.1 Modal Analyses

Table 4 shows the first natural frequency of the x and y translation direction from the modal analysis. The natural frequency depends on the mass and the stiffness of the structure. For the analysis, the mass includes all dead loads plus 30% of the live load.

Table 4 - Modal Frequencies (Hz)

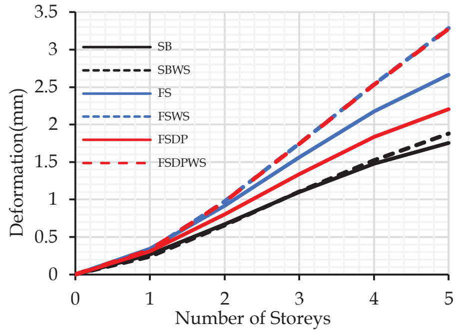
Mode	SB	SBWS	FS	FSWS	FSDP	FSDPWS
5 storey						
1	1.761	1.703	1.552	1.402	1.637	1.34
2	3.554	3.532	3.556	3.492	3.512	3.38
10 storey						
1	0.84	0.794	0.651	0.552	0.98	0.717
2	1.234	1.191	1.096	1.007	1.541	1.321
15 storey						
1	0.749	0.72	0.618	0.48	0.661	0.464
2	0.779	0.747	0.621	0.516	0.668	0.486

Based on the results there is no significant difference shown in model frequencies due to the presence of slab stiffness, and observed variation is also not in order within the various slab systems. However, the presence of slab stiffness increased the structure natural frequency.

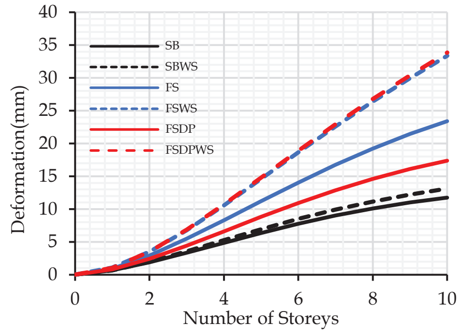
4.2 Wind Analysis

4.2.1 Storey Displacement

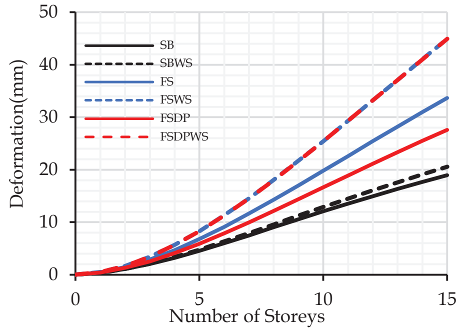
Displacements for wind load in X and Y directions for the SB, SBWS, FS, FSWS, FSDP and FSDPWS models are given separately for 5, 10 and 15 storeys and represented in line graphs as shown in Figures 17 and 18. It is observed that displacements increase with the number of storeys in all types of models for wind loads. The FS is the unfavourable model which displays the maximum displacement for Y direction in 15, 10 and 5 storey, models. SB appears a favourable model with the minimum displacement in both X and Y directions for all 5, 10 and 15 storey models. From the wind load analysis, it is observed that consideration of slab stiffness influences lateral displacement. Figures 17 and 18 show that presence of lateral slab stiffness variates the lateral displacement in the order of FSDP (32.8-54) %> FS (18.9-24.12) % > SB (6.6-7.4) %.



(a) 5 storey structure

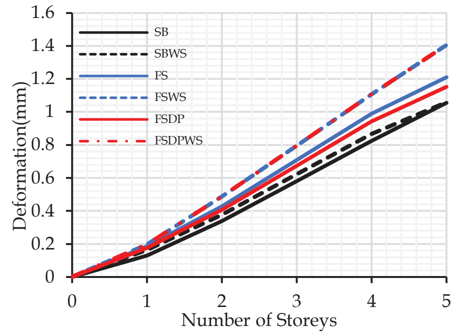


(b) 10 storey structure

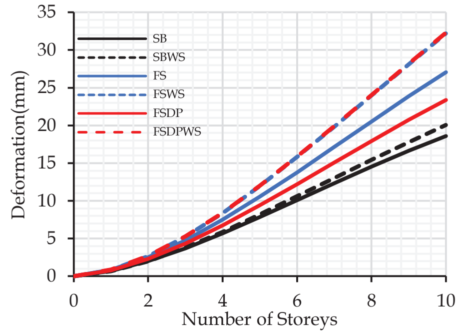


(c) 15 storey structure

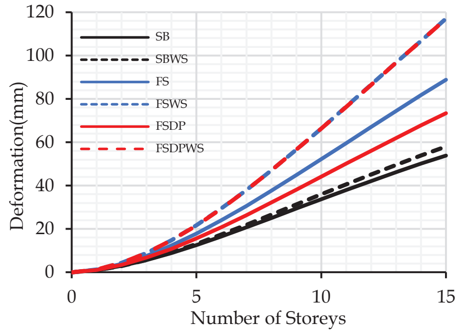
Figure 17 - Variation of Displacement for the Wind Load in the X Direction with the Storey



(a) 5 storey structure



(b) 10 storey structure

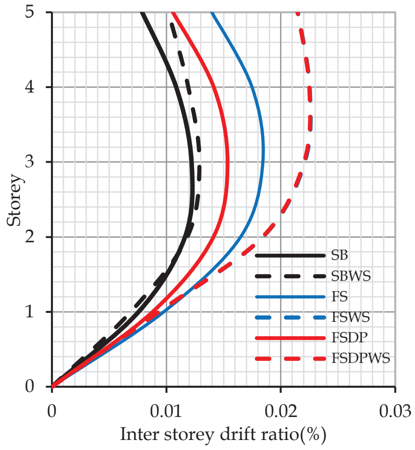


(c) 15 storey structure

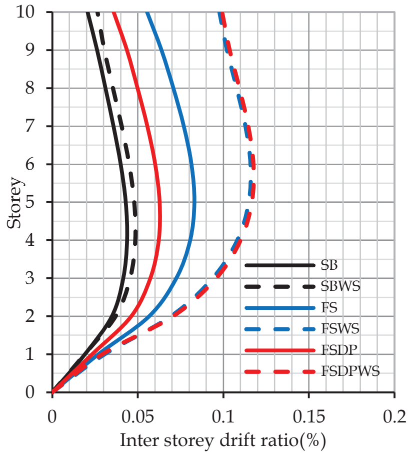
Figure 18 - Variation of Displacement for the Wind Load in the Y Direction with the Storey

4.2.2 Inter Storey Drift Ratio

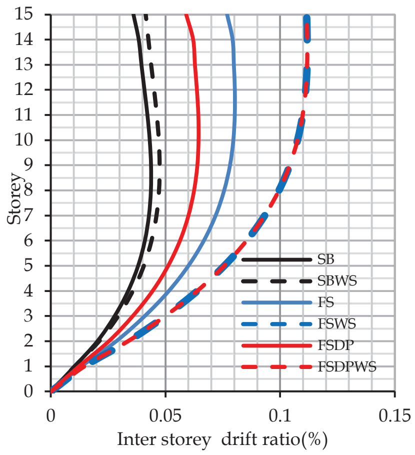
Inter story drift is one of the key parameters for assessing the damage of a structure due to lateral loadings. Inter storey drift ratio is calculated as a percentage by subtracting the maximum lateral displacement of two consecutive floors and divided by the floor height underneath the storey. In this research, the inter-storey drift ratio of 5, 10 and 15 storey models are analysed separately and are shown in Figure 19. It can be seen that inter storey drift ratio increases SB<FSDP< FS. Figures 20, 21 and 22 show the maximum deformation variation percentage of with lateral slab stiffness (LSS) and without lateral slab stiffness (WLSS) of SB structure, FS structure and FSDP structure. Variation of deflection due to the presence of slab stiffness increases with the storey height. The presence of lateral slab stiffness highly variates the lateral displacement in the order of FSDP>FS>SB.



(a) 5 Storey structure



(b) 10 Storey structure



(c) 15 Storey structure

Figure 19 - Variation of Inter Storey Drift Ratio with the Storey

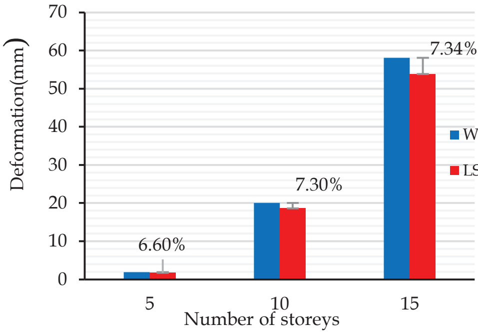


Figure 20 - Variation of Maximum Deflection for with and without Slab Lateral Stiffness of Slab Beam Structure

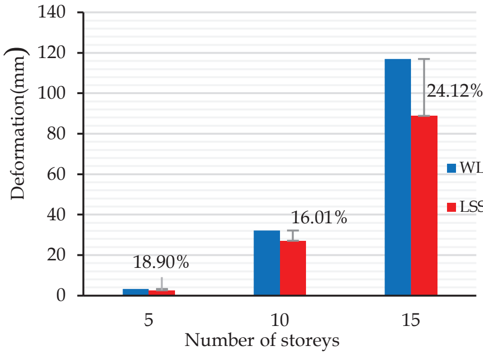


Figure 21 - Variation of Maximum Deflection for with and without Slab Lateral Stiffness of Flat Slab Structure

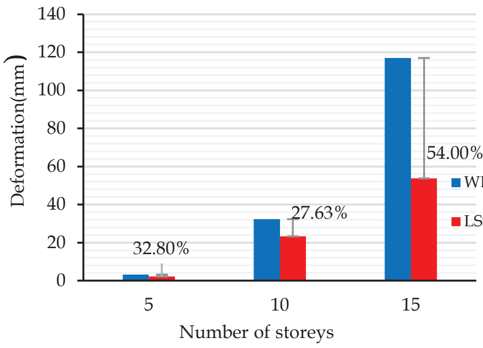


Figure 22 - Variation of Maximum Deflection for with and without Slab Lateral Stiffness of Flat Slab with Drop Panel Structure

4.2.3 Base Shear Distribution

The shear force at the base is mostly resisted by the shear wall; a small amount is resisted by the frame. Tables 5 and 6 show the distribution of shear in X and Y directions, respectively. It is clear from the results that there is not much variation among slab systems in base shear distribution.

Table 5 - Base Shear Distribution of Frame and Shear Wall in the X Direction

Base shear distribution for wind load -X direction (%)						
	SB	SBWS	FS	FSWS	FSDP	FSDPWS
15 Storey						
Wall	93.60	94.40	96.60	97.39	95.20	97.38
Frame	6.40	5.60	3.40	2.61	4.80	2.62
10 Storey						
Wall	92.41	92.90	96.52	96.85	94.67	97.46
Frame	7.59	7.10	3.48	3.15	5.33	2.54
5 Storey						
Wall	94.3	95.1	96.9	95.4	95.7	95.3
Frame	5.7	4.9	3.1	4.55	4.3	4.65

Table 6 - Base Shear Distribution of Frame and Shear Wall in the Y Direction

Base shear distribution for wind load -Y direction (%)						
	SB	SBWS	FS	FSWS	FSDP	FSDPWS
15 Storey						
Wall	93.60	94.40	96.60	97.38	95.20	97.37
Frame	6.40	5.60	3.40	2.62	4.80	2.63
10 Storey						
Wall	94.15	94.92	96.92	97.92	95.48	97.91
Frame	5.85	5.08	3.08	2.08	4.52	2.09
5 Storey						
Wall	94.30	95.10	96.90	96.20	95.70	96.10
Frame	5.70	4.90	3.10	3.70	4.30	3.87

4.3 Modal Response Spectrum Analyses

Figure 23 shows the displacement at the top in X and Y directions for the response spectrum load for 5, 10 and 15 storey structures. According to the response spectrum analysis, slabs with stiffness FS, FSDP, and SB are able to control deformation by 11%, 23% and 32%, respectively, in comparison to slab without lateral stiffness. Since no lateral stiffness contribution from the slab, FSDPWS and FSWS show no variation in the results.

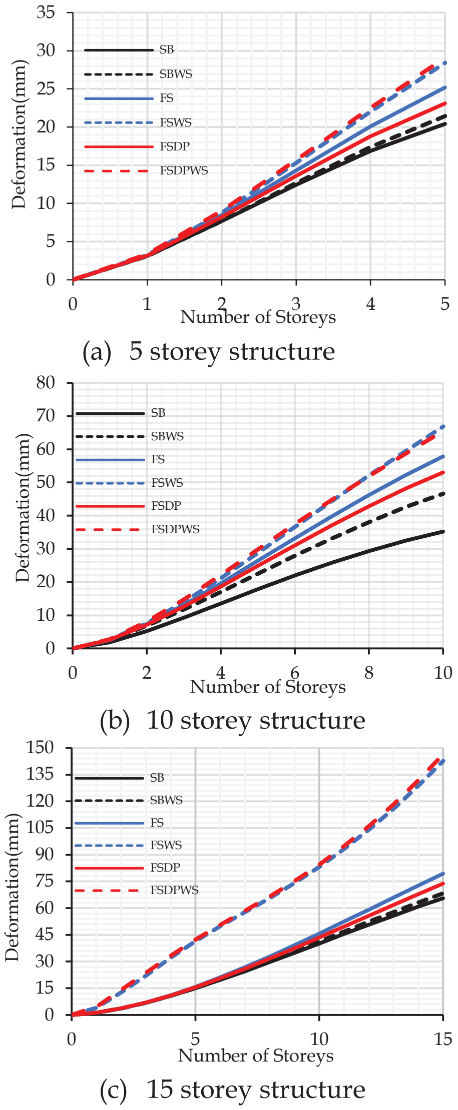
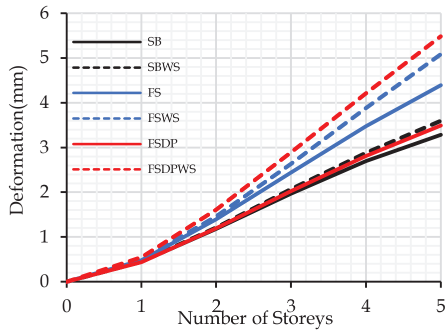


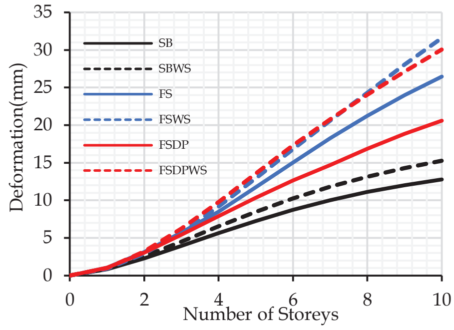
Figure 23 - Variation of Displacement for Response Spectrum Analysis with the Storey

4.4 Nonlinear Time History Analyses

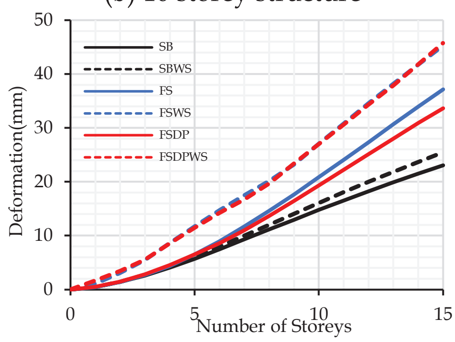
In time history analysis, five ground motions are considered. Based on the five motions, displacements for X and Y directions for each storey are evaluated. For both X and Y directions, maximum displacement for each storey has been taken into account. Figures 24 and 25 portray the displacements in X, Y directions from time history analysis in 5, 10 and 15 storey model structures, respectively. It can be seen that lateral displacement for time history analysis increases as SB>SBWS>FSDP>FS> FSDPWS>FSWS. SB system controls 8.7%, 16.3%, 11.3% of deflection for 5, 10 and 15 storey structures, respectively, compared with SBWS. FS system controls 13.5%, 16.3%, 36% of deflection for 5, 10 and 15 storey structures, respectively, compared with FSWS. FSDP controls 36.3%, 31.5%, 41% of deflection for 5, 10 and 15 storey structures, respectively, compared with FSDPWS.



(a) 5 storey structure

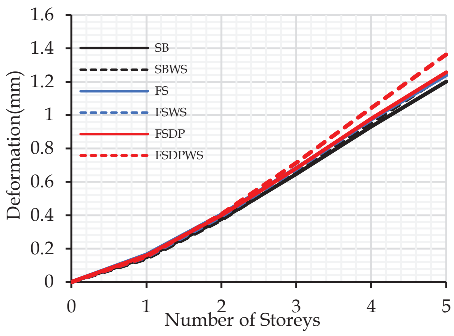


(b) 10 storey structure

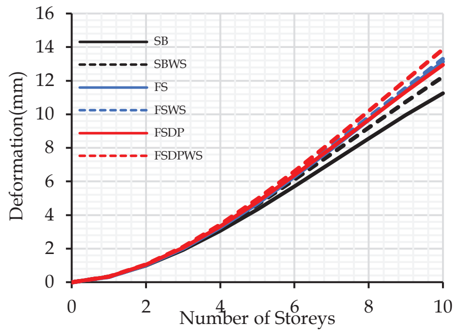


(c) 15 storey structure

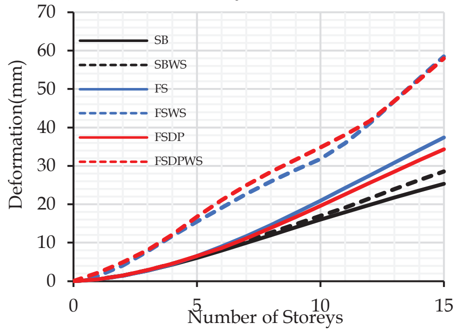
Figure 24 - Variation of Displacement for Non-Linear Time History Analysis in the X Direction with the Storey



(a) 5 storey structure



(b) 10 storey structure



(c) 15 storey structure

Figure 25 - Variation of Displacement for Non-linear Time History Analysis in the Y Direction with the Storey

5. Discussion and Recommendation for Selection of Slab System for Lateral Loadings

The stiffness and mass of the building affect the natural frequencies. If the building is stiff, the natural frequencies will be high. Although stiffness influences, it is difficult to compare the results of natural frequencies from the model analyses because the mass of each model is different. For the 5 and 10 storey buildings, the C type of shear wall is used. Therefore, the Y direction translation mode shows a higher modal frequency than the X direction (weaker direction of C shape shear wall).

Deflection and inter storey drift of the structure are highly reduced when considering slab lateral stiffness. The reducing ratio is increased with structure height for static wind analysis, modal response spectrum analysis and non-linear time history analysis. The deflection and inter-storey drift are compared from static wind analysis, modal response spectrum analysis and non-linear time history analysis. SB floor structure shows the best performance than the other five structures by controlling the deflection for 5, 10 and 15 storeys, compared with FS and FSDP. The deflection and inter-storey drift of FS is slightly higher than the

FSDP structures for wind forces. The results indicate that the performance of flat slab structures is very poor. By considering slab stiffness, FSDP system helps to control the deflection more effectively than SB and FS systems.

Based on the shear distribution to the wall and frame, the shear wall and frame receive a high percentage of lateral loads since the selected wall structure is stiffer. However, the percentage of distribution between the wall and the frame slightly varies with each floor system. For the FS system, a huge amount of lateral loads is transferred to the wall than the other floor structures, followed by the FSDP, SBWS and SB structures, even though there is not much significant variation in the base shear values of each slab system. In consideration of the slab stiffness for lateral loads, it is observed that the structure's response of base shear (for the design of ULS) shows less variation than the deflection and the inter storey drift (for the SLS).

6. Conclusions

This paper presents the outcome of the contribution of slab systems for lateral loads and how it varies for different types of slabs. Based on the structural responses obtained from the analysis, the following conclusions can be drawn.

Results of the analysis indicate that the slab stiffness contribution does not significantly influence the ultimate limit state design, while the service limit state design may be affected significantly. From various types of analysis results, it can be concluded that the structural performance of the building with different types of slab system varies in the order of SB>FSDP>FS. FSDP with slab stiffness will greatly enhance the structure's performance by (30-55) %when compared with FS (15-35) % and SB (5-15) % for the lateral loads based on the structure height. Further, some types of slabs such as the waffle slab, hollow core slab, precast slab panels, etc., need to be explored for the stiffness contribution for the lateral loads in future studies.

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