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SOIL-PILE INTERACTION UNDER SEISMIC LOAD FOR DIFFERENT GROUND CONDITION

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Abstract —*Pile foundations are commonly adopted for various types of multi storied and industrial structures, bridges and offshore structures. Their seismic design is very important to ensure efficient functioning of various structures even under severe seismic loading conditions. In the design process, ground conditions (soil type) play an important role in terms of seismic loads transferred to foundation and foundation capacity. This paper presents seismic design of pile foundations for different ground conditions. Estimation of seismic loads, for a typical multi-storied building considered being located in different seismic zones, for different ground conditions according to Indian standard are presented. Design considerations based on various theories evolved on pile foundation performance concepts under seismic conditions are discussed. Three different ground conditions are selected as exemplary cases in demonstrating the evaluation of seismic loads and seismic design of pile foundations as per codes of practice.*

Keywords*- Seismic Design, Pile Foundations, Ground Condition, Soil-pile-structure interaction.*

I. INTRODUCTION

Piles are the most commonly adopted deep foundations to support massive superstructures like multi-storey buildings, bridges, towers, dams, etc., when the founding soil is weak and result bearing capacity and settlement problems. In addition to carrying the vertical compressive loads, piles must also resist the uplift loads (loads due to wind or hydrostatic pressure) and the dynamic lateral loads which are common in the offshore structures, retaining walls and the structures in the earthquake prone regions. With increasing infrastructure growth and seismic activities, and the devastation witnessed, designing pile foundations for seismic conditions is of considerable importance. Several studies were conducted by various researchers on the seismic analysis and the design of pile foundations and evolved different theories on the same. Codes of practice available in suggest some procedures for seismic design of pile foundations. In the design process, ground condition plays an important role in selecting the design parameters and also to consider various failure mechanisms. The estimation of the loads that act on a structure during an earthquake depends on the seismicity of its location (zone) and the subsurface conditions of the site. Different codes of practice around the world have suggested different methods to estimate the seismic action on a structure. Indian standard (IS 1893: Criteria for Earthquake Resistant Design of Structures (2002)) recommend different ground conditions based on the nature of the engineering hard stratum in selecting design acceleration level.

II. AIB AND OBJECTIVE

AIM: To study the Soil-Pile Interaction under seismic forced exerted by earthquake in different zones and ground type.
OBJECTIVES:
1. To study various type of ground soil like rocky and hard soil, medium soil and soft soil.
2. To study different zones like Zone III, Zone IV, Zone V.
3. To find load Distribution using Indian Code (IS 1893) and Euro Code (EN 1998)
4. To analyze structure in SAP2000.
5. Compression between IS Code and EN Code

III. LITERATURE REVIEW

A. Seismic Design of Pile Foundations for Different Ground Condition, 15 WCEE 2012, LISBOA2012

A. Murali Krishna, A. Phani Teja, S. Bhattacharya, Barnali Ghosh;
1. The frictional resistance offered by the soil in the liquefiable layer must be neglected. This leads to increase in the pile length for the same factor of safety.
2. Due to change in fixity point after liquefaction and loss of lateral confinement to the pile in the liquefied layer, the pile is essentially designed as a column against buckling. Bhattacharya and Bolton (2004) suggested the minimum pile diameters needed to be adopted based on thickness of the liquefiable layer.

3. The natural period of the system will change due to liquefaction because of the reduction in strength of the soil and the change in fixity point.
4. When the layer is liquefied, the soil layers above the liquefied zone move according to the liquefied zone movement, resulting in passive pressures on the pile. These additional passive pressures rise the moments at the fixity point and thus the moment capacity of pile has to be increased. This can be achieved by the increasing the reinforcement in the originally adopted section or by increasing the pile section to meet the requirement.

Considering the above points, the design of the pile for the estimated seismic loads is again done assuming the cohesion less soil layer in the soil profile is liquefiable. Variations of the pile capacity versus and the resulting Factor of safety values with the pile diameter and the cases with and without liquefaction. The results show that a driven cast in-situ, free headed pile of length 18 m and diameter 0.95 m must be adopted for the liquefiable case to get the factor of safety of 3.5.

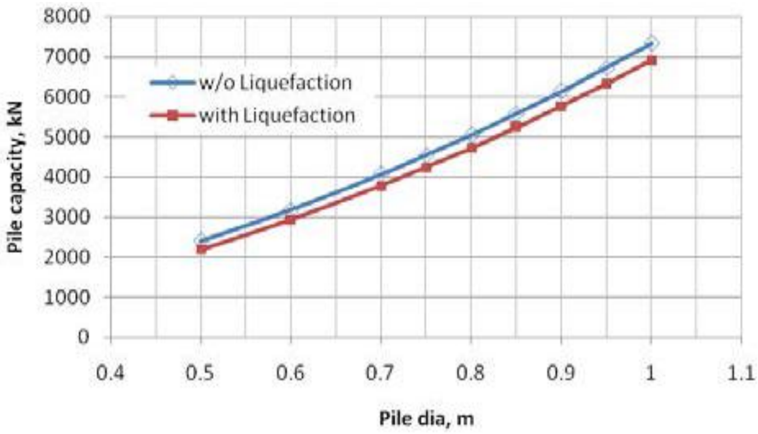


Figure.1 Variation of Pile Capacity (kN) with the Pile diameter (m) with and without Liquefaction

With the increasing seismic activities in the recent times an efficient design of the pile foundations to resist the estimated earthquake loads is a major concerned issue. In this interest, this study deals with the estimation of the seismic loads on a super structure as per the two international codes selected, IS 1893 and EN 1998. Different cases are considered assuming the location of the structure to be in different seismic zones of India and on different ground types (Type C and Type D). The estimated seismic loads are applied to the SAP2000 model of the structure and analyzed to find the maximum (design) foundation loads. Liquefaction potential was evaluated, before proceeding to the pile design, for the selected soil profiles in the Guwahati region. Then the pile is designed for a selected case of seismic zone V and the ground type C. The pile is first designed for using the Indian Standard IS 2911. Then the design was checked against lateral deflection and limiting moment capacity of pile for the estimated lateral loads and moments under seismic condition using commonly used method called the Characteristic Load Method. Further the seismic design is revised for both the cases considering the soil profile to be liquefiable. It is to conclude that ground conditions should be considered much prior in the analysis of any structure to evaluate the seismic loads acting on the structure which will further influence the foundation design loads and foundation capacity.

B. Non-Linear Analysis Of Soil-Pile-Structure Interaction Under Seismic Loads; The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China

Yingcai Han and Shin-Tower Wang; "An examination of the computation results for the seismic response of the vacuum tower structure, supported with different foundation conditions, suggests the following conclusions:
1. The nonlinear behavior of the soil-pile system can be simulated using the model of boundary zone.
The validity of the model has been verified by dynamic experiments on full-scale pile foundations for both linear and nonlinear vibrations.
2. The soil – pile interaction is an important factor which affects the stiffness and damping of foundation. The liquefaction of a layer of saturated fine sand can reduce the horizontal stiffness significantly, and further damage is possible.
3. The soil-pile-structure interaction should be considered in a seismic analysis. The theoretical prediction for a structure fixed on a rigid base without the interaction does not represent the real seismic response, since the stiffness is overestimated and the damping is underestimated.
4. The problem of soil-pile-structure interaction is complex in a seismic environment. The approximate and practical method described in this study is workable with the help of two computer programs (DYNAN 2.0 and SAP2000)."

C. Numerical Study of Piles Group under Seismic Loading in Frictinal Soil—Inclination Effect; Open Journal of Earthquake Research, 2014, 3, 15-21

Fadi Hage Chehade, Marwan Sadek, Douaa Bachir; "In this paper, we present a three-dimensional numerical modeling of the soil-pile-structure interaction under seismic loading. The effect of the plasticity has been investigated in the case of a frictional soil as well as the effect of the dilancy angle. The numerical modeling has been carried by using harmonic excitation and real seismic loading recorded during the Kocaeli earthquake (Turkey, 1999). The effect of the pile inclination has been also analyzed. For simplicity, we consider the case that the piles are embedded in a homogeneous soil. The case of heterogeneous soil could be treated in the future.
The harmonic loading leads to high values of the internal forces (Bending moment, shear) especially when the frequency of the load is near to the proper frequency of the soil. For the example treated here, the plasticity of the soil has a minor effect on the results. For frictional soil, the plasticity spreads from the surface due to the low confinement of the soil in this area. Plasticization of the soil around the piles head makes them more vulnerable, and the post seismic observations of damaged piles show the formation of a vacuum around the head of the piles. The inclination of piles leads to a reduction in the lateral amplification of the superstructure resulting from an increase in the rigidity of the system. The inclination of piles can be beneficial for both the dynamic behavior and the behavior of the superstructure. It depends on the interaction of the frequency of the seismic load with the frequencies of the soil-pile-structure. The inclination increases the lateral stiffness of the foundation which, unfortunately, can cause a significant increase in the load transmitted to the foundation of the superstructure. Despite the improved performance of inclined piles, the bending forces at the top of piles are still very significant."

D. Effect of Liquefaction on Soil Pile Interaction under Seismic Loading; Proceedings of International Conference on Architecture, Structure and Civil Engineering (ICASCE'15) Antalya (Turkey) Sept. 7-8, 2015 pp. 1-10

Jamal Ali, Syed Muhammad Jamil, Ph.D., Hamza Masud, Sandeerah Choudhary and Kamran Jilani; "In this study, aspects of the behavior of sandy soils towards seismic loading are discussed. A base shaking analysis was conducted for a singular circular pile in various formations of soil strata with major emphasis on the depth and relative position of a liquefiable layer under seismic loading.
This research study gives a general view of the minor features of soil and ground inclination that must be considered while designing the pile foundations. Even mild slopes and small lens of liquefiable layers can be very damaging in case of earthquakes.
A small lens of liquefiable layer sandwiched between the non-liquefiable strata can also cause great deflections and failure in pile. Similarly, pile displacement is a function of time and pile deflection is significantly more in liquefiable soil strata. The depth of liquefiable layer also dictates the total lateral displacement of pile. As the depth is more, the magnitude of acceleration is higher and the pile experiences higher lateral load. The effect of spacing and diameter of stone column have direct relation to end pile deflection. The effect of diameter of stone column is more important than varying the spacing between columns. Hence for design purposes, hit and trail method by varying the diameter of column can be employed to optimize the design."

E. Pile Design in Liquefying Soil; The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China;14 WCEE

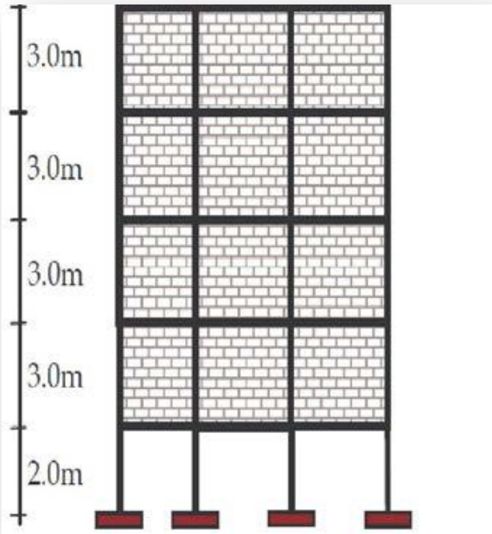
Vijay K. Puri and Shamsher Prakash; "The design of pile foundations in liquefying soil needs an understanding of soil liquefaction, behavior of soils following liquefaction and the soil-pile interaction. The practice of pile design in liquefying soil has progressed considerably in the last decade based on observations during the past earthquakes and experimental studies on centrifuge and large shake table. However, there are several parameters and questions which need to be examined further in detail."

IV. PROBLEM STATEMENT

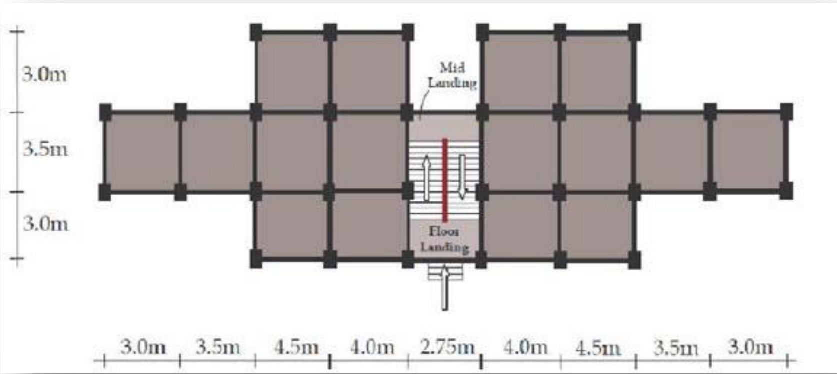
A model of a typical multi storied residential building is considered and the seismic action on it is determined for the different seismic zones in India and the different ground types. The two procedures, as per Indian Code (IS 1893) and Euro Code (EN8) are followed to estimate the seismic loads on the structure, and compared.
As a case study, to estimate the seismic loads that act on a structure during an earthquake, a typical multi storied building frame model is considered. The building frame is a moment resisting frame with reinforced concrete members. The plan and elevation of the concrete building frame considered are shown in Fig. 1.5 and 1.6. The parameters used for the modeling of the building were based on the values used in general practice during the construction of a residential complex. Suitable cross-sectional dimensions of beams and columns, as well as the thickness of slabs and unreinforced brick masonry infill walls were assumed (all in accordance with the Indian standards). The assumed values are shown in Table 1. The grade of concrete and the grade of steel were considered to be M30 and Fe415 respectively. Also a uniform imposed load intensity of 3.0 kPa and 1.5 kPa were assumed to be present on all the floors and roof slab respectively. The modeling of the building without the staircase was done in the computer program SAP2000 with the assumed geometry and material properties.

Members	Dimensions
Beams	230 mm x 450 mm
Columns	450 mm x 450 mm
Slab Thickness	150 mm
Masonry Wall Thickness	230 mm

Dimensions of the members of the RC Building Frame



ELEVATION OF THE BUILDING:



PLAN OF THE BUILDING:

V. METHODOLOGY

ESTIMATION OF SEISMIC LOADS ON THE STRUCTURE

For an efficient seismic design of the foundation, it is important to estimate the loads that are being transferred to the foundation during an earthquake. These loads depend on the seismic loads that act on the super structure during an earthquake. Different codes around the world propose different methods of estimation of these seismic loads on the super structure. The methods proposed by the Indian standard (IS 1893) and the Eurocode (EN 1998) are reviewed and used to estimate the seismic loads. A case study of a typical multi storied structure is considered as a model super structure for the purpose.

Seismic Loads as per IS 1893 (2002)

The Indian Standard (IS 1893) identifies three types of soils as foundation soil, based on N values obtained from the standard penetration test (SPT). Type I, Type II and Type III being the rock or hard soils, medium soils and soft soils respectively. In the present discussion, the seismic loads on the structure are evaluated for the Type II and Type III soils which are equivalent to the ground types C and D of the Euro code (EN8). Also, different cases are considered for the location of the building being in different seismic zones: Zone V, Zone IV and Zone III of India.

Calculating the Base Shear

The total lateral force that acts at the base of the structure during an earthquake is called the design seismic base shear (VB). As per IS 1893, base shear is calculated using the Eqn. 1.

$$\mathbf{Vb = Ah \, . \, Ws} \qquad (1)$$

Where; Vb= Base Shear
Ah= horizontal seismic coefficient
Ws= Seismic weight of the structure

The seismic weight of the structure (Ws) is as calculated above.
Equation 2 is being used to calculate the design horizontal seismic coefficient.

$$\mathbf{Ah=Z. \, I. \, Sa \, / \, 2. \, R. \, g} \qquad (2)$$

Where; Z= Zone factor
I= Importance factor
Sa/g=Average spectral acceleration coefficient
R= Special moment resisting frame

The time period of the structure is calculated for a RC frame building using the Eqn. 3 as per IS code.

$$\mathbf{T = 0.075 \, . \, h^{0.75}} \qquad (3)$$

Where; h= Height of 14 m
T = 0.543s

Assuming the damping to be five percent, the base shear acting on the structure in different zones and different soil types is calculated.

Foundation loads

The earthquake loads calculated from the aforementioned equations are applied to the structure in addition to the normal loads for structural analysis using a computer program SAP2000. The analysis is performed for the dead, live and the earthquake loads for various load combinations prescribed in the code. The results of the analysis consisted of the forces, displacements and reactions of all the members of the structure. The results are sorted to find the maximum loads that are transferred to the foundation of the system. Table 3 shows the maximum (design) loads transferred to the foundation in each case. Where '*P*' is the axial load, '*V*' is the lateral force and '*M*' is the moment.

Seismic Loads as per IS 1893 (2002)

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Foundation loads

Results of structural analysis in SAP2000 including various load combinations with the above evaluated seismic loads are shown the Table 5. The table presents the maximum loads at the foundation level according to Eurocode (EN1998): '*P*', the axial load; '*V*', the lateral load and '*M*', the moment. Out of the all these cases, the most severe one which is Zone V, Type D is selected for the liquefaction evaluation case study and the pile design.

VI. RESULTS

➢ **SAP2000 v14**

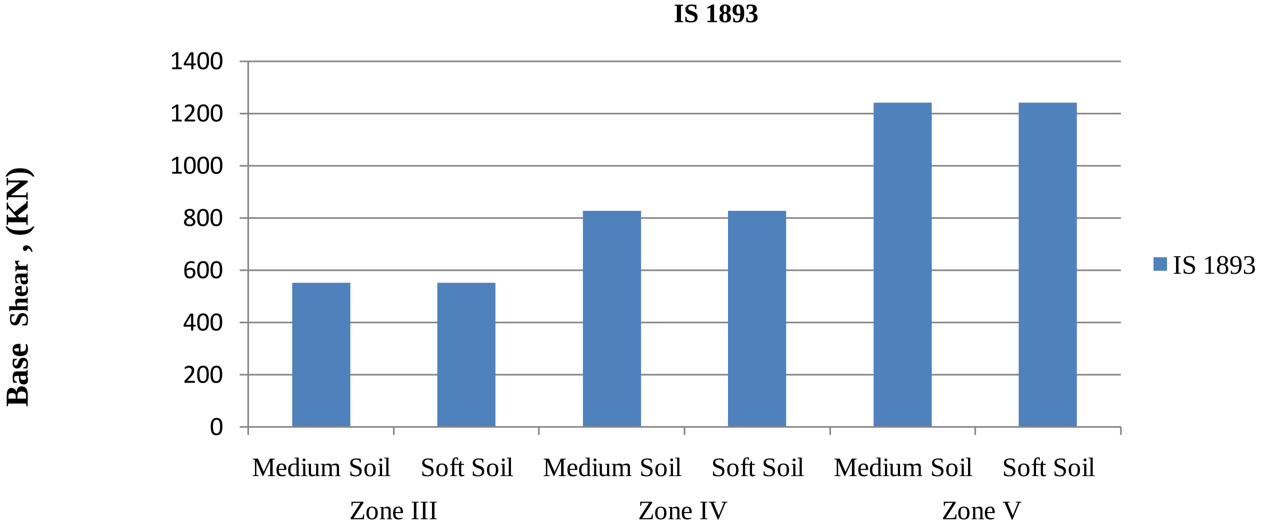
The seismic weight of the building (*Ws*) is calculated as the total dead load plus one-fourth of the imposed load. The seismic weight of each floor of the structure is calculated to be **1908.52 kN** and that of the roof to be **1551.64 kN**. So the seismic weight of the entire structure is four times the seismic weight of each floor plus the seismic weight of the roof. Thus, the seismic weight
(*Ws*) of the considered structure is **9185.72 kN.**

➢ **IS 1893: Criteria for Earthquake Resistant Design of Structures (2002)**

Base Shear Calculation:

Seismic Zone	Ground Type	Z	Sa/g	Ah	VB(KN)
Zone III	Medium Soil	0.16	2.5	0.06	551
	Soft Soil	0.16	2.5	0.06	551
Zone IV	Medium Soil	0.24	2.5	0.09	827
	Soft Soil	0.24	2.5	0.09	827
Zone V	Medium Soil	0.36	2.5	0.135	1240
	Soft Soil	0.36	2.5	0.135	1240

Base Shear calculated for different cases as per IS 1893



A bar chart of the base shear as per IS 1893

Foundation Load Calculation:

Seismic Zone	Ground Type	Max. P (kN)	Max. V (kN)	Max. M (kN-m)
Zone III	Medium Soil	898	128	126
	Soft Soil	931	175	171
Zone IV	Medium Soil	909	70	166
	Soft Soil	1191	240	234
Zone V	Medium Soil	1158	233	225
	Soft Soil	1580	338	328

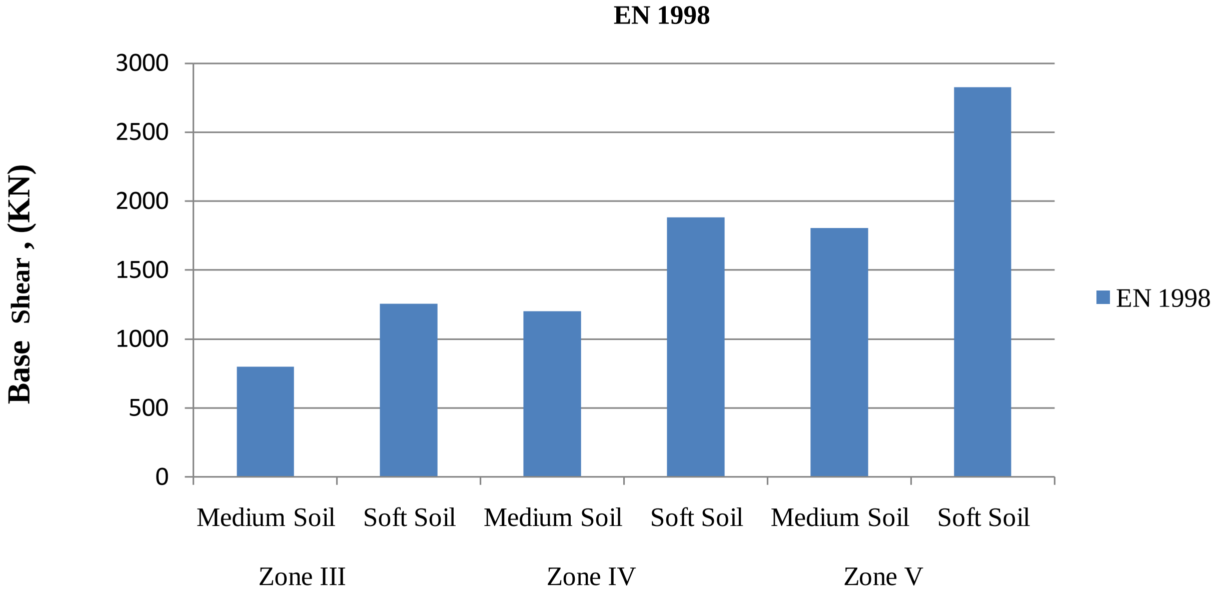
Design Loads transferred to the pile as per IS 1893

➢ **Eurocode (EN 1998: Design of Structures for Earthquake Resistance (2004))**

Base Shear Calculation:

Seismic Zone	Ground Type	Sd (T)	Fb (kN)
Zone III	Medium Soil	1.01	802
	Soft Soil	1.58	1256
Zone IV	Medium Soil	1.15	1203
	Soft Soil	2.37	1883
Zone V	Medium Soil	2.27	1805
	Soft Soil	3.55	2825

Base Shear calculated for different cases as per EN 1998



A bar chart of the base shear as per EN 1998

Foundation Load Calculation:

Seismic Zone	Ground Type	Max. P (kN)	Max. V (kN)	Max. M (kN-m)
Zone III	Medium Soil	898	128	126
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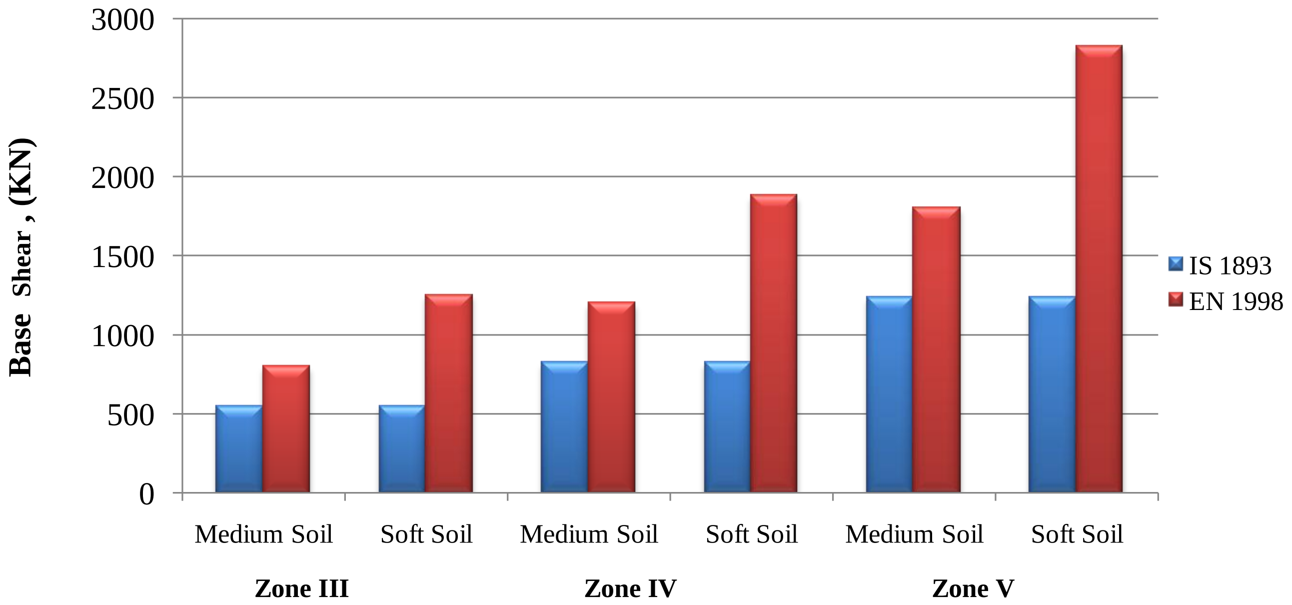
Design Loads transferred to the pile as per EN 1998

- **Comparing Base Shear of the two given codes.**



A bar chart comparing the base shear forces as per the two codes

VII. CONCLUSION

The variations in the values of the seismic loads calculated for the same structure in the above sections show that the two codes differ in their considerations.

1. The first and the major difference one can spot is the identification of the soil types. The Indian Standard IS1893 considers only three types of soils for determining the design accelerations from the response spectrum, while the Eurocode identifies five types.
2. Base Shear results in IS 1893 for medium and soft soil in different seismic zones like Zone III, Zone IV, Zone V to be 551, 827, 1240 respectively. And for Medium and Soft soil value to be same.
3. Base Shear results in EN 1998 for medium and soft soil in different seismic zones like Zone III for Medium soil 802 and Soft soil 1256; Zone IV for Medium soil 1203 and Soft soil 1883; Zone V for Medium soil 1805 and Soft soil 2825.
4. The other difference that is observed is the difference in distribution of the estimated base shear force in the two codes (Graph 6.3). The Indian code distributes the base shear force to the floor levels by the proportions of the weighted average of the square of the height of the floor while the Eurocode distributes it by the proportion of the weighted average of just the heights of the floor level. This causes the lower stories to carry much less lateral load as compared to the top floors as per the Indian Standard whereas as per the Eurocode the distribution much more even, in the proportion of their heights.
5. The considerations and the narrow classification of soil types and spectral acceleration values recommended by IS 1893 cause the estimated seismic loads to be same for the two cases of ground types.
6. Also the values of calculated design loads show that the Indian code is more lenient in estimating the loads while the Eurocode estimates more sterner (and thus more safer) values.

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