Study on Vertical Settlement and Lateral Displacement in Different Types of Soils

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Abstract— **The behaviour of a structure is significantly influenced by the design of foundation, types of soils, type of spans present in the structure (Small or large span), number of storeys and types of loads to which the structure is subjected to. It is important to determine the magnitude of foundation settlement and differential settlements to assess the ability of super structure to carry the loads acting on the structure. The lateral displacement of structure under loads is also a great concern to limit it to minimum especially in tall structures. In this paper the investigation is carried out to study the estimation of vertical settlement and lateral displacement in small and large span buildings in different types of soils when subjected to gravity and lateral loads. The foundation support is assigned by springs known as sub grade modulus of soil, which is an important parameter for the soil interaction. The lateral loads acting on the structure correspond to various earthquake zones; wind zones specified in the relevant IS codes of practice. The amount of vertical settlement and lateral displacement occurring in different types of buildings with small and large column spacing and the impact of size of foundation on these buildings is studied.**

Index Terms— **Building with small span and Building with large span, Lateral displacement, Size of footing, Sub grade modulus reaction 'K_s', Vertical settlement.**

I. Introduction

The behaviour of the structure includes its ability to carry loads, foundation settlement and lateral displacement at various heights of the structure. The settlement of foundations under working load conditions is an important design consideration; since small settlements of the foundations will also alter forces of the structural members. As per IS: 1904-1986 the total settlement of the foundation should not be more than the permissible limits [6]. The permissible values of settlement for RC structures is the maximum settlement for isolated foundation on sand is 50mm and on clay is 75mm and the angular distortion is 1/666. A structure is taken such that the columns have large span of 6m for one building and small span of 3m for another building in both x and y directions for both 5 storey and 10 storey buildings for the same plinth area. The study has been carried out on the structure which is subjected to dead load, live load, earthquake loads for all zones and wind loads having wind velocities as V_b = 55m/s, V_b = 50m/s, V_b = 47m/s and V_b=39m/s. The structure is supported by isolated square foundation that rests on ground which transmits the loads of the structure to the soil which causes vertical settlement δy and lateral displacement δx. The structure is modeled by springs known as sub grade modulus of soil 'K_s' as support. Winkler (1867) carried out Flexural analysis of foundations on soils by modeling the soil medium as a system of identical but mutually independent, closely spaced, discrete and linearly elastic springs which led to the development of the concept of modulus of sub grade reaction [1,2]. The sub grade modulus reaction gives the relation between soil pressure and deflection, is one of the most efficient parameter that is used for structural analysis of foundation members. The sub grade modulus reaction (K_s) depends to some parameters like soil type, size, shape and depth of foundation. Many researches including Biot (1937), Terzaghi (1955), Vesic (1961) and have investigated the effective factors and determination approaches of K_s [1, 2]. Geometry and dimensions of the foundation and soil layering are assigned to be the most important effective parameters on K_s [3]. The foundation support is assigned by giving the values of size of the footing and sub grade modulus reaction K_s. Depending upon the type of the soil the values of sub grade modulus reaction K_s have been assumed to be 12000, 24000, 36000, 48000 and 60,000 KN/m^3 for the study.

Manuscript received September 12, 2014.

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II. Modeling and Analysis of the Structures

A 5 storey and 10 storey structures are taken in such a way that the columns have large span of 6m for one building and small span of 3m for another building in both x and y directions for the same plinth area. The total height of 5 storey building is considered as 15m and 10 storey building is considered as 30m. The height of each storey is taken as 3m respectively. The structure is supported by isolated square foundation that rests on ground which transmits the loads of the structure to the soil which causes vertical settlement δy and lateral displacement δx. The foundation support is assigned by giving the values of size of the footing and sub grade modulus reaction K_s. Depending upon the type of the soil the values of sub grade modulus reaction K_s have been assumed to be 12000, 24000, 36000, 48000 and 60,000 KN/m^3 for the study. The calculated size of footing is measured for the assumed values of sub grade modulus reaction K_s using Vesic's equation shown in Table 1.

Table1: Calculated Size of the footing

K_s (KN/m^3)	12000	24000	36000	48000	60000
B(m)	2.29	1.145	0.763	0.572	0.458

The size of beams and columns for both the large span and small span buildings is taken in such a way that they are having same contact area. While providing large size of footing, the size of the footing for both the large span and small span buildings is taken in such a way that they are having same contact area. The structure is analyzed and subjected to dead load, live load, earthquake loads for all zones and wind loads having wind velocities as V_b = 55m/s, V_b = 50m/s, V_b = 47m/s and V_b=39m/s using STAAD PRO. For both the buildings, providing calculated size of the footings and providing large size of footing than the required size for the different values of K_s is given and the maximum values of vertical settlement δy and lateral displacement δx are observed.

III. RESULTS AND DISCUSSIONDS

In the study the maximum vertical settlement δy and lateral displacement δx are estimated for 5 storey and 10 storey buildings in which the columns have large span of 6m for one building and small span of 3m for another building in both x and y directions for both the cases. It is observed that the top most nodes in the middle frame of the buildings is having the maximum vertical settlement δy and lateral displacement δx. The middle frame structure is considered to be more critical compared to other frames. The maximum vertical settlement δy and lateral displacement δx increases with the increase in the storey level of the building.

5 Storey Building:

Vertical Settlement:

As the K_s value ranging from 12000 to 60000 KN/m^3 increases, having calculated size of the footing the vertical settlement δy increases. For the K_s value 12000 to 60000 KN/m^3 the vertical settlement δy increases, for large span building from 78mm to 323mm and for the small span building from 30mm to 118mm. There is a need to provide more size of footing for the critical values of δy to minimize the vertical settlement.

As the K_s value ranging from 12000 to 60000 KN/m^3 increases, by providing more size of the footing the vertical settlement δy decreases. It is observed that for both large span and small span buildings having the K_s value 12000-24000 KN/m^3, there is significant reduction in the vertical settlements δy ranging from 100mm to 50mm. For the K_s value 24000-60000 KN/m^3, there is margin reduction in the vertical settlements δy ranging from 50mm to 27mm. Hence more concern should be taken when the soil has the K_s value ranging from 12000-24000 KN/m^3.

Lateral Displacement:

For both large and small span buildings as the K_s value ranging from 12000 to 60000 KN/m^3 increases, having calculated size of footing, the lateral displacement δx increases in all earthquake zones. The lateral displacement δx for the K_s value 60000 KN/m^3 in Zone II, for large span building is 23mm and for small span building is 15mm. In Zone III, for large span building is 36mm and for small span building is 24mm. In Zone IV, for large span building is 54mm and for small span building is 36mm. In Zone V, for large span building is 80mm and for small span building is 54mm. There is a need to provide more size of footing for the critical values of δx to minimize the lateral settlement.

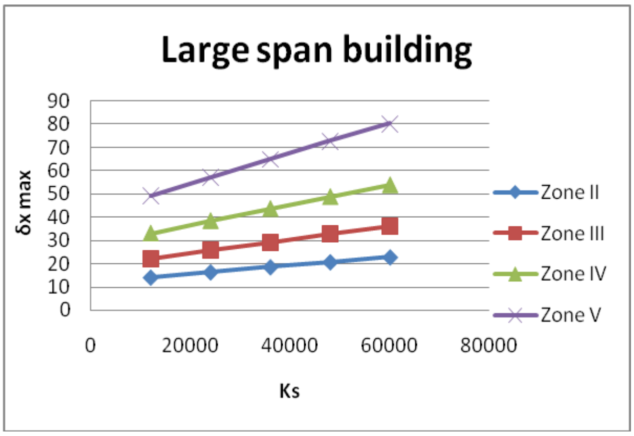

Fig 1: Lateral Displacement Vs Modulus of Subgrade Reaction for Calculated size of footing in Large span building

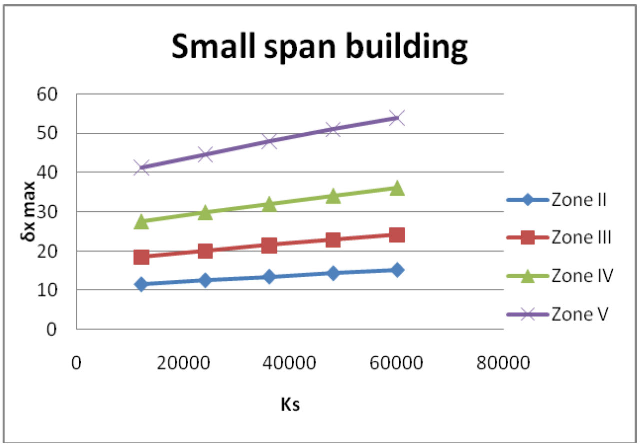

Fig 2: Lateral Displacement Vs Modulus of Subgrade Reaction for Calculated size of footing in Small span building

For both large and small span buildings as the K_s value ranging from 12000 to 60000 KN/m^3 increases, providing more size of footing the lateral displacement δx decreases in all earthquake zones. The lateral displacement δx for the K_s value 60000 KN/m^3 in Zone II, for large span building is 12mm and for small span building is 11mm. In Zone III, for large span building is 19mm and for small span building is 18mm. In Zone IV, for large span building is 29mm and for small span building is 27mm. In Zone V, for large span building is 43mm and for small span building is 41mm. It is observed that providing more size of footing the lateral displacement has decreased from 80mm to 43mm for large span building and decreased from 54mm to 41mm for small span building in higher earthquake zone.

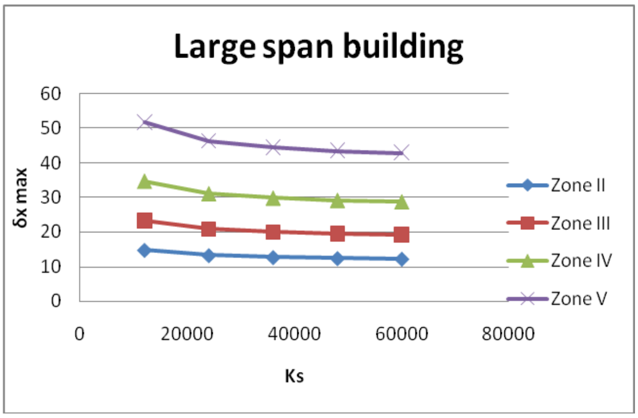

Fig 3: Lateral Displacement Vs Modulus of Subgrade Reaction for Provided size of footing in Large span building

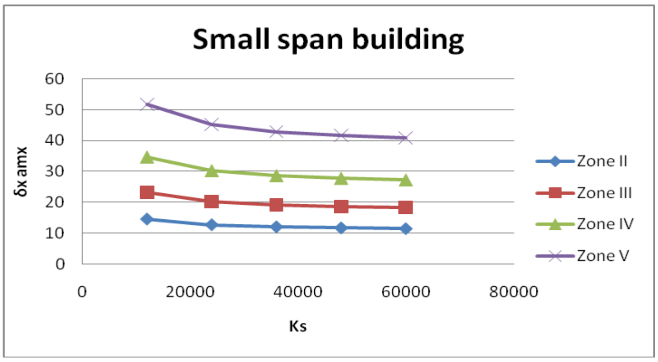

Fig 4: Lateral Displacement Vs Modulus of Subgrade Reaction for Provided size of footing in Small span building

For both large and small span buildings as the K_s value ranging from 12000 to 60000 KN/m^3 increases, having calculated size of footing, the lateral displacement δx increases for different wind velocities. The lateral displacement δx for the K_s value 60000 KN/m^3 with wind velocity V_b = 39m/s, in large span building is 24mm and in small span building is 16mm. For wind velocity V_b = 47m/s, in large span building is 34mm and in small span building is 23mm. For wind velocity V_b = 50m/s, in large span building is 38mm and in small span building is 26mm. For wind velocity V_b = 55m/s, in large span building is 46mm and in small span building is 31mm. There is a need to provide more size of footing for the critical values of δx to minimize the lateral settlement.

For both large and small span buildings as the K_s value ranging from 12000 to 60000 KN/m^3 increases, providing more size of footing the lateral displacement δx decreases for different wind velocities. The lateral displacement δx for the K_s value 60000 KN/m^3 with wind velocity V_b = 39m/s, in large span building is 13mm and in small span building is 12mm. For wind velocity V_b = 47m/s, in large span building is 18mm and in small span building is 17mm. For wind velocity V_b = 50m/s, in large span building is 21mm and in small span building is 19mm. For wind velocity V_b = 55m/s, in large span building is 25mm and in small span building is 23mm. It is observed that providing more size of footing the lateral displacement has decreased from 46mm to 25mm for large span building and decreased from 31mm to 23mm for small span building having higher wind velocity.

10 Storey Building:

Vertical Settlement:

As the K_s value ranging from 12000 to 60000 KN/m^3 increases, having calculated size of the footing the vertical settlement δy increases. For the K_s value 12000 to 60000 KN/m^3 the vertical settlement δy increases, for large span building from 140mm to 580mm and for the small span building from 57mm to 213mm. There is a need to provide more size of footing for the critical values of δy to minimize the vertical settlement.

As the K_s value ranging from 12000 to 60000 KN/m^3 increases, by providing more size of the footing the vertical settlement δy decreases. It is observed that for both large span and small span buildings having the K_s value 12000-24000 KN/m^3, there is significant reduction in the vertical settlements δy ranging from 110mm to 64mm. For the K_s value 24000-60000 KN/m^3, there is margin reduction in the vertical settlements δy ranging from 64mm to 36mm. Hence more concern should be taken when the soil has the K_s value ranging from 12000-24000 KN/m^3.

Lateral Displacement:

For both large and small span buildings as the K_s value ranging from 12000 to 60000 KN/m^3 increases, having calculated size of footing, the lateral displacement δx increases in all earthquake zones. The lateral displacement δx for the K_s value 60000 KN/m^3 in Zone II, for large span building is 58mm and for small span building is 29mm. In Zone III, for large span building is 92mm and for small span building is 47mm. In Zone IV, for large span building is 137mm and for small span building is 70mm. In Zone V, for large span building is 205mm and for small span building is 105mm. There is a need to provide more size of footing for the critical values of δx to minimize the lateral settlement.

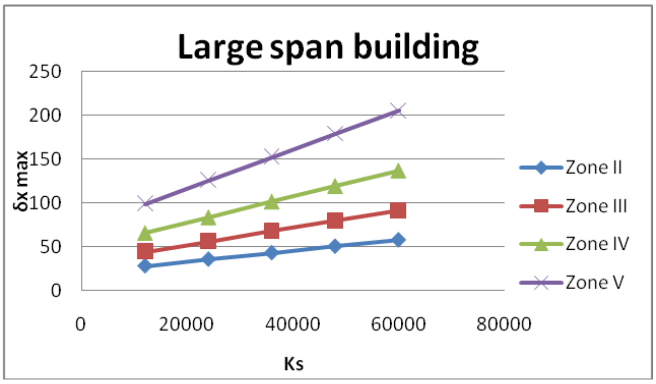

Fig 5: Lateral Displacement Vs Modulus of Subgrade Reaction for Calculated size of footing in Large span building

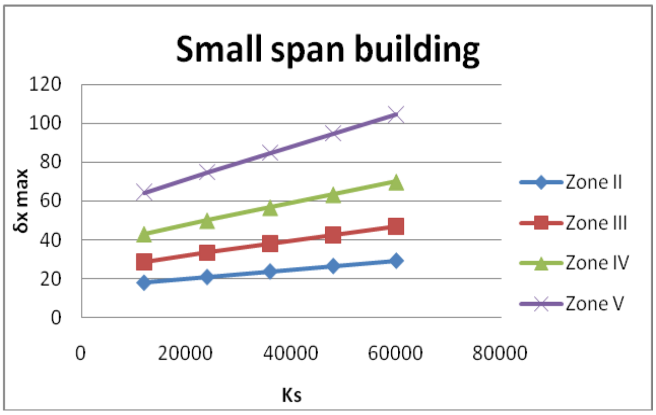

Fig 6: Lateral Displacement Vs Modulus of Subgrade Reaction for Calculated size of footing in Small span building

For both large and small span buildings as the K_s value ranging from 12000 to 60000 KN/m^3 increases, providing more size of footing the lateral displacement δx decreases in all earthquake zones. The lateral displacement δx for the K_s value 60000 KN/m^3 in Zone II, for large span building is 21mm and for small span building is 16mm. In Zone III, for large span building is 34mm and for small span building is 26mm. In Zone IV, for large span building is 50mm and for small span building is 39mm. In Zone V, for large span building is 75mm and for small span building is 58mm. It is observed that providing more size of footing the lateral displacement has decreased from 205mm to 75mm for large span building and decreased from 105mm to 58mm for small span building in higher earthquake zone.

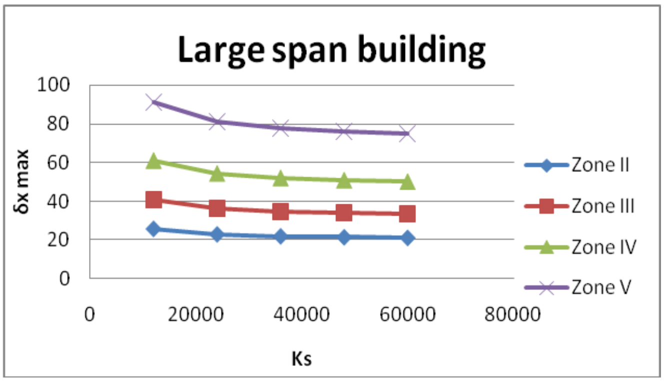

Fig 7: Lateral Displacement Vs Modulus of Subgrade Reaction for Provided size of footing in Large span building

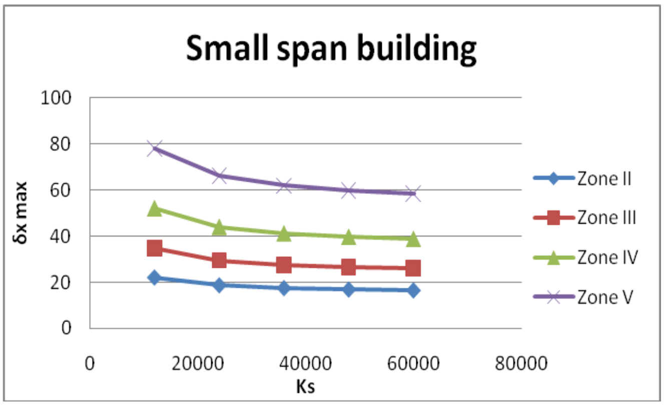

Fig 8: Lateral Displacement Vs Modulus of Subgrade Reaction for Provided size of footing in Small span building

For both large and small span buildings as the K_s value ranging from 12000 to 60000 KN/m^3 increases, having calculated size of footing, the lateral displacement δx increases for different wind velocities. The lateral displacement δx for the K_s value 60000 KN/m^3 with wind velocity V_b = 39m/s, in large span building is 109mm and in small span building is 55mm. For wind velocity V_b = 47m/s, in large span building is 158mm and in small span building is 80mm. For wind velocity V_b = 50m/s, in large span building is 178mm and in small span building is 91mm. For wind velocity V_b = 55m/s, in large span building is 215mm and in small span building is 110mm. There is a need to provide more size of footing for the critical values of δx to minimize the lateral settlement.

For both large and small span buildings as the K_s value ranging from 12000 to 60000 KN/m^3 increases, providing more size of footing the lateral displacement δx decreases for different wind velocities. The lateral displacement δx for the K_s value 60000 KN/m^3 with wind velocity V_b = 39m/s, in large span building is 40mm and in small span building is 31mm. For wind velocity V_b = 47m/s, in large span building is 58mm and in small span building is 45mm. For wind velocity V_b = 50m/s, in large span building is 66mm and in small span building is 51mm. For wind velocity V_b = 55m/s, in large span building is 79mm and in small span building is 61mm. It is observed that providing more size of footing the lateral displacement has decreased from 215mm to 79mm for large span building and decreased from 110mm to 61mm for small span building having higher wind velocity.

IV. Conclusion

The vertical settlement δy and lateral displacement δx are estimated for 5 storey and 10 storey buildings in which the columns are having large span of 6m for one building and small span of 3m for another building in both x and y directions for both th cases. The values of sub grade modulus reaction K_s have been assumed 12000, 24000, 36000, 48000 and 60,000 KN/m^3 for the study.

Vertical Settlement:

1.) With the increase in K_s values ranging from 12000 to 60000 KN/m^3 having calculated size of footing, the vertical settlement δy increases in both 5 storey and 10 storey buildings.

2.) In 5 storey, it increases from 78mm to 323mm for large span and 30mm to 118mm for small span buildings and in 10 storey, it increases from 140 to 580mm for large span and 57 to 213 for small span buildings. There is a need to provide more size of footing for the critical values of δy to minimize the vertical settlement especially for the large span buildings.

3.) With the increase in K_s values ranging from 12000 to 60000 KN/m^3 providing more size of footing, the vertical settlement δy decreases in both 5 storey and 10 storey buildings.

4.) It is observed that for the K_s value 12000-24000 KN/m^3, there is significant reduction in the vertical settlements δy; in 5 storey ranging from 100mm to 50mm and in 10 stor1ey ranging from 110mm to 64mm. For the K_s value 24000-60000 KN/m^3, there is margin reduction in the vertical settlements δy; in 5 storey ranging from 50mm to 27mm and in 10 storey ranging from 64mm to 36mm. Hence more concern should be taken when the soil has the K_s value ranging from 12000-24000 KN/m^3.

Lateral Displacement:

1.) With the increase in K_s values ranging from 12000 to 60000 having calculated size of footing, the lateral displacement δx increases in all earthquake zones and for different wind speeds in both 5 storey and 10 storey buildings. There is a need to provide more size of footing for the critical values of δx to minimize the lateral settlement.

2.) With the increase in K_s values ranging from 12000 to 60000 providing more size of footing, the lateral settlement δx decreases in all earthquake zones and for different wind speeds in both 5 storey and 10 storey buildings.

3.) It is observed that by providing more size, in 5 storey the lateral displacement has decreased from 80mm to 43mm for large span building and decreased from 54mm to 41mm for small span building in higher earthquake zone. In 10 storey the lateral displacement has decreased from 205mm to 75mm for large span building and decreased from 105mm to 58mm for small span building in higher earthquake zone. Especially the large span building show significant change than the small span building.

4.) It is observed that by providing more size, in 5 storey the lateral displacement has decreased from 46mm to 25mm for large span building and decreased from 31mm to 23mm for small span building in higher wind velocity. In 10 storey the lateral displacement has decreased from 215mm to 79mm for large span building and decreased from 110mm to 61mm for small span building in higher wind velocity. Especially the large span building show significant change than the small span building.

5.) Building with small span shows less lateral displacement δx in all earthquake zones and different wind velocities. Hence from the study small span buildings shows better results in higher earthquake zones and higher wind velocity areas.

Comparison between 5 and 10 storey buildings:

1.) There is a margin increase in the vertical settlement δy in 10 storey building compared to 5 storey building. This margin increase can be minimised by increasing the size of the footing than provided.

2.) There is increase in the lateral displacement δx in all earthquake zones and different wind velocities in 10 storey building compared to 5 storey building. There is significant increase in lateral displacement δx due to wind velocities than that of earthquake.

3.) It is observed that the lateral displacement δx has increased around 40 to 33mm in higher earthquake zones and increased around 52 to 40mm in higher wind velocity areas.

ACKNOWLEDGMENT

This is my M.Tech thesis which I had completed with the help of few people who had given me their full support and encouragement all the time and extend my heart full gratitude for them who made this thesis completion possible.

I would like to express my thankfulness and deep sense of gratitude to *Dr. M. Ramesh*, Head of the Department, Civil Engineering, GITAM Institute of Technology, GITAM University and my sincere thanks to honorable *Dr. M.R.S.Satyanarayana*, Coordinator, TEQIP Phase II, GITAM Institute of Technology, GITAM University, who has given me their valuable time, stimulated suggestions and encouragement in this thesis work.

I would like to show my special gratitude to my parents and friends for their affection and love all the time.

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