Effect of Soil Structure Interaction in Seismic Loads of Framed Structures

Shiji P.V, Suresh S., Glory Joseph

Abstract— Seismic response of structures is extremely complex because of the non-linear behaviour soils during earthquakes. Usually in the seismic design of buildings, soil structure interaction is neglected and the dynamic response of the structure is evaluated under the assumption of a fixed or a hinged base response. The code based method of seismic analysis is also seldom based on the soil structure interaction effect because of the complexity in the analysis procedures. In this paper, the interaction between the super-structure and sub-structure is investigated by modelling the soil as nonlinear spring and as elastic continuum. To illustrate the effects of soil-structure interaction on the seismic response of framed structures, frames with 5, 10, 20 and 40 storeys have been considered with base supported as fixed with and without considering the soil structure interaction. Influence of soil structure interaction by modeling soil as compression only spring and elastic continuum are presented in the form of fundamental period of vibration and base shear.

Index Terms— Base shear, compression spring, dynamic response, fundamental period,non linear spring, SAP 2000, soil structure interaction

1 Introduction

THE interactive dynamic response of a structure during an earthquake significantly depends on the characteristics of the ground motion, the surrounding soil medium, its properties and the structure itself. The soil structure interaction refers to the effects of the compression of supporting foundation medium on the motion of the structure. During an earthquake, seismic waves are transmitted through soil from the origin of disturbance to the structure; the wave motion of the soil excites the structure, which in turn modifies the input-motion by its movement relative to the ground. The movements of soil under foundation will interact with the deformations of the structure itself. The interaction phenomenon is generally affected by the mechanism of energy exchange between the soil and the structure, and the primary influence on the building is to modify the natural period of vibration and hence the response in terms of stress and strain [1].

Structures founded on rock are considered to be fixed based structures and when it is subjected to an earthquake, the extremely high stiffness of the rock constrains the motion of the rock to be very close to the free field motions. For soft soils, the foundation motion differs from that in the free field due to the coupling of the soil and structure during the earthquake. This interaction results from the scattering of waves from the foundation and the radiation of energy from the structure due to structural vibrations [1].

There are two main methods dealing with Soil Structure Interaction (SSI) analysis: Direct Method, and Substructure Method. In the direct method, the response of the soil and structure is determined simultaneously by analysing the idealized soil–structure system in a single step. The structure and soil are treated as a whole system in direct method. In substructure method, the structure and the soil are treated as two different substructures. Each substructure can be analysed using a best-suited computational technique.This is done by combining the force-displacement relationship of the soil with the discretized motion equation of the structure which results in the final system of equation of the total dynamic system.

Usually in the seismic design of framed buildings, soil structure interaction is neglected and the dynamic response of the structure is evaluated under the assumption of a fixed or a hinged base response. The period of vibration of the structure is calculated based on this assumption and the seismic loads are evaluated. However, during actual seismic loading the soil undergoes deformations or settlements, which are imposed to the foundation, and also due to the actual soil parameters, the period of vibration of the structure increases. The increase in period of vibration makes a structure more flexible and causes a reduction in the seismic loads acting on the structure. Spyrakos et al. [2] investigated the effects of soil structure interaction on the response of base isolated multistory buildings founded on an elastic soil layer overlying rigid bedrock and subjected to a harmonic ground motion. The study demonstrated that SSI effects are significant, and the interaction between soil and structure results in a decrease of the fundamental frequency of the response and a modification in the energy dissipation, which is attributed to radiation and material damping in the soil.

Bhattacharya et al. [3] assessed lateral period of building frames incorporating soil-flexibility. Flexibility of soil medium below foundation decreases the overall stiffness of the building frames resulting in a subsequent increase in the natural periods of the system. The study showed that the presented variation curves for dynamic characteristics can be used for reasonably accurate assessment of the effect of soil-structure interaction on any building frame and for calculating base shear through a simple methodology.

Hence a detailed soil structure interaction analysis considering the actual settlements, soil conditions and support conditions is required for the evaluation of seismic loads on framed structures.

2 METHODOLOGY

Frames with 5, 10, 20 and 40 storeys have been considered in the study. Fundamental period of vibration of the frame with fixed support using codal formula in IS 1893(Part I):2002) [4] and model analysis has been evaluated. Inorder to understand the effect of soil structure interaction on fundamental period of vibration soil has been modelled as nonlinear spring and as elastic continuum using SAP 2000. Base shear representing the seismic load on the frame is then evaluated and compared for various cases.

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International Journal of Scientific & Engineering Research Volume 4, Issue 5, May-2013
ISSN 2229-5518

2.1 Data considered for analysis

Location of the building = Zone III [4]
Soil condition = Soft weathered soil
Thickness of slab = 125 mm
Storey height = 3.5 m
Floor load = 1.5 kN/m^2
Unit weight of brick = 19 kN/m^3
Unit weight of concrete = 25 kN/m^3
Live load on floor and roof = 5 kN/m^2

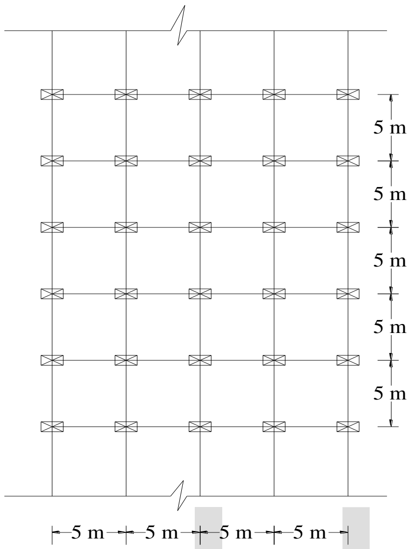

Fig. 1 Plan of building frame

2.2 Idealization of soil for modal analysis

The soil stratum is idealized by:

i) Non linear spring

The soil can take only compression during loading and this can be modelled by using a non linear compression only spring support. The stiffness of the spring in the vertical direction considering subgrade modulus of soil and type of foundation [5] used for defining the model for different frames are given in Table 1.

TABLE 1
STIFFNESS OF SPRINGS

Frame	Stiffness (kN/m)
5 storeys	243280
10 storeys	471857
20 storeys	1272500
40 storeys	2262000

ii) Elastic continuum model

This model can be considered as an approximation of real soil behaviour. The set of parameters adopted to represent the model in the analysis are young's modulus and poisson's ratio.

The soil is being idealized by 8 noded elements of solid model. Soil size of 60m×60m×40m is considered in the analysis. The building frame is placed centrally with a projection of 20 m on either side in plan. The dimensions are taken inorder to get a considerable stress distribution. At a depth of 40 m, the vertical stress has been reduced to about 25%.

The soil data used for the analysis is given in Table 2

TABLE 2
SOIL DATA USED IN ANALYSIS

Soil Condition	Soft weathered rock
Weight, γ	19 kN/m^3
Young's modulus, E	15×10^4 kN/m^2
Poisson's ratio, ν	0.33

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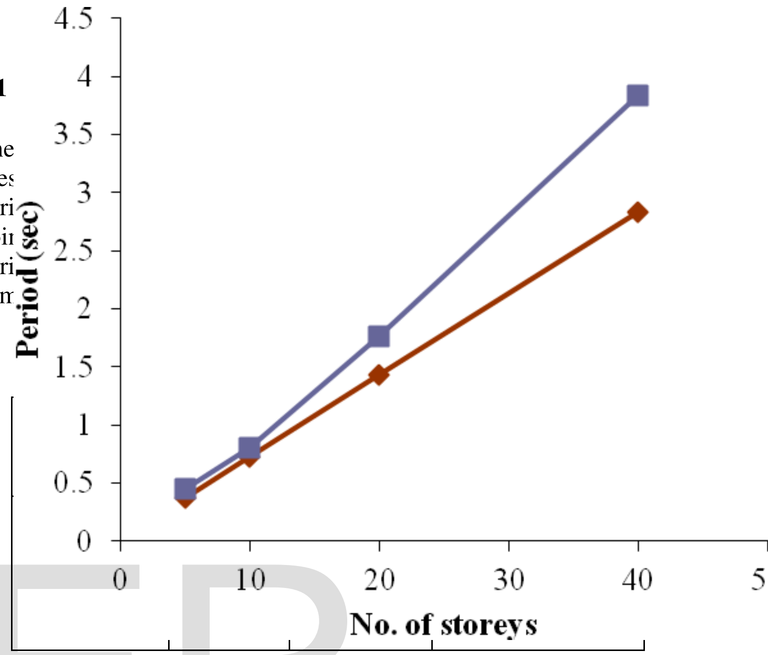

TABLE 4
EFFECT OF SSI ON FUNDAMENTAL PERIOD

No. of storeys	Fundamental period (sec)	
	Soil as non linear spring	Soil as elastic continuum
5	0.462	0.539
10	0.824	0.948
20	1.821	1.867
40	4.004	4.010

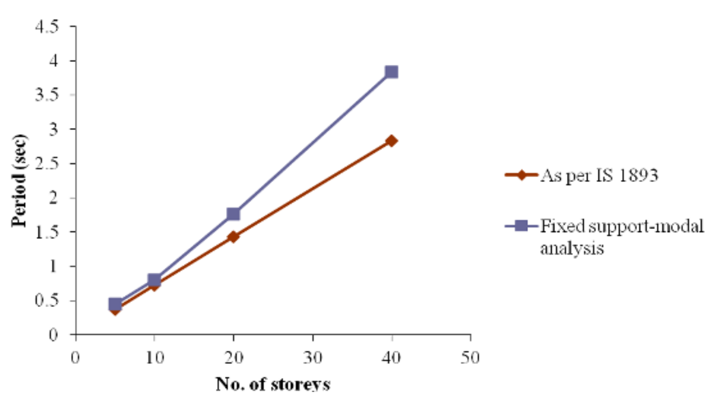

Fig. 3 Variation of Fundamental period with No. of storeys

International Journal of Scientific & Engineering Research Volume 4, Issue 5, May-2013
ISSN 2229-5518

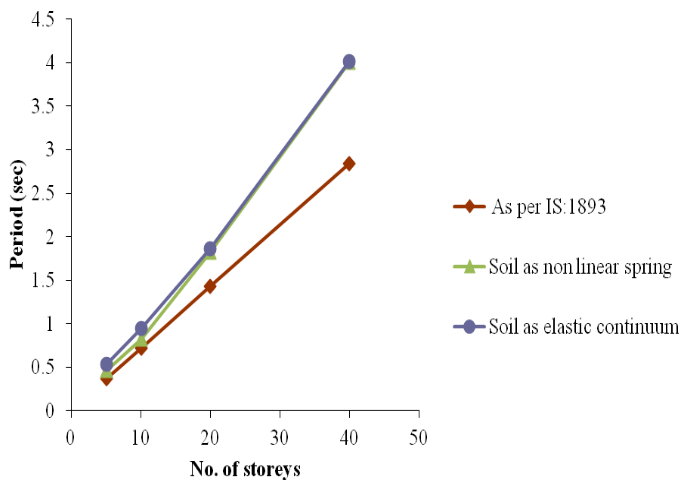

Fig. 4 Influence of soil modelling on fundamental period of vibration

3.2 Base shear

Base shear is computed from the equation [4] $V_B = A_h \times W$; where A_h - design horizontal seismic coefficient, W - seismic weight of the building, and,

$$A_h = \frac{Z\,I\,S_a}{2\,R\,g}$$

where, Z - Zone factor, I - Importance factor, R - response reduction factor and S_a/g - acceleration coefficient term (depending on the fundamental period and type of soil strata). Base shear evaluated for various frames with different support conditions are presented in Table 5 and Table 6. It can be noticed that soil structure interaction decreases the base shear value up to 29%. The percentage reduction increases with number of storeys. The decrease in base shear indicates a reduction in the lateral load on each floor causing a lesser moment in the members of the frame compared to analysis without considering soil structure interaction.

TABLE 5
BASE SHEAR FROM MODAL ANALYSIS USING SAP 2000

Support condition	No. of storeys	Base shear (kN)		% reduction in base shear from IS code method
		As per IS 1893	Modal analysis	
Frame with fixed support	5	321.23	321.23	0.00
	10	630.23	572.17	9.21
	20	767.50	622.73	18.86
	40	833.99	617.41	25.97

TABLE 6
BASE SHEAR FROM MODAL ANALYSIS USING SAP 2000

No. of storeys	Base shear		% reduction in base shear from IS code method	
	soil as non linear spring	soil as elastic continuum	soil as non linear spring	soil as elastic continuum
5	321.23	321.23	0.00	0.00
10	554.11	481.63	12.08	23.58
20	602.22	587.38	21.54	23.47
40	591.63	591.63	29.06	29.06

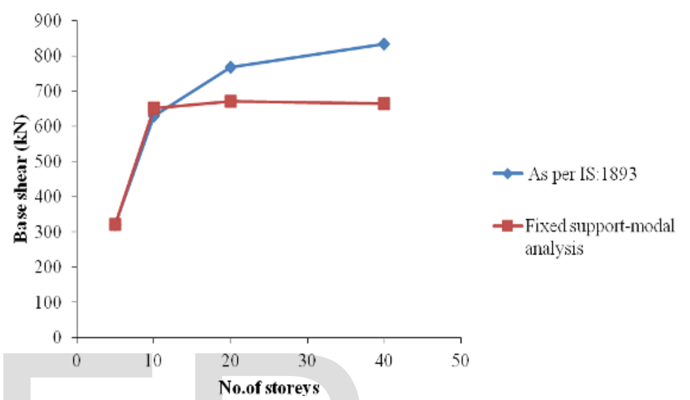

Fig. 5 Variation of base shear with No. of storeys

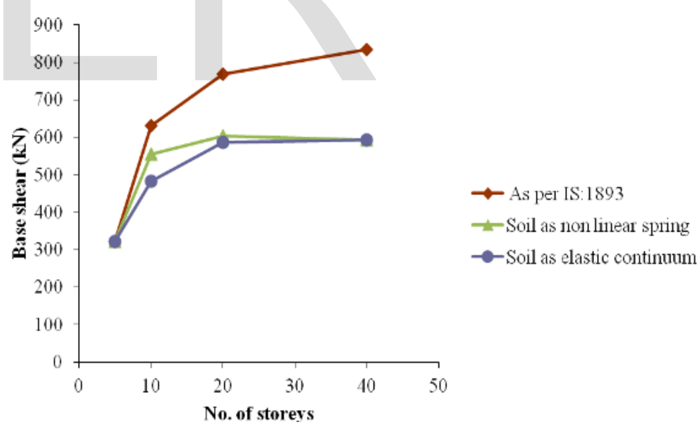

Fig. 6 Influence of soil modelling on base shear

4 CONCLUSIONS

The modal analysis of the frames were carried out with and without considering the soil structure interaction and the results are compared with those obtained through IS codal provisions.

i) The period of vibration increases for the modal analysis using as compared to the calculated value as per IS 1893(Part I):2002. The period of vibration is more when considering soil as elastic continuum models than as non linear spring model. The influence of soil structure interaction is more significant in frames with higher number of storeys.
ii) The influence of soil structure interaction on base shear is observed to be significant on frames with more than 10 storeyes.

International Journal of Scientific & Engineering Research Volume 4, Issue 5, May-2013
ISSN 2229-5518

iii) Variation in the fundamental period and base shear between modeling soil as nonlinear spring and as elastic continuum is observed to be marginal.

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