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# Study of Soil Structure Interaction of R.C.Frame Structure Supported on Different Types of Foundation

**Sameer P. Chambulwar[1], Sudhir L. Bhilare[2]**

[1]P.G. Student, [2]Assistant Professor

*Department of Civil Engineering, J.S.P.M's R.S.C.O.E, Tathawade, Pune, Maharashtra,(India)*

**ABSTRACT**

*In the analysis of R.C. frame structure, the base is considered to be fixed neglecting the effect of soil and foundation flexibility. Flexibility of the soil causes the decrease in stiffness resulting increase in the natural period of the structure. Such as increase in the natural periods, changes the seismic response of structure, it may be an important issue for design considerations. The present study provides systematic guidelines for determining the natural periods of frame buildings due to the effect of soil-flexibility and identification of spring stiffness for different regular and irregular story buildings and various influential parameters have identified and the effect of the same on change in natural periods has to be studied. The study has carried out for building with isolated and pile foundations for different soil conditions like soft, medium, and a comparison between the regular and irregular buildings and natures of change in the natural periods has to be present.*

***Keywords— Soil Structure Interaction, Spring Stiffness, Soil Flexibility, Base Shear, Displacement, Period*.**

## I. INTRODUCTION

The rapid development of urban populations and the pressure which are developing on limited space significantly some influence the residential development of city. The price of land is high to avoid the uneven and uncontrolled developing of urban area. The local topographical restrictions in the urban area only possible solutions for construction of multi-storey buildings to full fill the residential needs. The multi-storey buildings all initially a reaction to the demand by activity of business close to each other and in city centre, the less availability of land in the area. The multi-storey buildings are frequently developed in the centre of the city is prestige symbols for commercial organizations.

There having the soil structure interaction is special field of analysis of earthquake engineering and the soil structure interaction is defined as the "dynamic interrelationship between response of structure influenced by the motion of soil and response of soil influenced by the motion of structure is called as soil structure interaction." However engineering community discussed about the SSI only when the basement motion by interaction force as compared to the ground motion of free field. The stress and deformation in supporting soil cause vibration of structure which are generates the bases shear, moments, displacement, natural period, since reality it is not the fixed based structure, deformation of soil will be modified the response of structure.

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The structure with irregularity is to be design at most care by understanding detrimental effects of irregularities to fulfill the requirements. In this work to finding plan irregularities because of its mass distribution, non-uniform stiffness, strength in horizontal direction, even through structure are of same region, same configuration and same earthquake magnitude but damage will happens during the earthquake are not same pattern. This means that the some factors that affects damage patterns like earthquake characteristic, structural system of plan, mass, stiffness and vertical irregularities.

## II. ISOLATED FOOTING

It is type of shallow foundation which are transferring the building loads in to the soil and also it is circular, square or rectangular slab of uniform thickness. Sometimes, it is stepped to spread the load over a larger area, when footing is provided to support an individual column; it is called “Isolated footing”.

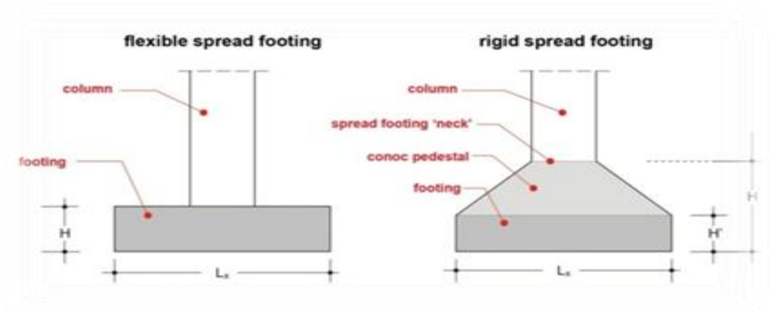


**Figure 1: Flexible and Rigid Spread Footing**

The isolated footings essentially consist of bottom slab. This bottom slab can either flat, stepped or sloping in nature. The bottom of the slab is reinforced with steel mesh to resist the two internal forces namely bending moment and shear force. And in this work we going to used Fixed and flexible supports for determining the Base shear, time period, displacement, moments etc of regular and irregular building.

## III. PILE FOUNDATION

A pile is basically a long cylinder of a strong material such as concrete that is pushed into the ground to act as a steady support for structures built on top of it. When there is a layer of weak soil at the surface. This layer cannot support the weight of the building, so the loads of the building have to bypass this layer and be transferred to the layer of stronger soil or rock that is below the weak layer and when a building has very heavy, concentrated loads, such as in a high rise structure, bridge, or water tank. and pile foundation are capable to talking higher loads than spread footing.

## IV. END BEARING PILE

In end bearing piles, the bottom end of the pile rests on a layer of especially strong soil or rock. The load of the building is transferred through the pile onto the strong layer. In a sense, this pile acts like a column. The key principle is that the bottom end rests on the surface which is the intersection of a weak and strong layer. The load therefore bypasses the weak layer and is safely transferred to the strong layer.

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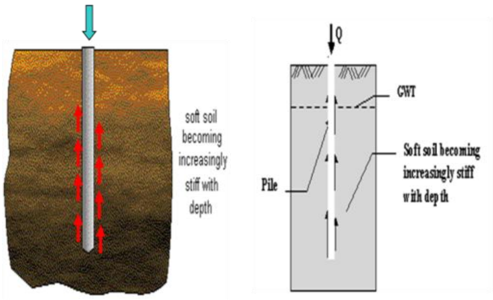


**Figure 2- End bearing pile**

As pile foundations carry a lot of load, they must be designed very carefully. A good engineer will study the soil the piles are placed in to ensure that the soil is not overloaded beyond its bearing capacity. Every pile has a zone of influence on the soil around it. Care must be taken to space the piles far enough apart so that loads are distributed evenly over the entire bulb of soil that carries them, and not concentrated into a few areas.

## V. MODELLING AND ANALYSIS

### A) Details of Soil Parameters considered

The soil-flexibility effects on frame building resting on different types of soils, viz, medium, soft is also trying to be studied in the present work.

The value of the spring's stiffness of the varieties of soil, the shear modulus (G) is estimated to use the following expression.

$$G = Vs^2 \rho \qquad (1)$$

The shear wave velocity is estimated to use the following expression.

$$Vs = \sqrt{\frac{E}{(2\rho(1+v))}} \qquad (2)$$

where,

Vs = Shear wave velocity, in m/sec.

ρ = Mass density of soil in $kN/m^3$

(ν) = Poisson ratio

| Type of Soil | N value considered | Mass density of soil (ρ) $kN/m^3$ | Shear wave velocity (m/sec) | Poisson ratio |
|---|---|---|---|---|
| Medium soil | 20 | 17 | 63.04 | 0.48 |
| Soft Soil | 9 | 18 | 88.96 | 0.33 |

Table 1- Details of Soil parameters Considered

Where N = Applied for Number of in Standard penetration test (SPT) on the soil.

Table 2- N and Φ value are used to get SBC and the size of footing

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| Type of Soil | N value | Angle of internal friction | Allowable SBC of soil($KN/m^2$) | Size of footing (m) |
|---|---|---|---|---|
| Medium Soil | 20 | 33 | 200 | 2.1x2.1 |
| Soft Soil (Pile Foundation) | 9 | 29 | 120 | 0.6 |

Table 3- Expressions for Static stiffness of equivalent soil springs along various degrees of freedom

| Degree of freedom | Stiffness of equivalent soil spring |
|---|---|
| Horizontal (longitudinal dirc.)$K_x$ | $2GL/(2-v)](2+2.5x^{0.85})$–$[0.2/(0.75-v)]GL(1-(B/L)]$ |
| Vertical $K_y$ | $[2GL/(1-v)](0.73+1.54x^{0.75})$with $x=Ab/4L^2$ |
| Horizontal ( lateral dirc.) $K_z$ | $[2GL/2-v)](2 +2.5x^{0.85})$ with $x=Ab/4L^2$ |
| Rocking (about longitudinal) $K_{rx}$ | $[G/(1-v)]I^{0.75}(L/B)^{0.25}[2.4+0.5(B/L)]$ |
| Torsion $K_{ry}$ | $3.5GI_{bz}^{0.75}(B/L)^{0.4}(I_{bz}/B^4)^{0.20}$ |
| Rocking ( about lateral) $K_{rz}$ | $[3G/(1-v)]I_{by}^{0.75}(L/B)^{0.15}$ |

| Degree of freedom | Stiffness of foundation at support |
|---|---|
| Translation along X axis | $K_x=\{GB/(2-v)[3.4(L/B)^{0.65}+1.2]\}$ |
| Translation along Y axis | $K_Y=\{GB/(2v)[3.4(L/B)^{0.65}+0.4(L/B)+0.8]\}$ |
| Translation along Z axis | $K_Z=\{GB/(1-v)[1.55(L/B)^{0.75}+0.8]\}$ |
| Rocking about X axis | $K_{rx} = \{GB^5/(1-v)[0.4(L/B)+0.1]\}$ |
| Rocking about Y axis | $K_{ry}= \{GB^5/(1-v)[0.47(L/B)^{2.4}+0.034]\}$ |
| Torsion about Z axis | $K_{rx} = \{GB^5/0.53(L/B)^{2.45}+0.51]\}$ |

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| Degree of freedom | Spring stiffness of pile foundation |
|---|---|
| Translation along X axis | $K_x$=((8Gr/2-v) x (1+(2d/3r)) |
| Translation along Y axis | $K_Y = K_x$ |
| Translation along Z axis | $K_Z$ =((4Gr/1-v) x (1+0.4(d/r))) |
| Rocking about X axis | $K_{rx} = K_z \sum_{i-1}^{np} d^2_{yi}$ |
| Rocking about Y axis | $K_{ry} = K_z \sum_{i-1}^{np} d^2_{xi}$ |
| Torsion about Z axis | $K_{rx} = K_x \sum_{i-1}^{np} (d^2_{xi}+d^2_{yi})$ |

| | | |
|---|---|---|
| Size of columns | 0.25m x 0.45m | 0.25m x 0.45m |
| Moderate seismic zone | IV | IV |
| Grade of steel ( $F_y$) | 500 N/mm$^2$ | 500 N/mm$^2$ |
| Grade of concrete ($F_{ck}$) | 30 N/mm$^2$ | 30 N/mm$^2$ |
| Density of concrete(ρ) | 25 kN/m$^3$ | 25 kN/m$^3$ |
| Dead load | 5 kN/m$^2$ | 5 kN/m$^2$ |
| Live load | 4 kN/m$^2$ | 4 kN/m$^2$ |
| Floor finish load | 1.5 kN/m$^2$ | 1.5 kN/m$^2$ |
| Load on wall | 11.73 kN/m | 11.73 kN/m |
| Parapet wall load | 5.75 kN/m | 5.75 kN/m |
| Poisson ratio | 0.15 | 0.15 |
| damping | 0.05 | 0.05 |
| Importance factor | 1.5 | 1.5 |

**B) Description of Analytical Model**

Different building models are analyzed in ETABS. The properties of the building configurations are considered in the present work are summarized below.

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**Table 4- Details Specification of Frame Structure**

| Specifications of structure | Regular frame structure | Irregular frame structure |
|---|---|---|
| Plan size | 12m x 9m | 12m x 9m |
| Height of each floor | 3m | 3m |
| No. of storey's | 5, 10, 15 | 5,10,15 |
| Size of beams | 0.25m x 0.45m | 0.25m x0.45 |

| Foundation | Size of Footing |
|---|---|
| Isolated Footing | 2.1m x 2.1m |
| Pile Foundation (Diameter of Pile ) | 0.6 m |

## VII. REGULAR AND IRREGULAR R.C. FRAME

When the mass and stiffness are constant of the structure then is called as Regular RC frame and also it just a box shape like rectangular and square shape and there has no re-entrant corners and setback.

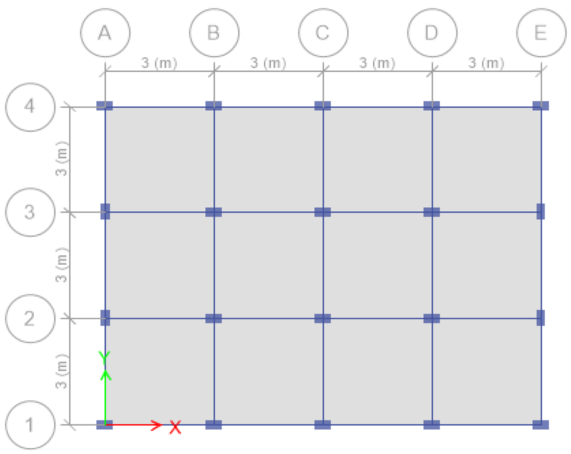


**Figure 3: Plan of Regular Frame**

When the mass and stiffness of structure is not constant means vary then the building called as Irregular building. for irregular building will used Re-entrant corner method will be used.

Re-entrant Corners – Plan configuration of structure and its lateral force resisting system contain re-entrant corners, where the both projections of structure beyond the re-entrant corner are greater than the 15 percent of its plan dimensions in the given direction.

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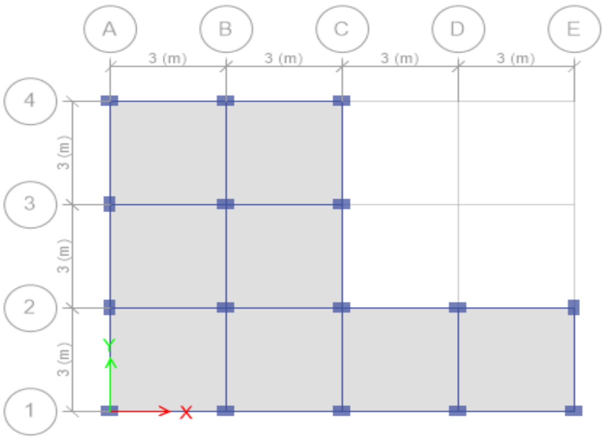
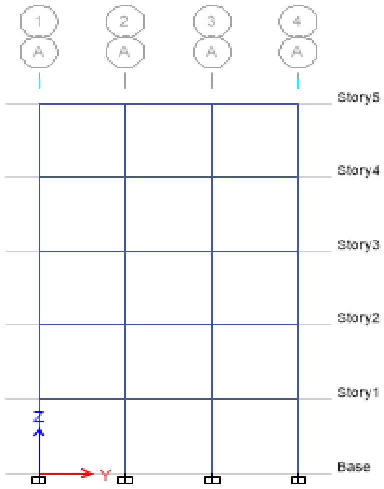



**Figure 4: Plan of Irregular Frame**



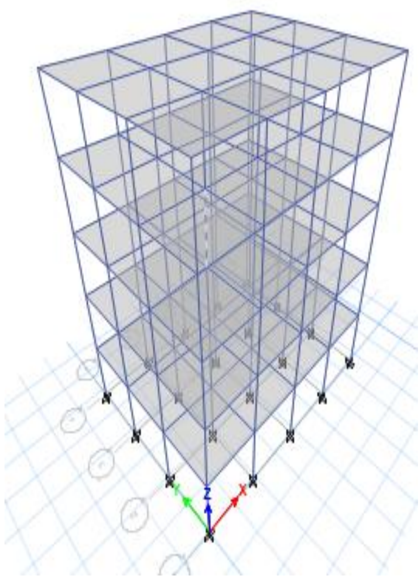



**Figure 5- 3d Model of 5 Storey Regular Frame Structure**

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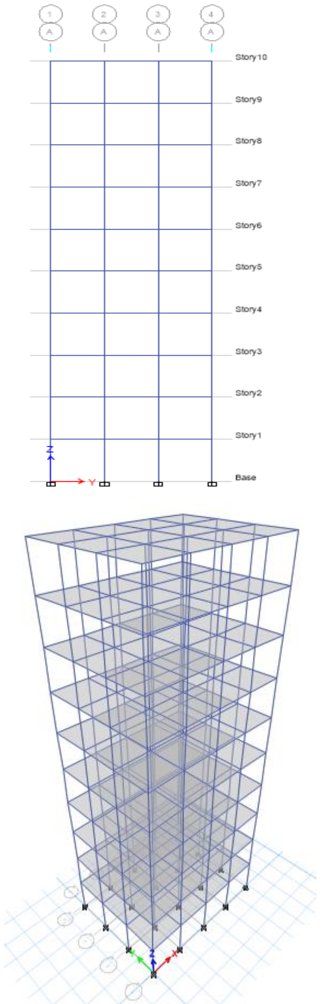


**FIGURE 5- 3D MODEL OF 10 STOREY REGULAR FRAME STRUCTURE**

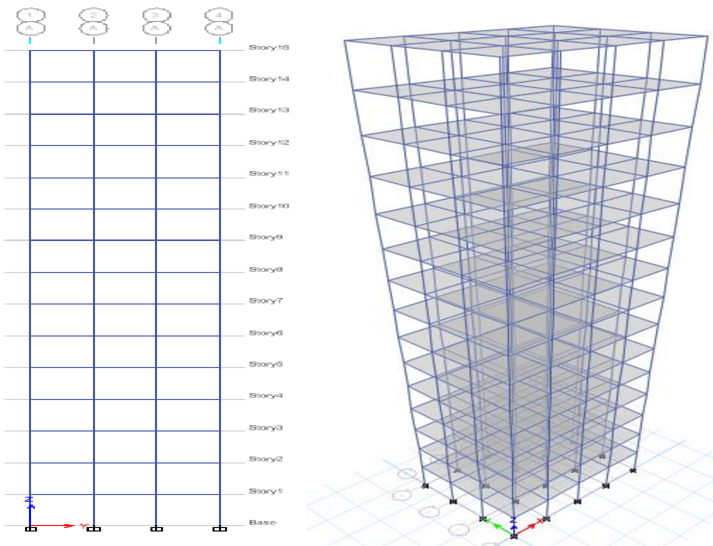

**FIGURE 6- 3D MODEL OF 15 STOREY REGULAR FRAME STRUCTURE**

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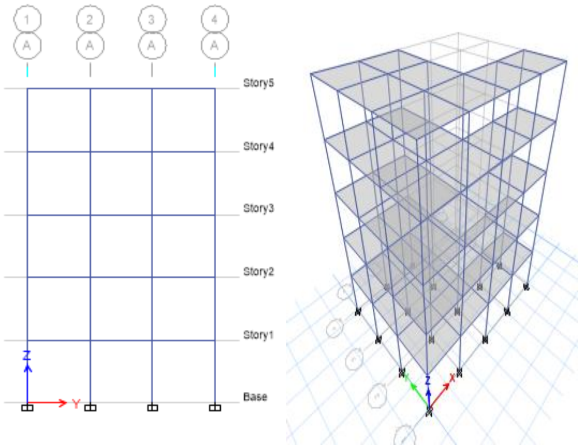


**FIGURE 7- 3D MODEL OF 5 STOREY IRREGULAR FRAME STRUCTURE**

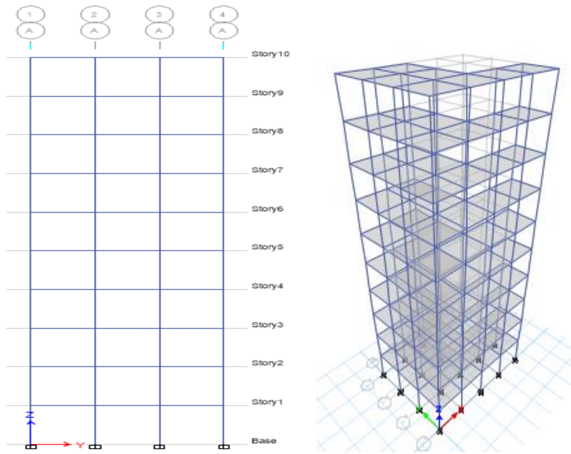


**Figure 8- 3d Model of 10 Storey Irregular Frame Structure**

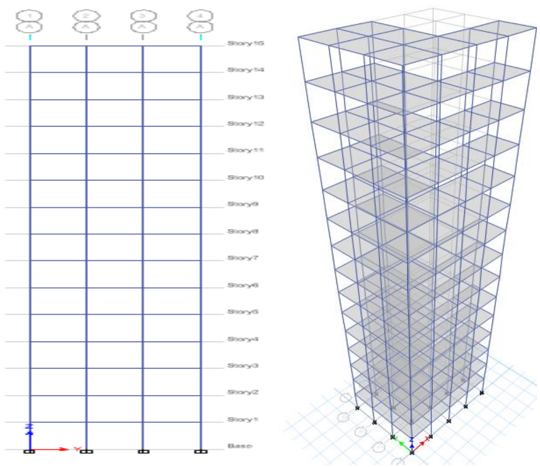

**FIGURE 8- 3D MODEL OF 15 STOREY REGULAR FRAME STRUCTURE building for soft soil**

**Table 5- Stiffness for equivalent soil spring**

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| Type of soil | Medium soil |
|---|---|
| L (m) | 2.1 |
| B (m) | 2.1 |
| $K_{ex}$ (KN/m) | 28935.48 |
| $K_{ey}$ (KN/m) | 48210.15 |
| $K_{ez}$(KN/m) | 29305.80 |
| $K_{erx}$(KN-m/deg) | 14071.64 |
| $K_{ery}$(KN-m/deg) | 10290.82 |
| $K_{erz}$(KN-m/deg) | 7242.058 |

**Table 6- Stiffness of foundation at surface**

| Type of soil | Medium soil |
|---|---|
| L (m) | 2.1 |
| B (m) | 2.1 |
| $K_{ex}$ (KN/m) | 37283.96 |
| $K_{ey}$ (KN/m) | 72554.21 |
| $K_{ez}$(KN/m) | 38273.61 |
| $K_{erx}$(KN-m/deg) | 30180.71 |
| $K_{ery}$(KN-m/deg) | 21523.90 |
| $K_{erz}$(KN-m/deg) | 17508.68 |

**Table 6- Spring Stiffness of pile foundation**

| Type of soil | Medium soil |
|---|---|
| D (m) | 0.6 |
| d (m) | 10 |
| $K_{ex}$ (KN/m) | 175810.60 |
| $K_{ey}$ (KN/m) | 175810.60 |
| $K_{ez}$(KN/m) | 157619.80 |
| $K_{erx}$(KN-m/deg) | 8444734.10 |
| $K_{ery}$(KN-m/deg) | 2819816.20 |
| $K_{erz}$(KN-m/deg) | 12708765.90 |

## VII. RESULT AND DISCUSSION

The present work attempts to study the behaviour of framed structures with rigid and flexible foundation. Framed structure having same height with regular and irregular plans have been considered with fixed and flexible foundation resting on three different types of soil and different types of foundation, a framed structure of rectangular plan with 5, 10 and 15 storey is analysed for earthquake load consider in zone-IV, importance

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factor of 1.5, with the different soil type like medium and soft soil with fixed and flexible base condition. Response spectrum analysis is done and the parameters like time period, base shear, bending moment in column and top storey displacement are measured and are present below.

For 5, 10, 15 storeys framed structure the foundations are designed as isolated footing for medium soil. and also for 5,10,15 storey framed structure the foundation for soft soil is pile foundation. 5, 10 and 15 storey frame is considered and is analyzed for dead load, live load, and earthquake load with base as fixed and flexible, the response of the structure is measured with the different soil type. in the flexible base condition the soil and foundation is modeled as spring element. The stiffness of spring is calculated based on soil properties.

- **Base Shear:**

| Storey | Regular Building | | Irregular Building | |
|---|---|---|---|---|
| | Fixed | Flexible | Fixed | Flexible |
| 5 | 480.78 | 356.04 | 250.58 | 180.61 |
| 10 | 477.78 | 351.22 | 228.18 | 195.57 |
| 15 | 458.30 | 441.20 | 210.58 | 200.70 |

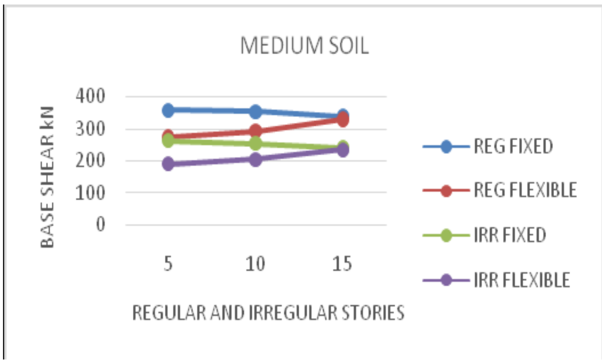


**Figure 10: Base shear of regular and irregular building for Medium soil**

| Storey | Regular Building | | Irregular Building | |
|---|---|---|---|---|
| | Fixed | Flexible | Fixed | Flexible |
| 5 | 592.30 | 403.47 | 431.27 | 283.70 |
| 10 | 585.44 | 464.46 | 422.48 | 320.61 |
| 15 | 560.65 | 525.05 | 400.02 | 365.92 |

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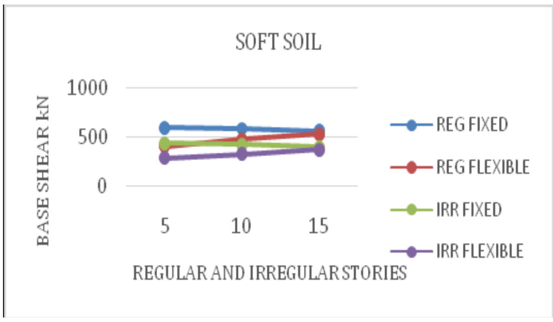


**Figure 11: Base shear of regular and irregular**

- **Displacement:**

| Storey | Regular Building | | Irregular Building | |
|---|---|---|---|---|
| | Fixed | Flexible | Fixed | Flexible |
| 5 | 13.4 | 13 | 12.8 | 14 |
| 10 | 29.8 | 35.4 | 25.9 | 30.9 |
| 15 | 46.4 | 47.4 | 41.3 | 42.6 |

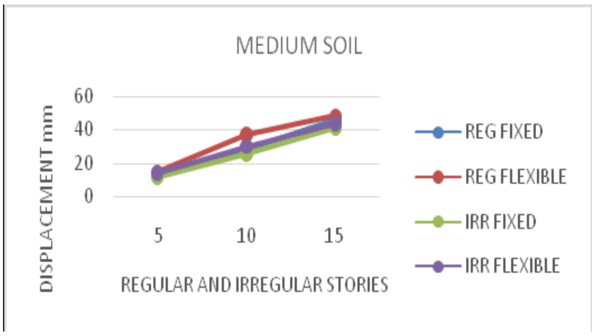


**Figure 12: Displacement of regular and irregular frame for medium soil**

| Storey | Regular Building | | Irregular Building | |
|---|---|---|---|---|
| | Fixed | Flexible | Fixed | Flexible |
| 5 | 18.9 | 17.9 | 12.5 | 18.8 |
| 10 | 33.2 | 43.1 | 30.7 | 41.5 |
| 15 | 55.2 | 59.9 | 48.7 | 53 |

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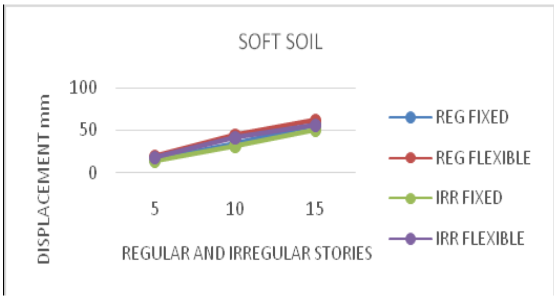


**Figure 13: Displacement of regular and irregular frame for soft soil**

- **Time Period :**

| Storey | Regular Building | | Irregular Building | |
|---|---|---|---|---|
| | Fixed | Flexible | Fixed | Flexible |
| 5 | 0.8606 | 1.087 | 0.8817 | 1.1397 |
| 10 | 1.7335 | 2.5068 | 1.7599 | 2.2959 |
| 15 | 2.8061 | 3.0104 | 2.3948 | 3.2314 |

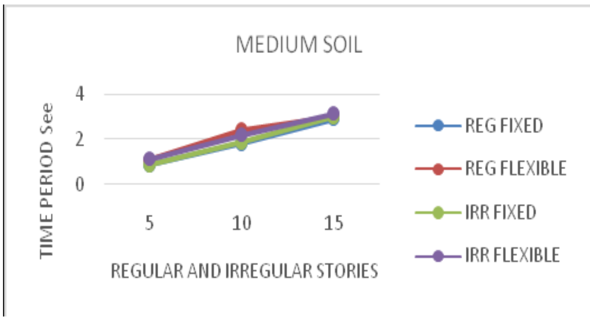


**Figure 13: Time period of regular and irregular frame for medium soil**

| Storey | Regular Building | | Irregular Building | |
|---|---|---|---|---|
| | Fixed | Flexible | Fixed | Flexible |
| 5 | 0.8706 | 1.2758 | 0.8817 | 1.2508 |
| 10 | 1.7335 | 2.3765 | 1.9599 | 2.3315 |
| 15 | 2.9061 | 3.2162 | 2.9948 | 3.3466 |

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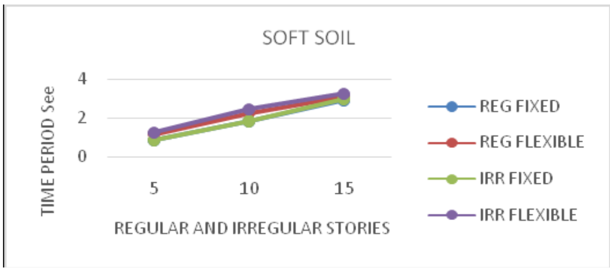


Figure14- Time period of regular and irregular frame for soft soil

- **Moments :**

| Storey | Regular Building | | Irregular Building | |
|---|---|---|---|---|
| | Fixed | Flexible | Fixed | Flexible |
| 5 | 17.95 | 28.92 | 21.03 | 32.64 |
| 10 | 30.17 | 45.06 | 33.69 | 39.6 |
| 15 | 41.59 | 44.45 | 43.31 | 34.27 |

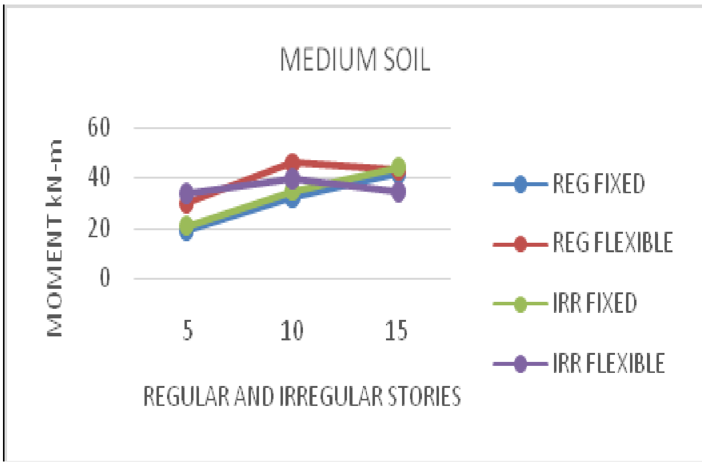


**Figure 15 - Moments of regular and irregular frame for medium soil**

| Storey | Regular Building | | Irregular Building | |
|---|---|---|---|---|
| | Fixed | Flexible | Fixed | Flexible |
| 5 | 17.95 | 28.92 | 21.03 | 32.64 |
| 10 | 30.17 | 45.06 | 33.69 | 39.6 |
| 15 | 41.59 | 44.45 | 43.31 | 34.27 |

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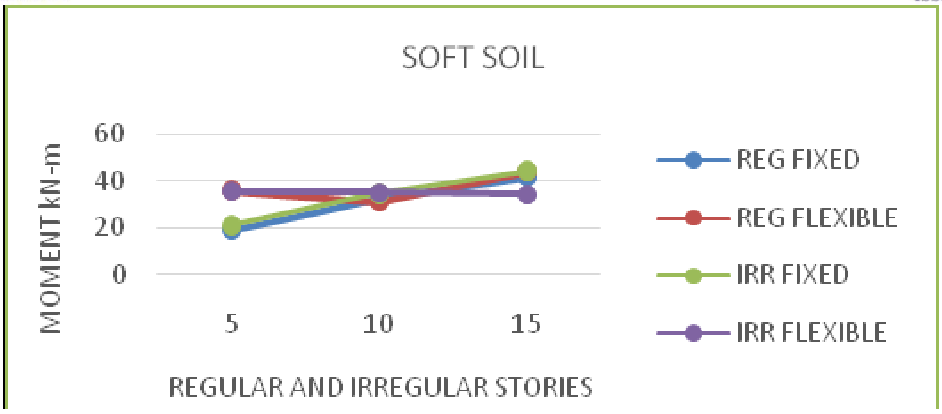


**Figure 16- Moments of regular and irregular frame for soft soil**

## VIII. CONCLUSION

1. Base shear has reduced for flexible foundation in comparison with fixed base analysis since the natural period increases for flexible base condition.
2. There is no much variation in time period for frame model with pile foundation of flexible base in comparison with the fixed base model.
3. Framed structure with pile foundation modelled as flexible base shows no difference in Base shear value in comparison with fixed base analysis.
4. Response of the structure increases with change in soil type from medium and soft irrespective of height of structure and type of foundation.
5. Framed structure with pile foundation resting on soft soil and medium soil can be treated as fixed since no much variation in the response of the structure.
6. Bending moment and displacement increases from fixed base analysis to flexible base analysis.
7. Framed structure with Irregular and regular plan did nost differ much in its response since the percentage of irregularity is less.

## IX. ACKNOWLEDGMENT

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