# Effect of subsoil on the seismic response of the setback buildings

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**Abstract.** From previous studies it is observed that due to the effect of the earthquake, irregular buildings fail vulnerably. Further the effect of soil where the building has been founded also plays an important role in the behaviour of the buildings. Soil structure interaction (SSI) has been carried out, because conventional fixed-base analysis ignoring the effect of soil-flexibility may result in unsafe design. In this present study behaviour of setback buildings with SSI has been measured experimentally, for this a five-storey building was considered founded on very soft soil having density 1470kg/m$^3$ with the help of pile foundation. Buildings, soil and also pile foundation has been scaled down according to suitable scaling laws. The scaled building models are subjected to vibrations at resonant frequencies using shake table facility. Results such as resonant frequency, time period, displacements are presented.

**Keywords:** Regular Building, Setback building, Prototype, Scaled Model, Resonance, Soil Structure Interaction.

## 1 Introduction

Earthquake is the most devastating and random phenomenon in nature. Many Stepped buildings which are vertically irregular in nature have been constructed in order to enhance the aesthetic view; these vertically irregular buildings are commonly called as setback buildings as shown in Fig. 1. Setback buildings have vertically discontinuities with respect to geometry. However, geometric irregularity also introduces discontinuity in the distribution of mass, stiffness and strength along the vertical direction, thereby results in the failure of the structure. In this present study a five-storey setback R.C buildings have been analysed when subjected to sinusoidal ground motion experimentally. In order to observe their behaviour experimentally, these buildings are scaled down using scaling laws.

Most of the buildings are directly in contact with the soil. In the seismic analysis of a buildings founded on ground, the ground motion passes to the base of buildings and then loads on buildings. The response of the foundation system affects the response of the structure and vice versa, which is called dynamical soil-structure interaction (SSI). Soil structure interaction plays an important role in seismic response of the structure by altering the dynamic properties of the system. From the previous studies it is observed that influence of the under-laying soil on the seismic response of the structure can be neglected when the ground is stiff enough, and consequently the structure can be analysed considering fixed base conditions. However, the same structure behaves differently when it is constructed on the soft soil deposits.

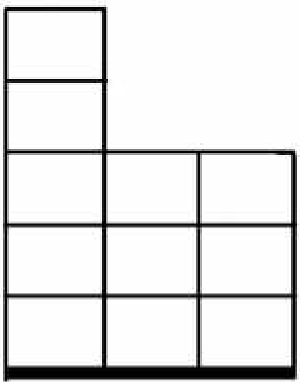
(a) Setback Building

(b) Stepped setback building

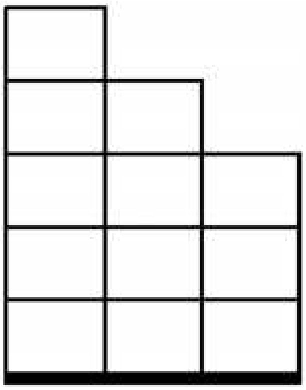
Fig. 1 Setback Building

In this study a five storey vertically irregular RC buildings were considered which can be called as setback building and stepped setback building to observe their behaviour considering SSI experimentally.

Figure 2 shows the building geometries considered in the present study along with their plan at base as shown in Fig. 3. These irregular buildings have a uniform storey height of 3m.



(a) Setback Building



(b) Stepped setback building

• Fig. 2 Building elevation of setback building

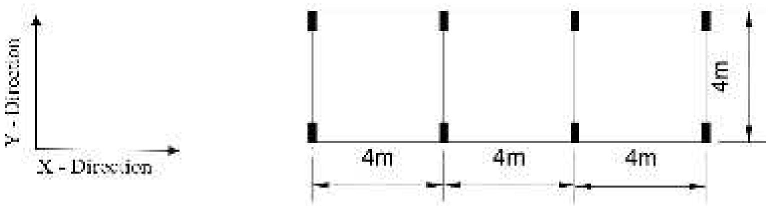



Fig. 3 Plan of the building along with column orientation

The RC building shown in Fig.2 are designed according to IS: 1893(Part 1)-2016 and IS: 456-2000. While designing it has been considered that the first mode of vibration is obtained along longitudinal direction (X-axis). Live load of 3kN/$m^2$ and floor finish of 1 kN/$m^2$ is considered at each floor. At roof, live load of 1.5kN/$m^2$ and floor finish of 2kN/$m^2$ is considered in design of these buildings. Table 1 shows the dynamic details of the buildings considered for the present study. Table 2 shows the details of the designed structural elements of the buildings.

**Table 1.** Dynamic properties of the building

| Sl. No. | Contents | Description |
|---|---|---|
| 1 | Structure | SMRF |
| 2 | Seismic Zone | V |
| 3 | Importance factor | 1 |
| 4 | Type of soil | I |

**Table 2.** Details of structural elements of the building**.**

| Sl. No. | Contents | Description |
|---|---|---|
| 1 | Slab thickness | 150mm |
| 2 | Beams dimension | 300mm X 400mm |
| 3 | Columns dimension | 250mm X 600mm |

The soil medium beneath the structures is a clayey soil as shown in Table 3. The peak load that can be carried by the pile or at which the pile continues to sink without further increase in load is known to be as ultimate bearing capacity of pile or ultimate bearing resistance of pile. Safe load that can be carried by the pile is called as its allowable load and it is obtained by dividing ultimate bearing capacity of pile by factor of safety of 2.5.

**Table 3.** Properties of the soil

| Sl. No. | Contents | Description |
|---|---|---|
| 1 | Young’s modulus | 25MPa |
| 2 | Poisson’s ratio | 0.4 |
| 3 | Density of soil | 1470kg/$m^3$. |
| 4 | Shear wave velocity | 200m/sec |

A friction type of pile group is adopted in this study which is having a pile group of 1 x 2(Fig. 4) A square pile foundation of M25 grade concrete has been designed according to IS:456-2000 and BS: 8110 (part 1). Table 4 shows the details of the piles and pile cap.

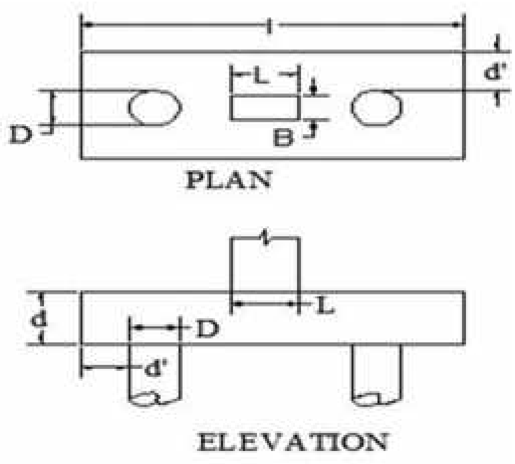



**Fig. 4.** Pile cap

**Table 4.** Size of pile and pile cap

| Sl. No. | Contents | Description |
|---|---|---|
| 1 | Pile size | 0.7m x 0.7m |
| 2 | Pile length | 9.6m |
| 3 | Pile spacing | 3 times the pile size |
| 4 | Pile cap size | 1.4m X 3.5m X 0.7m |

## 2 Scaling of the building and soil

Here after regular R.C. building is called as prototype and scaled down model is called as scaled model. The critical part for the experimental study was to develop an experimental model which is able to represent prototype with less degree of distortion, so geometric scaling, dynamic scaling and material scaling have been chosen properly in the present study. Table 5 shows the parameters for scaling along with scale factor.

**Table 5.** Scaling relationships in terms of geometric scaling factor (Aslan et al. 2014)

| Sl. No. | Parameters | Scale Factor |
|---|---|---|
| 1 | Mass density | 1 |
| 2 | Stiffness | $S^2$ |
| 3 | Force | $S^3$ |
| 4 | Modulus | S |
| 5 | Acceleration | 1 |
| 6 | Frequency | $S^{-1/2}$ |
| 7 | Time | $S^{1/2}$ |
| 8 | Shear wave velocity | $S^{1/2}$ |
| 9 | Length | S |
| 10 | Stress | S |
| 11 | Strain | 1 |
| 12 | EI | $S^5$ |

Adopting an appropriate geometric scale factor is one of the important steps in scale modelling on shake table, a scale factor of 30 is adopted. The appropriate modulus of elasticity of concrete have been adopted and also taken care that it has to be help full in fabrication of the model. Table 6 shows the geometric and material properties of the scaled model.

**Table 6.** Geometric and material properties of scaled model

| Sl. No. | Parameters | Scale Factor |
|---|---|---|
| 1 | No. of story's | 5 |
| 2 | Storey height | 0.1m |
| 3 | Bay width (X-axis) | 0.133m |
| 4 | Bay width (Y-axis) | 0.133m |
| 5 | Slab thickness | 11mm |
| 6 | Size of Columns | 2mm x 12mm |
| 7 | Material | Aluminium |

**Table 7.** Mass by volume ratios of all the models

| Sl. No. | Description | Setback Building | Stepped Setback Building |
|---|---|---|---|
| 1 | Scaled Model | 335.42k[illegible] | 335.26 k[illegible] |
| 2 | Prototype | 350.13k[illegible] | 343.33k[illegible] |

The mass by volume ratios of the prototype to scaled model are considered such that dynamic similarity is achieved and these are presented in Table 7. According to scaling relations (Table 5).

The thickness of slabs and column dimensions are shown in Table 6. For connection between slabs to columns, bolts of 6mm diameter are used. 4 numbers of exterior columns are connected with 6 mm diameter bolts which are driven in to the plates. At the junction i.e., at the connection of the plates with the interior columns small angle sections with the bolts are employed, as shown in the Fig 5. Base plate is adopted of same thickness to connect scaled model to shake table using 10mm diameter bolts placed at 100mm centre to centre as shown in fig. 5.

(a)Set back

(b)Stepped set back

**Fig. 5.** Experimental setup of setback models

## 2.1 Scaling of soil

Adopting the soil scaling mix which has been used by Aslan (2014) i.e soil mix that consisted of 60% Q38 kaolinite clay, 20% Active Bond 23 bentonite, 10% Class F fly ash and lime each, and 100% water (percentage of the dry mix) produced the required scaled shear-wave velocity of 36 m/sec$^2$ .The second day of its cure age. the soil density on the second day was determined to be 1,470kg/m$^3$.

### 2.2 Scaling of Pile

Adopting acrylic material geometric and dynamic and material scaling has been adopted for piles and only dimensional scaling has been adopted for scaling of pile cap. The scaled dimensions of the pile group are as shown in the Table 8.

**Table 8.** Size of scaled pile and pile cap

| Sl. No. | Contents | Description |
|---|---|---|
| 1 | Pile size | 1.5cmX1.5cm |
| 2 | Pile length | 32cm |
| 3 | Pile spacing | 5cm |
| 4 | Pile cap size | 12cmX5cmX0.35cm |

## 3. Experimental Study using Shake Table

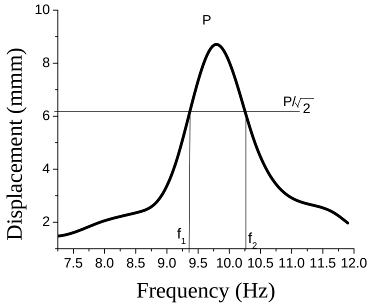
The Shake Table at the Department of Civil Engineering, UVCE, Bangalore, is an uniaxially driven having table size 1m x 1m with maximum payload capacity of 100kg. The table has an operating frequency range of 0.05–25 Hz. In the present study, objective is to evaluate the change in the dynamic properties of scaled models such as natural frequency and time period for flexible base condition.

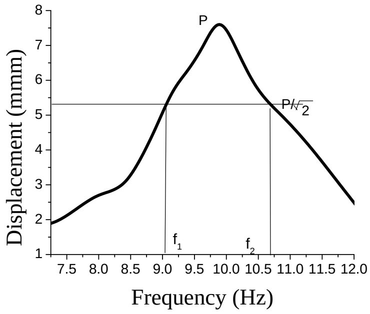
Two models were evaluated experimentally, one is set back model of and another is stepped setback model. In order to get natural frequency of scaled model, the model was subjected to a gradually increasing uni directional harmonic excitation (sine sweep wave) with an amplitude in the range of 0.4–0.7 mm and sweep rate in the range of 0Hz–15 Hz.. The response parameter such as displacements, accelerations and resonant frequences were recorded by Data Acquisition System (DAQ) as in Fig.5.

For an experimental study, frequency has been sweeped from 0 Hz at an increment of 0.25Hz and the resonance is recorded and it is found to be 9.89 Hz for setback model and 9.77Hz for stepped setback model. Displacement versus frequency has been plotted and structural damping has been computed by Half power band width using equation 1.

$$\xi = \left(\frac{f_2 - f_1}{2 f_n}\right) \qquad (1)$$

Here $\xi$ = damping ratio, $f_1$ and $f_2$ are the frequencies corresponding to half power band width, and $f_n$ is the resonant frequency. Fig. 6 shows the displacement versus frequency plot along with the computation of structural damping. Where ‘P’ is the peak displacement. The damping is computed as 4.87% and 7.07% for models respectively, which is as shown in Fig. 6.




(a)Set back (b)Stepped set back

**Fig 6.** Displacement versus frequency of setback scaled models

At resonance the displacements at different floor levels were measured through data aqusition systems and are presented in table 9 and 10 for setback model and stepped setback model respectively. Figure 7 indicates the same.

**Table 9.** Displacement of scaled setback model

| Storey No's. | Displacement of Setback Scaled Model ( mm) | Displacement of Setback Scaled Model ( mm) *30 |
|---|---|---|
| 1 | 1.23 | 36.9 |
| 2 | 2.56 | 76.95 |
| 3 | 3.9 | 117 |
| 4 | 5.36 | 160.8 |
| 5 | 6.83 | 204.9 |

**Table 10.** Displacement of scaled stepped setback model

| Storey No's. | Displacement of Setback Scaled Model ( mm) | Displacement of Setback Scaled Model ( mm) *30 |
|---|---|---|
| 1 | 2.1 | 63 |
| 2 | 3.98 | 119.4 |
| 3 | 5.85 | 175.5 |
| 4 | 7.05 | 211.5 |
| 5 | 8.25 | 247.5 |

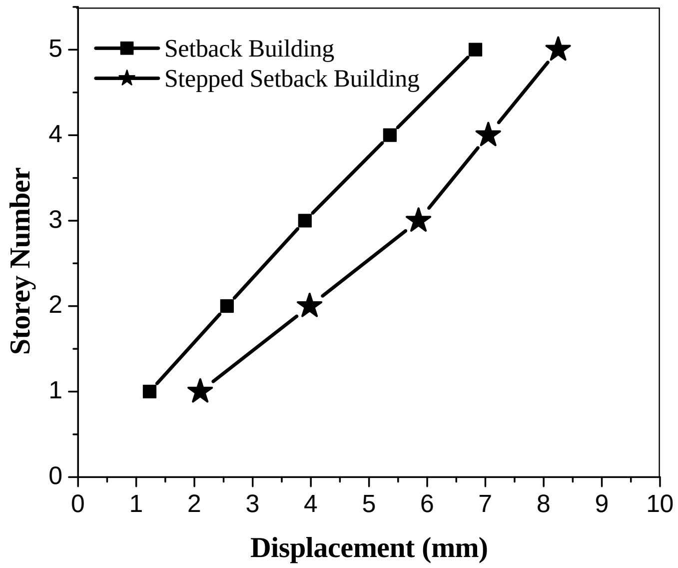



**Fig 7.** Storey displacements of setback scaled models

## 4. Conclusion

The damping value has been adopted to represent SSI. Depending upon the damping accounting for effect of subsoil condition and the structure the displacement of the scaled model has been measured, from the experimental study it is observed that the structural damping of setback and stepped setback models are 7.07% and 4.87% depending upon its geometrical irregularity. Since structural damping of the stepped setback model is less, storey displacements are observed to be more compared to setback building.

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