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# Dynamic Soil Structure Interaction Behaviour of Building Frames with Strip Foundation using SAP 2000

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**Abstract**: Conventional method of structural analysis adopted for practical design of most of structures, ignores the effect of soil compressibility medium. It causes an underestimation of forces in certain members leading to unsafe design. For a realistic estimation of design forces, it is necessary to carry out analysis considering soil structure interaction. Hence, the analysis, which considers the flexibility characteristics of soil, foundation and superstructure, is called as interaction analysis. The soil structure interaction can be ignored, probably if the structure is very flexible or differential settlements under the column are negligibly small. Only a limited number of studies have been made on soil-structure interaction effect for three-dimensional space frames and few of them, carried to observe maximum possible extent of the effect of excitation frequency on seismic response of building. Therefore, this study compares the behaviour of the soil-structure interaction between seismic three-dimensional building with combined footing supported by soil types and also rigid bases. Such a study helps in providing guidelines to determine more precisely how seismically vulnerable building frames resting on strip foundations are, also being valuable for seismic design.

***Key words:*** *Interaction between soil and structure, natural period and base shear.*

**Introduction:** Analysing foundation and structure independently has long been standard procedure. Typical load distributions within the building frames are computed under presumption that foundation transfers load directly onto a solid rocky stratum, or that bottom of structure is fixed. Without a doubt, this is a simplifying assumption that is often relevant if the superstructure is significantly more compliant or flexible than the soil layer beneath the foundation. On other side, if opposite is true, means if structure is significantly stiffer than soil medium, soil's flexibility may have major impact on structure's response. when earthquake causes structure to be subject to earthquake force. When the seismic waves enter structure, structure begins to move. The structural layout and the vibrational properties of structure, find these motions. The structure will resist its own inertia in order to respond to motion causing an interaction between structure and soil. In current context, this interdependent behaviour between structure and soil which controls overall response referred as soil flexibility. In another way, phenomenon Known as "soil-structure interaction" entails analysing how link is between structure and soil influences motion that structure experience during earthquake. The estimation of response amounts is shown as lower when the structure is analysed as a fixed base condition.

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The common design practice for dynamic loading assumes building as fixed at the bases. In reality, supporting soil medium allows movement to some extent due its natural ability to deform, which decreases complete stiffness to structural system, which may increase natural periods of system. This type of influence of partially fixed structures at foundation because of soil being flexible alters response. On contrary, extent of fixity offered by soil at bases of structures depend on load transferred from structure to soil as same decides type and size of foundation needs be provided. This interdependent behaviour between the soil-structure which regulates overall response is referred as soil structure interaction. There is not much research on influence of soil and structure interaction for three-dimensional space frames, and even few of those have been done to investigate greatest extent to which excitation frequency can affect a building's seismic response. The objective of the study was to compare behaviour of the soil-structure interaction between seismic three-dimensional building frames with strip foundations that are supported by various soil types and rigid bases. Such a study could be helpful in providing guidelines to help determine more precisely how seismically vulnerable building frames resting on strip foundations are, also being valuable for seismic design.

**Scope Of Present Study**: The aim of present investigation has been to study dynamic behaviour of building structure which rests on strip foundation and comparing the dynamic responses which incorporates soil flexible being represented by the continuum soil model. In current study an attempt has been made to observe effect for soil being flexible on the fundamental lateral natural period, seismic shear, Maximum lateral displacement, column axial forces and beam bending moments of the building frames resting on strip foundation.

**Modelling and Analysis Method**:

Buildings are modelled using SAP 2000 version 11. Superstructure of frame of building has been idealized as 3-dimensional space frames with the 2-noded line element with slab modelled as membrane element with rigid diaphragm wherein footing and the soil has been being modelled as SOLID element. Soil is modelled as the continuum-model and will be compared with results of fixed base model. Dynamic analyses (Response Spectrum Method) is carried out as per IS 1893-2002 (part 1) for structure modelled with rigid and flexible base. The various types load combinations are considered as per IS1893-2002(part 1).

**Description of building Model**

Two bay, two bay one, two and four storied Reinforced concrete frame which are frame of moment resisting buildings are selected for the current study (without taking into account the stiffness of the infill). The height of base storey is 4.5m (henceforth termed Ratio of Base storey to higher stories Hr=1.5) and is kept at 3m for all the other stories in the model. In order to introduce certain amount of unsymmetry in the structures considered, the independent spans of the 2bay 2 bay structure are taken as 6m and 3m (henceforth referred as Ratio of higher to lower span Sr=2). No parapets on the roof storey but all-round one brick infill masonry wall 230mm thick including plaster in the floor storeys is considered for the structure. Also, the building has been as modelled as bare frame. However, mass of all walls are included.

**Design Properties for the Buildings**

The material properties considered are: Young's modulus of M25 concrete, E= 25× $10^6$ $KN/m^2$,Density of Reinforced Concrete= 25 $KN/m^3$,Density of brick masonry= 20 $KN/m^3$, Dead load are floor finish = 1.5 $KN/m^2$,Roof finishes= 1.5 $KN/m^2$,Live load intensity for Roof is 1.5 $KN/m^2$ and on Floor is 3.0$KN/m^2$,Member properties are Thickness of Slab=120mm,Column size =350 mm × 500 mm, Beam size=250 mm × 600 mm, Thickness of wall=230 mm, live load for slab as per section 7.3.1 and section 7.3.2 of IS:1893-2002 Part 1 has been calculated mentioned as: on Roof (clause 7.3.2)= 0,Floor (clause 7.3.1) =0.25 × 3.0 is 0.75 $KN/m^2$,Type of the use=office, Response spectra = as per 1893(part 1)2002, Importance factor =1,Response factor = 5. The foundation dimensions were designed for the gravity load and all its design combinations, using STAAD ETC software package. Also Autocad has been used for plan and elevations and drawings details initially.

**Soil Properties Considered**

The soil type considered is sandy clay (Bowles, 1988) which is classified as soft, medium and stiff soil based on dynamic shear modulus. Properties of soil types considered for present study as Stiff(Type-I),Medium(Type-II)and Soft (Type-III) with Poisson Ratio μ=0.5 for all, Mass Density p=2000 $kg/m^3$,1700 $kg/m^3$ and 1400 $kg/m^3$, Shear Wave Velocity, v=1400 m/s,700 m/s and 150 m/s, Shear Modulus G=3920005 $KN/m^2$, 833005 $KN/m^2$ and 31505 $KN/m^2$, Elastic Modulus E=11760010 $KN/m^2$, 2499001 $KN/m^2$ and 94502 $KN/m^2$ respectively.

**Mathematical Modeling Of The Building Frame And Footings.**

**Three-dimensional model of building frame**

The structure of building has been idealized to three-dimension space frame (Fig.1) with two nodded beam elements, at each joint with the degree of freedom as six. If any torsional effect, then are considered automatically in model. Here ground motions are applied in X, Y or Z directions individually. The slab is modelled as membrane element with rigid diaphragm.

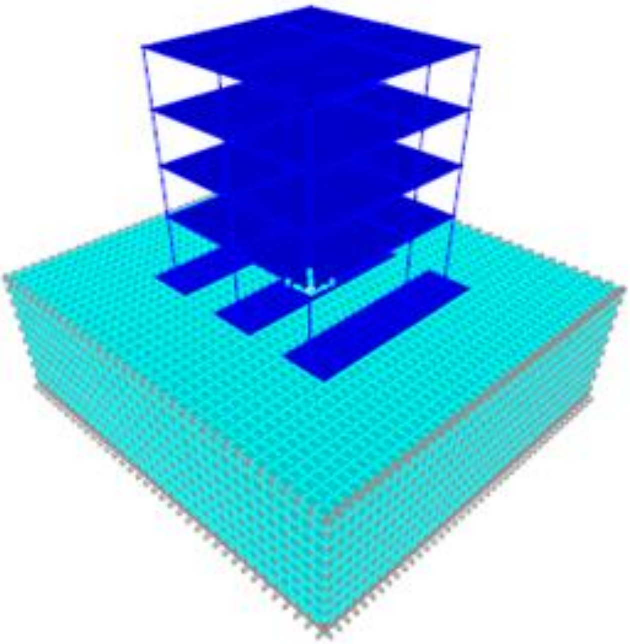

**Fig 1:** Three-Dimensional Model with Continuum base

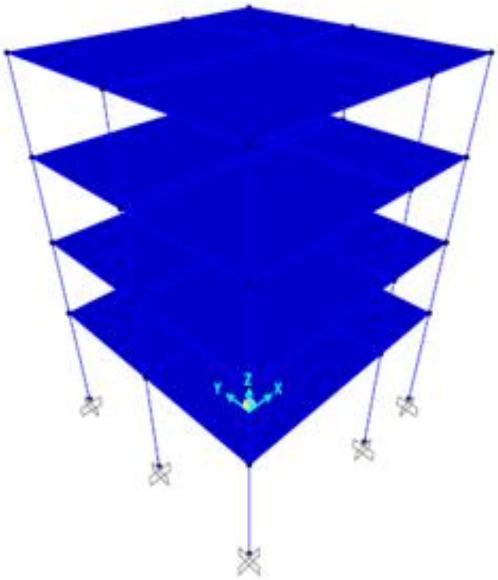

**Fig 2:** Three-Dimensional Model with the fix base

**Modelling of floor slab**

Typically, the consideration has been made for slabs to be rigid supports. Also, analysis and design has been done for gravity loads considering separately from frame system. The floor slab has been represented in three dimesional model of structure for which their dead load and also live loads have been properly accounted for. For seismic loads, floor slabs transmit inertia loads to frame also tying them together the element of latter into 3D model. To execute these, slabs have to be connected adequately with the walls, beams and the columns. Slabs are modelled in two types either floor diaphragms being rigid or flexible. In current study, three dimensioned space frame having rigid diaphragms for slabs which have been considered in modelling in SAP.

***Idealization of soil in present study:***

Soil flexibility has been modelled by continuum model of soil. Finite element method is adopted to formulate mass along with stiffness matrix for building frames wherein 3D frame analysis has been done using software. Soil modelled as eight node element (SOLID) which has 3 degrees of freedom of translation in respective co-ordinate direction at each node. The soil idealized as an isotropic, homogenous half space where shear modulus(dynamic) and also Poisson’s ratio were the inputs. At boundary of the bottom, vertical translation arrested whereas lateral translation is arrested for vertical boundaries. For, the soil region below foundation, Isobars(pressure) which are on grounds of Boussinesq's equations (Bowles 1988) is used where breadth and depth of soil were twice and thrice least of width foundation respectively. The important soil modelling effect is soil of damping. various studies for the same aspect were made. Based on such studies as listed in Gazettes, the guide lines are prescribed in the literature for the calculation of soil damping considering radiation and material damping. The damping was calculated for a Strip footing -soil system due to large variation in foundation sizes. The calculation showed that for such a strip-soil system, the overall soil damping has not been greater than 5% of the critical damping. Hence 5% critical damping has been considered for each of the mode of the vibration in all the cases for current study. The function of foundation is to resist forces applied on that by base of buildings on to the soil and resist the resulting reaction from soil. when earthquake occurs, rigid base can be subjected to the displacement having six degrees of freedom, also resistance of soil be expressed as to the six resultant components of force corresponding to it. So, the behaviour of structure of elastic half space represented by force displacement relationships which is defined for the corresponding degrees of freedom. To simulate the static behaviour of soil and structure system, it is evident that the foundation medium could be modeled by Solid element which has three degrees of freedom having translation in corresponding directions of coordinate for each node.

**Modelling of Strip foundation:**

Finite element-based idealization of strip footing has been carried as in the way soil which used 8 noded Solid element which has three degrees of freedom in translation for co-ordinate respective for directions at each node. Convergence is made by generating finite element mesh of different aspect ratios for system of soil. For selection of optimum element size, maximum principal stress value results are used which occur exactly below the footing i.e. common node between superstructure and footing meet) where stress is high. As the modelling of the foundation-soil system for the fixed dimensions had to be accommodated, for a particular modelling aspect ratio of 0.25 has been considered.

**Results And Discussion:**

In this paper, fundamental natural period and Base shear obtained from analysis of Interaction are compared with Non-interaction (NI)analysis (Non interaction Fixed base and Interaction-considering Soil flexibility).

**Lateral Natural period**: Table 1 gives the fundamental natural period (Tn) of various structures considered for different soil types (Type I, Type II and Type III for Stiff soil , medium soil and soft soil respectively) and its percentage variation from Non-Interaction (IS 1893:2002) case. In comparison to Non interaction analysis, Tn substantially increases in the interaction analysis as the structure foundation soil system is rendered flexible.

**Table 1:** Variation of fundamental Natural period(secs), in zone V of IS 1893:2002

| Sl No | Frame type | Fixed (Non-Interaction - NI) | With Interaction(I) | | | % change from Non-Interaction | | |
|---|---|---|---|---|---|---|---|---|
| | | | Stiff | Medium | Soft | type I | type II | type IIII |
| 1 | 2bay2bay 1storey (Sr=2) | 0.1421 | 0.2872 | 0.2887 | 0.2932 | 102.10 | 103.17 | 106.32 |
| 2 | 2bay2bay 2storey (Hr=1.5, Sr=2) | 0.4236 | 0.8870 | 0.8885 | 0.8930 | 109+.38 | 109.74 | 110.80 |
| 3 | 2bay2bay 4storey (Hr=1.5, Sr=2) | 0.6796 | 1.3607 | 1.3632 | 1.3706 | 100.23 | 100.60 | 101.68 |

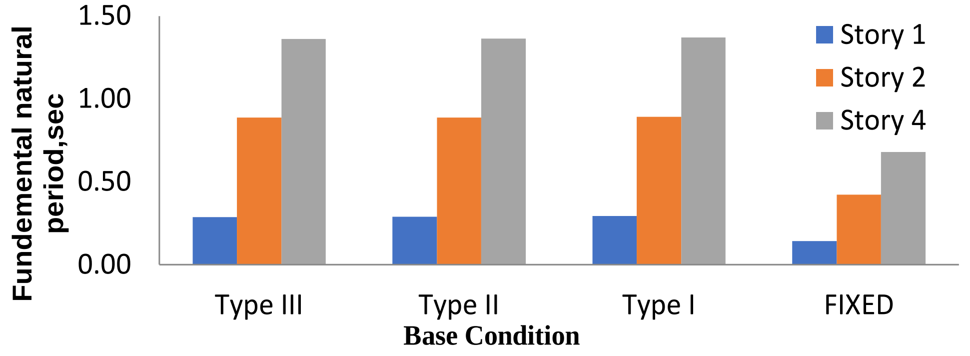


**Fig 3: 2x2 (Sr=2,Hr=1.5) Zone5 as per 'Storey' Variation**

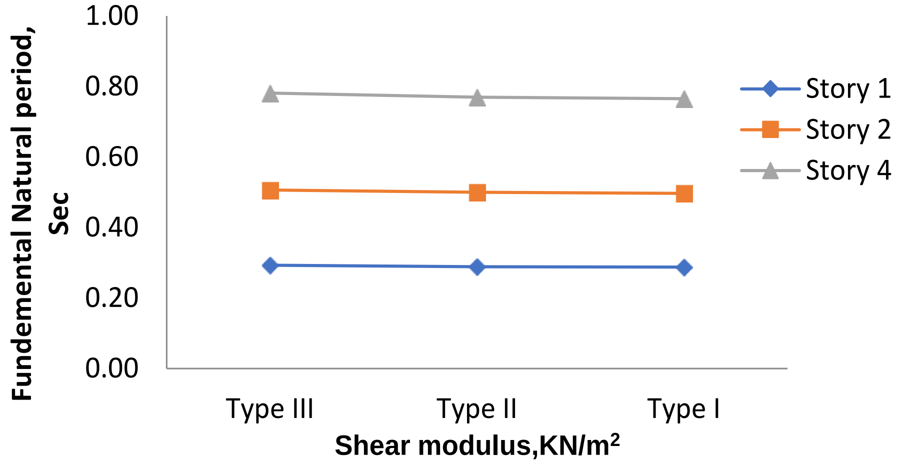


**Fig 4: 2x2 (Sr=2,Hr=1.5) Zone5 as per 'Storey' Variation**

**Table 2:-** Variation for base shear (KN) in Zone V of IS1893:2002

| Sl No | Frame type | Fixed (Non-Interaction - NI) | With Interaction(I) | | | % change from Non-Interaction | | |
|---|---|---|---|---|---|---|---|---|
| | | | Stiff | Medium | Soft | type I | type II | type IIII |
| 1 | 2bay2bay 1storey (Sr=2) | 94.11 | 107.71 | 109.90 | 115.06 | 14.45 | 16.73 | 22.26 |
| 2 | 2bay2bay 2storey (Hr=1.5, Sr=2) | 278.2 | 207.72 | 282.1 | 324.3 | -25.34 | 1.382 | 16.56 |
| 3 | 2bay2bay 4storey (Hr=1.5, Sr=2) | 606.8 | 323.44 | 424.9 | 506.58 | -46.70 | -29.97 | -14.87 |

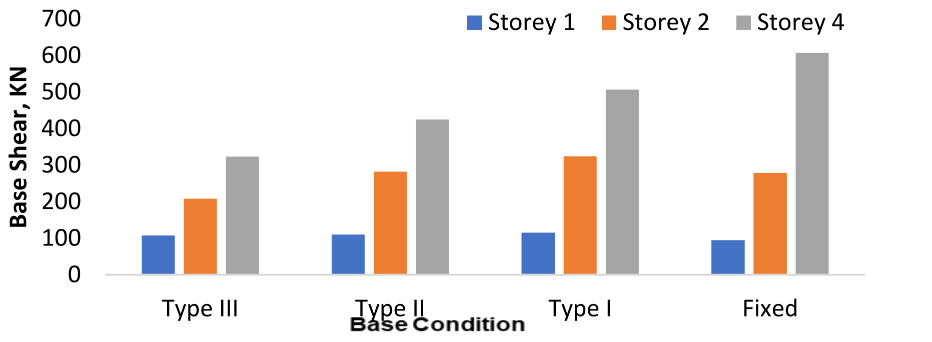


Fig 5: 2x2 (Sr=2,Hr=1.5) Zone5 as per 'Storey' Variation

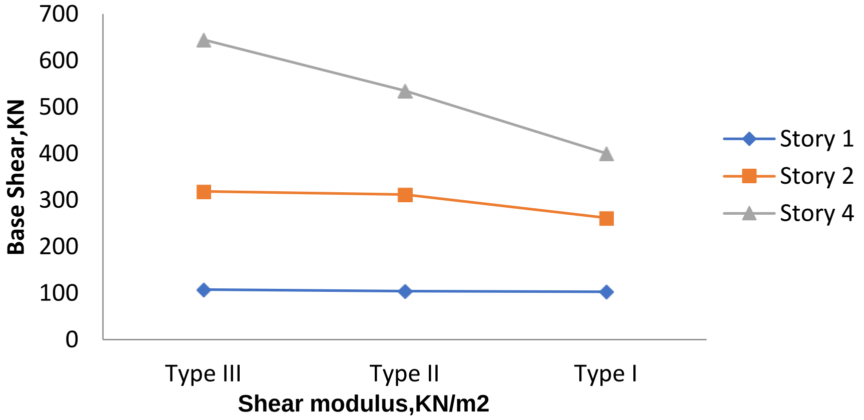


Fig 6.: 2x2 (Sr=2,Hr=1.5) Zone5 as per 'Storey' Variation

**Conclusions:**

This study is an effort of effect of soil flexibility on dynamic characteristics of structural frames rests on Strip foundation, namely Lateral natural period, Seismic base shear.

**Fundamental Natural Period:**

Natural period(fundamental) of particular structure considering interaction is greater than that of non-interaction analysis. Also, the natural period(fundamental) of particular structure increases as the modulus of shear of soil decreases (i.e. as soil becomes more flexible).

**Base Shear:**

Base shear values for the Interaction case is found to be higher than that of Non-Interaction case which can be seen predominantly in longitudinal direction of the Strip. Along any direction, base shear values for a particular structure increase as the shear modulus value of soil decreases i.e. as soil changes from type I to type III.

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