Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444

Volume 3, Issue 6, June-2016

Dynamic analysis of soil pile structure interaction in sandy soil by small scale model test on shake table

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***Abstract* — Seismic behavior of structures built on soft soils is influenced by the soil properties and the foundation type, where the response is significantly different from the fixed base condition owing to the interaction between the ground and the structure. The aim of present work is to understand the behavior r of soil pile structure interaction RCC framed low rise structure by experimental study. Two bay Ground plus 4 stories RCC framed structure is considered for the soil pile structure interaction behavior study. Small scale model is derived, constructed and tested in laboratory on shake table. Fix based structure and Structure supported by end-bearing pile foundation of experimental results are compared.**

Keywords-Shake table, Sandy soil, Soil pile structure interaction (SPSI), Lateral displacement, Story drift, Small scale model.

I. INTRODUCTION

The scarcity of land compels engineers to construct buildings at locations with less favourable geotechnical conditions in seismically active regions. Numerous midrise buildings have been built in earthquake prone areas employing different types of foundations. In the selection of the foundation type for the mid-rise buildings, several options such as shallow foundation, pile foundation, or pile-raft foundation, might be considered by design engineers to carry both gravity and earthquake loads. However, different types of foundations behave differently during the earthquake considering the soil-structure interaction (SSI) that may influence the seismic behaviour of the superstructure. Figure 1.1 displays a building structure that has been collapsed in an earthquake as a result of soil pile structure interaction. In order to prevent such collapse, seismic demands must be determined accurately.

Figure 1. Failure due to soil pile structure interaction (SPSI)

There are many reasons for collapse of buildings during earthquake but history of earthquake shows that one of the major reasons is soil pile structure interaction (SPSI) effect. It is essential that behaviour of soil pile structure interaction (SPSI) should be understood clearly under earthquake loading. Small scale modelling and testing is one of the best tools for this. But history of earthquake photo shows that the one measure reason is soil pile structure interaction (SPSI) effect. When we carry out a test, we often use models instead of full-scaled objects (prototypes).The reasons for using models are Civil Engineering structures being giant in size are difficult to test. So to make testing easy small scaled model are used. Small scale models are easy to build, install and test in a Laboratory. Although it may be difficult to model all details, many times there is no alternative to use models. Small scale models give accurate results within elastic range.

II. SMALL SCALE MODEL

A structural model is defined as “any physical representation of a structure or a portion of a structure.” The use of small-scale models by engineers and builders dates many hundreds and even thousands of years. However, these early models were primarily aids for planning and constructing structures and were not useful for predicting deformations and strengths of prototypes. Similitude is a tool to establish the sufficient and necessary condition of similarity between models and prototypes, using which test setup is adjusted. It helps to understand under laying principles for proper design, construction and result interpretation. The theory of similitude includes a consideration of the condition under which the behaviour of two separate entities or systems (model and prototype) will be similar. The similarity is essentially proportionality. Following two figures are geometrically similar with following relation.

Table 1. Scale factor for different quantity

Items	Physical Quantity	Actual parameter(mm)	Small scale model(mm)	volume(m3)	weight(kg)
	Diameter(D)	9000	600		
CONTAINER	Internal dia (d)	-	596	**0.002253264**	**17.688122**
	Depth	-	600		
	Thickness	-	2		
	Length	7500	500		
	Width	7500	500		
BASE PLATE	Height	-	-	**0.0015**	**11.775**
	Thickness	-	6		
	No of base plate	-	1		
	Length	6000	400		
	Width	6000	400		
STOREY PLATE	Height	-	-	**0.008**	**62.8**
	Thickness	150	10		
	No of storey plate	-	5		
	Length		10		
	Width		10		
COLUMN	Height	15000	1000	**0.0004**	**3.14**
	Thickness	-	-		
	No of column	-	4		
	Diameter(D)	360	24		
PILE	Depth	9045	603	**0.00109061**	**2.6174638**
	No of pile	-	4		

III. SHAKING TABLE TESTS MODEL COMPONENTS

The developed soil-structure model for shaking table tests have three main components including the model structure, the model pile foundations, the soil container. Employing geometric scaling factor of 1:15, height, length, and width of the structural model are determined to be, 1 m, 0.40 m, and 0.40 m, respectively. The model structure, the model pile is subjected to the competing scale model criteria.

The model piles have a diameter of 24 mm with L/d ratio of 25. Model pile is made from RCC M25 grade concrete having diameter of model pile is 24 mm and depth of pile is 600 mm considered. The ideal soil container should simulate the free field soil response by minimising boundary effects. Since the seismic behaviour of the soil container affects the interaction between the soil and structure, the performance of the soil container is of the key importance for conducting seismic soil-structure interaction model tests successfully (Pitilakis et al. 2008). A laminar soil container with final diameter and depth of 0.60 m, and 0.60 m, respectively, are designed and constructed for this study.

A sandy soil was designed to provide soil medium for the shaking table testing considering required dynamic similarity characteristics. Accordingly, the maximum dry density, optimum moisture content, liquid limit, plastic limit, cohesion , angle of internal friction were determined to be 2.078 gm/cc, 9.6%, 21.45%,Non plastic, 0 Kg/cm^2 and 30º, respectively.

The shaking table tests have been carried out in two stages

a Fixed-base condition,

b End bearing pile foundations.

Displacement transducers (levels 1, 2, 3, and 4) and accelerometers (level 1, 2, 3, and 4) were installed on the structure in order to monitor the dynamic response of the structure and to primarily measure the structural lateral displacements. The recorded accelerations can be used to check the consistency and accuracy of obtained displacements through a double integration in time domain. The final setup of the tests for the fixed – base condition system on the shaking table shown in Figure 2.

Figure 2. Final setup of the shaking table tests for the structure with Fixed base condition

IV. PROBLEM FORMULATION

In present study, G+5 RCC framed structure located in Gandhidham city of Gujarat state of India (zone –V), is considered. Plan Size is 6m x 6m with storey height 3m.The height of building is 1m.The depth pile foundation is 12m. Slab thickness is 150 mm. The beam size 230 mm x 450 mm (Over All) is used. The column size is 400mm × 400mm. Material Fe415 steel is considered.

Time history of Bhuj 2001 earthquake. Fixed base condition and end bearing pile foundation models are small scale model with 1/15 scale ratio so they are analysis with scaled time history as per similitude rules.

V. RESULTS AND CONCLUSIONS

Accordingly, the maximum lateral deflection of the structure supported by end-bearing pile foundations is increased by 15% based on the experimental values to the fixed base structure. Thus, pile foundations reduce the lateral drifts in comparison to the shallow foundation case. This is due to the presence of stiff pile elements in the soft soil which increase the stiffness of the ground and influences the dynamic properties of the whole system such as the natural frequency and damping.

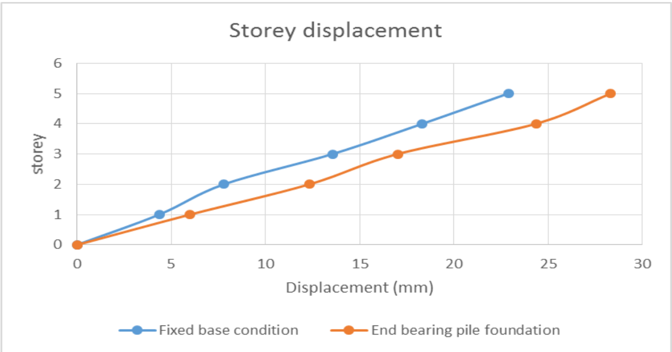

Figure 3. Average value of maximum lateral displacement

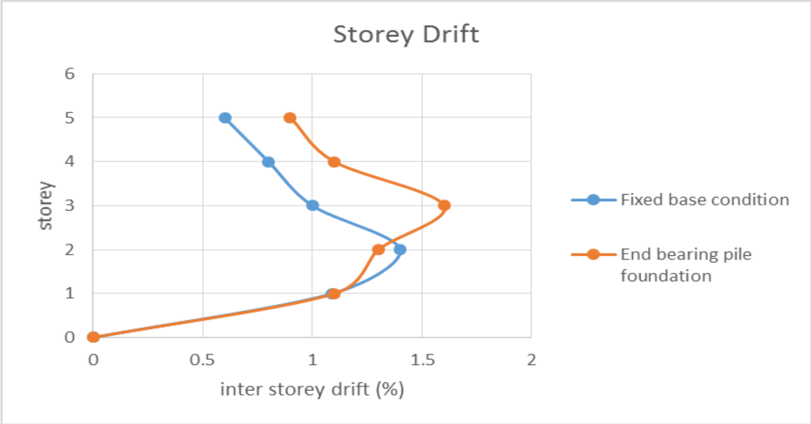

Figure 4. Avearage experimental inter storey drift: (a) fixed base structure (b) structure supported on end baering pile foundation

VI. CONCLUSION

1. In this paper, conducted shaking table tests in this paper, soil-foundation-structure models were physically simulated with geometric scaling factor of 1:15.
2. According to the shaking table test results, the maximum lateral deflection of the five storey structure supported by end-bearing increases on average by 16% comparison to the fixed-base structure.
3. Therefore, comparing types of foundations, pile foundations increase the lateral displacements of the superstructure in comparison with the fixed base assumption.
4. Pore water pressure in the sandy soil layer increased quickly with the increasing of the acceleration value under the excitation of either small EQ or larger EQ.

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