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Research Article

Effect of Shear Wall in the Seismic Analysis of Building Frames Considering Soil Structure Interaction–A Study by Winklerian Approach

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Abstract

The significance of incorporating soil-structure interaction (SSI) effect in the analysis of building frames is increasingly recognized but, still not penetrated to all the level owing to various complexities involved in the modeling of SSI. The SSI effect considerably influences the design of multi-storey buildings situated in the seismic zone. Hence, there is a need to incorporate certain elements in the structure which will counterbalance the effect of SSI. The provision of shear walls is one of the potential option as these acts as major earthquake resisting element and also, increases the overall stiffness of the structure. The geometrical configuration of these shear walls alters the response of buildings, and therefore, it is important to evaluate the most beneficial locations of the shear walls. In present study, multi-storey reinforced concrete framed buildings of different heights with shear wall at five alternate locations in the building incorporating the effect of soil flexibility is considered to investigate the effectiveness of shear walls to control SSI. The study is carried out using Winklerian approach. The study reveals that, shear walls play important role to control SSI effect and very effective when placed centrally, near to centroid of building in resisting seismic load.

Keywords: *Shear wall, Soil structure interaction, Natural period, Base shear, Winklerian approach.*

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1. Introduction

Normally the conventional structural analysis of a RC space frame is carried out assuming base of building frame to be fixed and by neglecting the effect of soil flexibility. However, in practice the building frames always rest on deformable soil resulting in redistribution of forces and moments due to SSI effect, caused not only by the response of the superstructure, but also by the response of the subsoil beneath. Thus, conventional analysis is unrealistic and therefore, may be unsafe also in many cases. Applying SSI effects enables the civil engineers to evaluate the realistic performance of the soil-structure system under seismic motion. It is observed that the SSI effect is more pronounced in case of multi-storied buildings resting on soft soil and may become further aggravated when such buildings are subjected to seismic influence.

Therefore, under such circumstances there is a need of investigation of the certain provisions in the structure to improve the performance under the flexible base conditions. From the literature it is inferred that the SSI effect is possible to counterbalance by increasing the stiffness of the structure. Reinforced concrete shear walls are one of the options which effectively control the SSI effect.

Shear walls are generally used in the building to control the detrimental effect of earthquake. Shear walls have very high in-plane stiffness and strength, which can be used to simultaneously resist large thrust and to support gravity loads, thus, making shear wall quite advantageous in many structural applications. Thus, shear wall are one of the excellent means of providing earthquake resistance to multistoried reinforced concrete building. When shear wall are situated in advantageous positions in the building, they can form an efficient lateral force resisting system.

In present work, a comparison is made between building frames resting on fixed base and flexible condition. The buildings with flexible base condition are further studied by incorporating the shear wall at various locations to evaluate its effectiveness to control the SSI effect. In view of this, the building is carried out in three stages, namely, (1) Frame with Fixed Base, (2) Frame with Flexible Base (Spring Model), (3) Frames with Flexible Base incorporating Shear Wall. The study is made to describe the effect of insertion of shear wall on SSI. The effectiveness of shear wall locations in

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*Corresponding author **Tambake R.N.** is a P.G. Student; **Dr. Halkude S.A.** is working as Principal and **Kalyanshetti M.G.** as Assistant Professor buildings is also investigated to identify the most beneficial location to control SSI effect.

2. Building Frames Considered For Analysis

The symmetric 3 × 3 bay reinforced concrete building frames of G+5, G+7, G+10, and G+12 storeys resting on isolated footing are considered in present analysis. Buildings constitute ordinary moment resisting frames of 3 bays of equal length of 4 m in each direction with storey height of 3 m. Shear walls with thickness varying from 150 to 250mm were considered at various locations in the plan.

Building components dimensions are evaluated on the basis of structural design in accordance with IS 456:2000 considering M25 concrete and Fe 415 steel. These details of building frames are given in Table 1. The thickness of slab is taken as 0.15m and beam dimensions as 0.30 × 0.45m.

Table 1 Dimension of Components of Building

Bldg. Frame	Description	Column (m × m)	Shear Wall Thickness (m)	Footing Size (m× m ×m)
G+5	For 4-6 storey	0.30 × 0.40	0.15	2.05 × 1.90 × 0.45
	Up to 3 storey	0.30 × 0.45		
G+7	For 6-8 storey	0.30 × 0.40	0.15	2.35 × 2.15 ×0.5
	For 4-6 storey	0.30 × 0.45		
	Up to 3 storey	0.30 × 0.50		
G+10	For 10-11 storey	0.30 × 0.40	0.2	2.75 × 2.55 × 0.5
	For 5-9 storey	0.30 × 0.45		
	Up to 4 storey	0.30 × 0.50		
G+12	For 11-13 storey	0.30 × 0.40	0.25	3.0 × 2.8 × 0.8
	For 8-10 storey	0.30 × 0.45		
	For 4-7 storey	0.30 × 0.50		
	Up to 3 storey	0.30 × 0.55		

Dr. S.A. Halkude et al [2015] studied the effect of shear wall at various locations with varying percentage. The study reveals that, for square type of building the shear wall shall be provided equally (i.e. 50-50%) in both directions of buildings. Length of shear wall in the range of 10 to 20% of plan dimension shows efficient seismic performance.

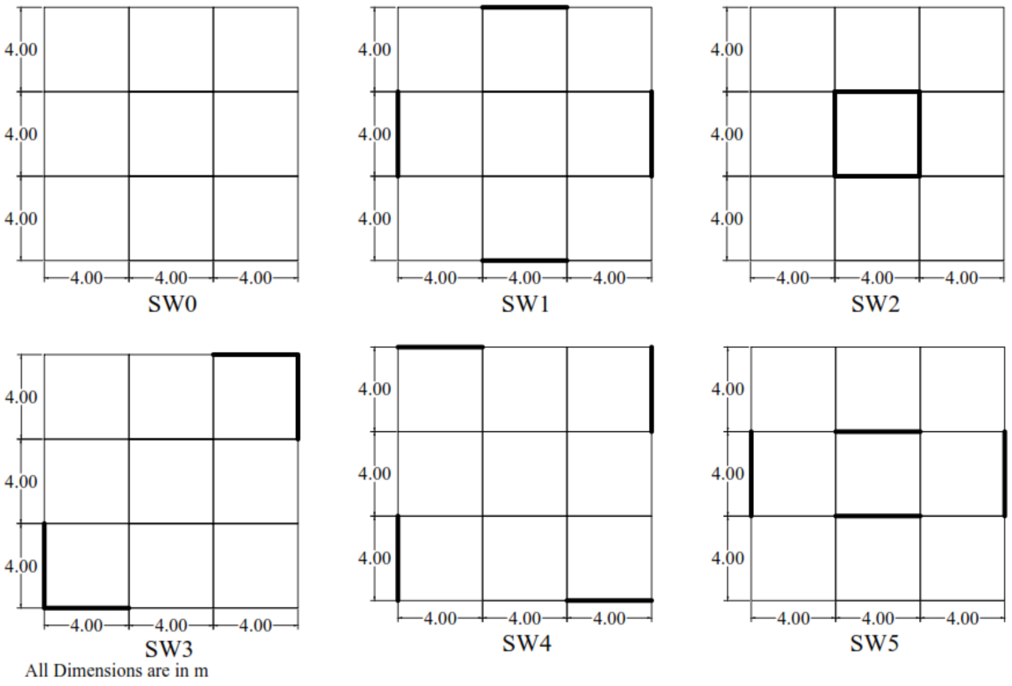

Fig.1 Various Locations of Shear Wall in the Building Frame

So, for the present study shear walls were placed such that the area of shear wall in both principal directions remains the same and symmetric with length almost 20% of plan dimension. These considerations are given in Fig 1. Buildings frames without shear wall are denoted as "SW0" and frames with shear wall at different locations as "SW1, SW2, SW3, SW4, and SW5" are represented schematically in Fig. 1.

3. Footing Idealization (Spring Model)

The soil mass in the influence zone below the footing is idealized as a spring of equivalent stiffness with six DOF, three in translation and three in rotation in all three directions using the Winklerian approach. Soil is treated as a homogenous, isotropic, and elastic. This idealization is shown in Fig. 2.

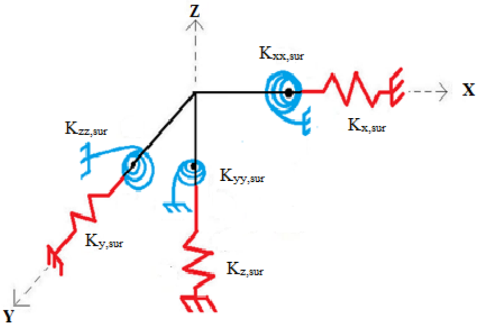

Fig.2 Equivalent Spring Stiffness

FEMA (Federal Emergency Management Agency) with ASCE (American society of Civil Engineering) presented a document FEMA 356 / November 2000 - Prestandard and Commentary for the Seismic Rehabilitation of Buildings has derived and presented the equivalent soil stiffness in terms of formulae and charts for foundation stiffness at surface and for embedment. A complete set of algebraic formulas and dimensionless charts is presented for readily computing the dynamic stiffness (K) of foundations. At the base of footing springs are provided to simulate the flexibility of soil. The spring stiffness is given in Table 2.

Table 2 Spring Stiffness (FEMA 356 (2000))

Degree of Freedom	Stiffness of foundation at surface
Translation along X-axis	$K_{x,sur} = \frac{GB}{2-\mu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right]$
Translation along Y-axis	$K_{y,sur} = \frac{GB}{2-\mu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 0.4\left(\frac{L}{B}\right) + 0.8\right]$
Translation along Z-axis	$K_{z,sur} = \frac{GB}{1-\mu}\left[1.55\left(\frac{L}{B}\right)^{0.75} + 0.8\right]$
Rocking about X-axis	$K_{xx,sur} = \frac{GB^3}{1-\mu}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$
Rocking about Y-axis	$K_{yy,sur} = \frac{GB^3}{1-\mu}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$
Torsion about Z-axis	$K_{zz,sur} = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45} + 0.51\right]$

Where,
$K_{x,sur}$, $K_{y,sur}$, $K_{z,sur}$ = Stiffness of equivalent soil springs along the translational DOF along X,Y and Z axis, $K_{xx,sur}$, $K_{yy,sur}$, $K_{zz,sur}$ = Stiffness of equivalent rotational soil springs along the rotational DOF along X,Y and Z axis, L= Length of footing, B= Breath of footing, G= Shear modulus, μ= Poison's Ratio.

Building frames are considered to be resting on Soft Soil with Modulus of Elasticity 15000 (kN/m^2), Poisson's Ratio 0.4 (μ) as per Bowel's. The Unit Weight (γ) of soil is considered as 16 (kN/m^3).
The values of equivalent stiffness along 6 DOF for all building frames are calculated as per FEMA-356 (2000) Guidelines and are shown in Table 3.

Table 3 Soil Stiffness for Soft Soil (FEMA-356 (2000))

Degree of Freedom		Stiffness of foundation at surface (kN/m)			
		G+5	G+7	G+10	G+12
$K_{x,sur}$	Horizontal (longitudinal direction)	30358.51	34570.62	40734.84	44586.98
$K_{y,sur}$	Horizontal (lateral direction)	30559.40	34838.47	41002.69	44854.84
$K_{z,sur}$	Vertical	41408.11	47164.25	55560.64	60807.89
$K_{xx,sur}$	Rocking (about the longitudinal)	32554.46	47669.53	78668.64	103600.00
$K_{yy,sur}$	Rocking (about the lateral)	31479.22	46957.80	76018.30	99182.33
$K_{zz,sur}$	Torsion	42199.36	62241.70	101948.95	133782.24

4. Formulation of Problem

The analysis of building frames with spring model mentioned above is carried out using software package (SAP2000 V15) in accordance with IS: 1893-2002 [5] considering Z (Zone Factor) =0.16 (zone-3), I (Importance Factor) =1 (All other buildings), R (Response Reduction Factor) =3 (Ordinary RC moment-resisting frame). A typical building frame with spring model without and with shear wall is shown in Fig. 3 and Fig. 4 respectively.

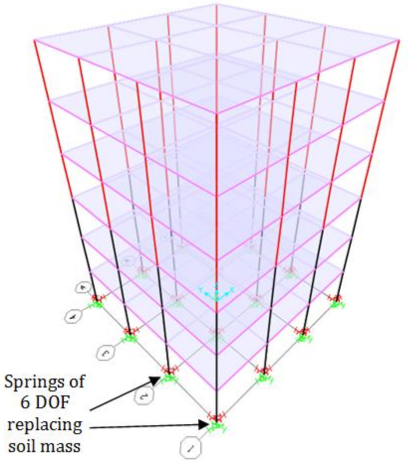

Fig.3 Spring Model without Shear Wall

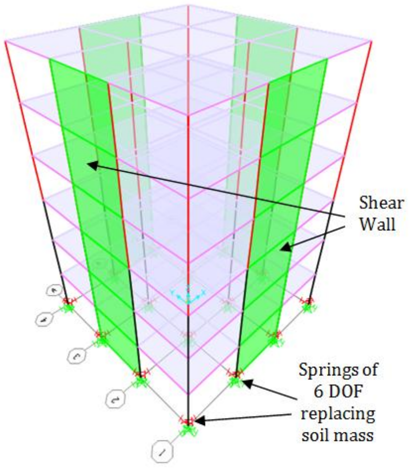

Fig.4 Spring Model with Shear Wall

4.1 Parametric Variations

The SSI analysis is carried out assuming the structure, shear wall and soil to act as a single compatible structural unit and to behave in linear elastic manner. The following notations are used for building frames with different base conditions and with different shear wall locations;

1) FIX- Fixed Base Frame
2) SSW0- Spring Model without Shear Wall
3) SSW1- Spring Model with SW1 configuration
4) SSW2- Spring Model with SW2 configuration
5) SSW3- Spring Model with SW3 configuration
6) SSW4- Spring Model with SW4 configuration
7) SSW5- Spring Model with SW5 configuration

The seismic analysis is carried out as per the equivalent lateral load method of IS 1893 (Part 1): 2002. The different load combinations of dead load (DL), live load (LL) and seismic load (EL) are considered as per Clause 6.3.1.2 of IS 1893 (Part 1): 2002 and the maximum value is considered for the study.

5. Results and Discussions

In present work, a comparison is made between building frames resting on fixed base and flexible base to understand the effects of SSI. The buildings with flexible base condition are further studied by incorporating the shear wall at various locations to evaluate its effectiveness to control the SSI effect. The structures are analyzed so as to study the dynamic parameters such as Natural Time Periods, Base Shear and structural parameters such as Beam Moment, Column Moment and Column Axial Force using Equivalent Static Method as per IS 1893(Part 1) : 2002. The results are discussed to highlight the effect of shear wall.

5.1 Natural Time Period

Natural time period is a primary parameter which regulates the seismic lateral response of the building frames. Thus evaluation of this parameter without considering SSI may cause serious error in seismic design. The modification in natural period due to the soil–structure interaction effect is studied on a G+5, G+7, G+10, G+12 storey buildings, resting on soft soil. The variation in natural period for fixed base condition and flexible base condition are presented. The effect of shear wall is also studied by placing shear wall at various locations in flexible base frame. The results are presented in Fig. 5.

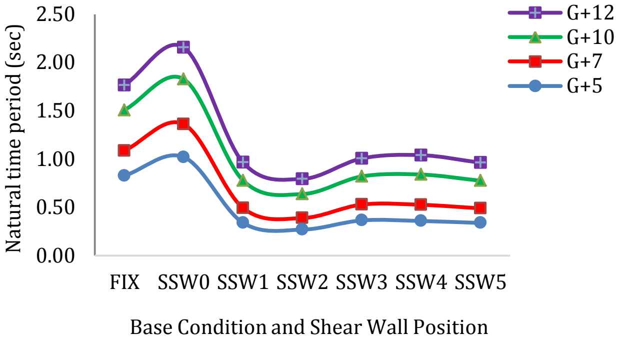

Fig. 5 Variation of Natural Time Period

- It is observed from Fig. 5 that, the SSI increases the natural time period of the building. For given base condition natural time period increases with increasing storey height. Due to support flexibility time period increases thus, SSI increases the time period. However, due to insertion of shear wall it reduces suddenly.
- The study shows that the SSI increases the fundamental natural time period of the building by 20% to 25% as compared to fixed base condition. However, incorporation of shear wall decreases the natural time period by 55% to 65% as compared to flexible base for the different configuration of shear wall.
- The SSW2 configuration shows the lowest time period for all building frames signifying its effectiveness to control the SSI effect.

5.2 Base Shear

One of the primary inputs considered for seismic design is Seismic base shear. Base shear is stated as; the maximum expected lateral force that is likely to occur at the base of a structure due to seismic ground motion The effect of SSI on base shear of building frames is presented in Fig. 6.

- It is observed from Fig. 6 that, Base shear of building is increases by 25% to 30% due to SSI effect except in case of G+5 building where it reduces by @ 23%.
- Shear wall insertion increases the base shear as compared to SSI case. For G +5 and G+7 building the percentage increase in base shear is about 150% and 95% respectively which remains almost constant for all the configurations of shear wall. Thus, in case of low rise building frames the location of shear wall is observed to be not significant.

- For G+10 and G+12 building the base shear increases almost by 150 to 200 %. Therefore the percentage increase in the base shear due to shear wall is higher for high rise building
- Among all the position of shear wall, SSW2 and SSW3 shows relatively more values of base shear for high rise buildings.

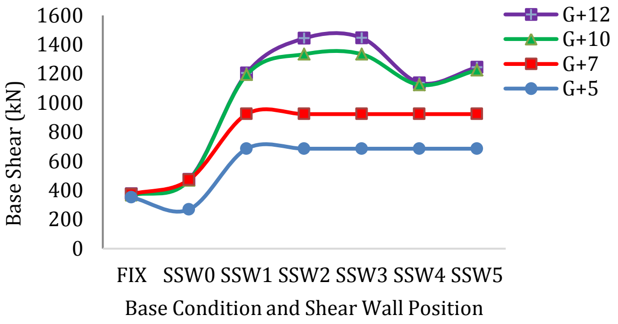

Fig. 6 Variation of Base Shear

5.3 Beam Bending Moment

The comparison of beam bending moment for bare frames and building with frame-shear wall is studied and shown in Fig. 7.

Fig. 7 Variation of Beam Bending Moment

- The study shows that SSI incorporation increases the beam bending moment by around 40% to 60% in all the building frames.
- Due to insertion of shear wall in the flexible base frame the beam bending moment is decreased by 20% to 40% for G+5 and G+7 and in case of G+10and G+12 building it is increased by almost 20% to 70 % highest being for SSW3 configuration. Thus, in case of low rise building the shear wall effect is more advantageously observed as it leads to reduction in bending moment than high rise building where bending moment increases.
- Shear wall frames with SW2 and SW5 configuration shows comparatively lesser beam bending moment values signifying its effectiveness.

5.4 Column Bending Moment

The effect of SSI and shear wall inclusion on column bending moment on building frames is studied and shown in graphical form in Fig. 8.

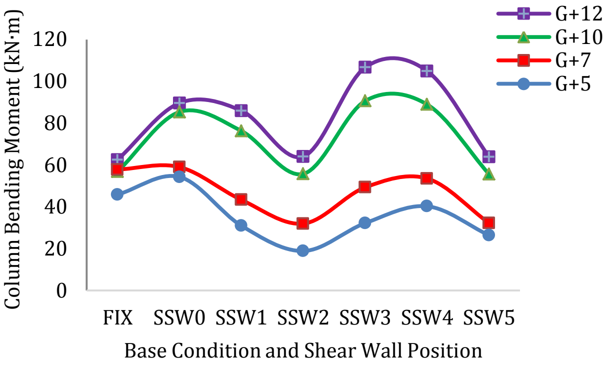

Fig. 8 Variation of Column Bending Moment

- From Fig. 8, it is observed that the column bending moment increases by around 20% for G+5 to 50% for G+12 due to SSI effect; thus, showing more increase in high rise buildings.
- Due to insertion of shear wall in the building, the column bending moment is observed to be decreased thus, reducing SSI effect. Addition of shear walls decreases the column bending moment for SSW1, SSW2, SSW5 whereas; it increases for cases SSW3 and SSW4, due to peripheral shear walls.
- The highest percentage decrease in column bending moment is observed for SSW2 configuration which is in the range of 60-65 % for G+5 and G +7 building and 25 – 35 % in case of G+10 and G+12 building. Thus, the shear wall frame cases SSW2 and SSW5 shows lesser column bending moment compared to other shear wall configured frames.

5.5 Column Axial Force

Variations of column axial force for fixed and flexible base condition are compared to understand the SSI effect. Then, in frames with flexible base condition shear walls are provided at different locations to evaluate its effectiveness. The effect of SSI and shear wall inclusion on column axial force on building frames is studied and the results are represented in Fig. 9.

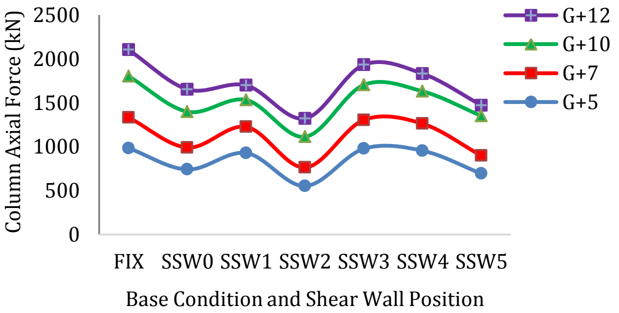

Fig. 9 Variation of Column Axial Force for Different Building Frames

- From the observations it is revealed that, due to SSI effect the column axial force is decreased by 20% to 25%.

- The above study shows that, the SSI effect cause significant reduction in axial force. Insertion of shear wall in flexible base frame increases the axial force in SSW1, SSW3 and SSW4 whereas; it marginally decreases in case of SSW2 and SSW5. Thus, cases SSW2 and SSW5 are observed to be effective in reducing the axial force.

6. Conclusion

The present study makes an effort to evaluate the effect of SSI on the buildings frames of varying heights resting on isolated footing. The study is also carried out on flexible base building frames with shear wall placed at various locations in view of identifying the most beneficial position to control SSI. The results of the study lead to the following conclusions.

1) Fundamental natural time period of the soil-structure system are more than the values of the same building with fixed-base. It increases with increase in height of the building. Thus, evaluation of natural time period without considering SSI may cause serious failure in seismic design. It also reflects that, natural time period decreases with insertion of shear walls. Thus, it is possible to control SSI by providing shear wall.

2) The parameters beam bending moment and column bending moment are observed to be increased due to SSI effect while due to shear wall incorporation these parameters decrease. Thus, it can be inferred that, shear wall plays important role to control SSI effect and can be conveniently used in the building frame to improve the seismic performance.

3) The study reveals that, the soil flexibility alters forces in the member of structures. However, addition of shear walls counter balances the SSI effect by providing additional stiffness to resist the lateral earthquake forces. Thus, to reduce the SSI effect, structures with shear wall are found very useful.

4) The usefulness of shear wall provision is observed to be more significant in case of high rise building as the increase in the time period due to SSI is effectively controlled in case of high rise buildings as compared to low rise buildings.

5) By providing shear walls in proper position, effects and damages due to earthquake and winds can be minimized. The results reveal that, the case SSW2 have advantageous position of shear walls i.e. the shear wall placed centrally, near to centroid of building shows effective resistance to seismic load. While Placing Shear wall away from centre of gravity resulted in increase in most of the member forces. Shear wall at the periphery of the structure i.e. away from C.G. of the building shows relatively adverse effect as compared to shear wall placed near core of the building.

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