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Response of two structures supported on common foundation

Joshi, M.H.[1], Kulkarni, M.R.[1], Subramanian, K.V.[1], Palekar, S.M.[1], Warudkar, A.S.[2]
1) Tata Consulting Engineers, Bombay, India
2) Nuclear Power Corporation of India Limited, Bombay, India

ABSTRACT: In nuclear power projects, two or more structures have to be supported on common foundation due to various reasons such as compact layout of the plant. In such situations there is a possibility of interaction between the two structures through the common foundation. This interaction influences the dynamic characteristics of the two structures. The present paper describes a parametric study of structure-structure interaction. The parameters selected are stiffness and mass of the structures and stiffness of foundation medium. The paper concludes that in case of weak soils structures do interact through the common foundation and for rock-like foundation conditions there is no interaction between the structures.

1 INTRODUCTION

Structural engineers have to opt for common foundations for adjacent structures, due to various reasons. In case of structures supported on a common foundation, the interaction between the two structures under dynamic conditions is one of the issues to be addressed in the analysis of these structures. The structure-soil-structure interaction depends on mass and stiffness of structures, stiffness of foundation medium, etc. The interaction influences the dynamic characteristics of the structures. It is necessary to ascertain that there is no interaction between the structures before taking up fixed-base analysis of the structures. ASCE-4-86 recommends that for structures supported on foundation strata having shear wave velocity more than 1100 m/s, fixed-base analysis can be performed. From this it follows that two structures founded on such strata would have no interaction between them. For one of the nuclear projects in India, the regulatory body suggested to verify the above recommendation of the ASCE for a range of values of stiffness of super-structure.

2 PROCEDURE

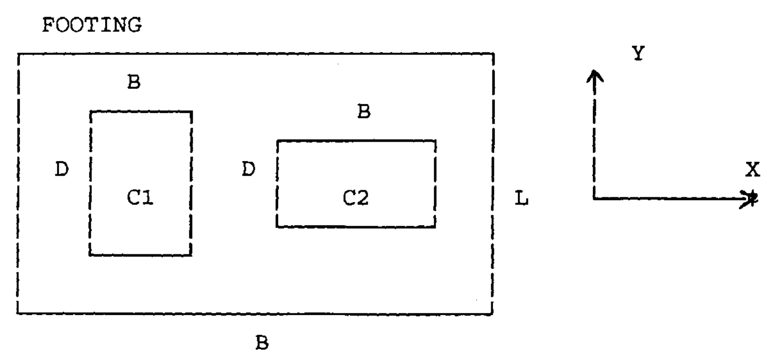
The procedure essentially consists in comparing combined analysis of two structures with common foundation with their individual analysis. A simple model consisting of two structures with common foundation is prepared.

Two columns are considered to represent the two structures with common foundation. The two columns have dimensions of 0.5 m x 1.5 m x 6 m height, and 1.5 m x 1.0 m x 9 m height. Column C1 has M1 mass and C2 has masses M2, M3 and M4 as shown in Tables-5 and 6. Center to center distance between two columns is taken as 1.25 m. The columns have been idealised as 3-D beam elements. The footing has been modelled as quadrilateral shell elements. The foundation medium is represented by Winkler springs. The shell elements representing the footing are modelled at the bottom of the footing. To represent the rigid behaviour of the footing, a rigid link of height equal to thickness of footing is provided. The horizontal degrees of freedom of all the nodes of the shell elements have been restrained. The masses and stiffness of structures in the model were varied to cover the frequency range of 1 to 6 Hz as the structures of the above project are expected to have their fundamental frequency in this range.

To verify the above model, a model consisting of a column and a footing idealised by 3-D brick elements was used and the results compared with those obtained with the above model. The capability of the adopted model to bring out interaction between the structures, was tested by assigning a low value to soil-stiffness. In this case the frequencies of the structures were found to be different than those with fixed-base assumption, indicating that the structures were interacting.

Dynamic analysis is performed for various combinations of stiffnesses of the two structures. The frequency obtained from these analyses are compared with those obtained from individual analysis of the two structures. Frequencies along X-direction have been used for comparison. For definition of X-direction refer Fig.1.

In order to understand the structure - structure interaction vis-a-vis, soil structure interaction in its proper perspective, the modulus of subgrade reaction has been varied from 100,000 to 30,00,000 t/cu.m thus representing a range of foundation conditions .



B: WIDTH D: DEPTH

FIG. 1

3 DISCUSSION

While studying the phenomenon of structure-structure-interaction it is necessary to vary the stiffnesses of both the super-structure and the foundation-structure, so as to make the study exhaustive. In principle , the aim of the study was to cover following four combinations of stiffnesses of foundation-structure and super-structure.

FOUNDATION STRUCT. STIFFNESS L x B x T & K	SUPER STRUCT. STIFFNESS E OF COLUMN 2
HIGH	LOW
HIGH	HIGH
LOW	LOW
LOW	HIGH

For this purpose individual analysis of Column-2 is performed to study the effect of variation of parameters like stiffness of column-C2 , plan dimensions of footing(Table-2) , thickness of footing(Table-3), modulus of subgrade reaction(Table-4) on the fundamental frequency of the column. This analysis helped to identify and include the above combinations of stiffnesses in the study of structure-structure-interaction. It was observed that for all the above variations and combinations of various parameters, the frequencies of column-C1 and C2 came out to be the same in combined analysis and individual analysis. The modulus of subgrade reaction was varied from 100,000 t/cum to 30,00,000 t/cum in these analyses. However, when the modulus of subgrade reaction is reduced to a low value of 1000 t/cum the frequency of column-C1 gets modified in the combined analysis as shown in Table-6. This indicates that structure-soil-structure interaction does exist for weak foundation conditions and it does not exist for rock-like foundation conditions where fixed-base analysis can be resorted to.

Though a large number of examples were solved taking different combinations of mass and stiffness of structures, only eight sets of results have been presented here owing to lack of space. Table-5 consists of four sets of results which do not indicate any interaction between the structures while Table-6 consists of four sets of results which show such an interaction.

The range of first mode frequencies exhibited by the columns is from 0.07 to 9.92 Hz. The range of ratio of first mode(in X-direction) frequencies of column 1 and column 2 is from 0.10 to 5.0.

4 CONCLUSION

The issue of interaction between two structures was resolved without resorting to a complex analysis. The ASCE recommendation was verified for different values of stiffness of super-structure. Also, the study was able to bring out the fact that for low values of soil-stiffness i.e. for weak soils there is interaction between the structures.

5 ACKNOWLEDGEMENT

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TABLE-1

VARIATION OF E-VALUE OF COLUMN-2
M1=20 M2=M3=M4=200

E OF COL.2	L x B OF FOOTING	T OF FOOTING	K	f2 Hz
1.0E6	4.0 x 3.5	5.0	1.0E5	0.31
10.0E6	"	"	"	0.64
100.0E6	"	"	"	0.75
1000.0E6	"	"	"	0.77

TABLE-2

VARIATION OF FOOTING PLAN-DIMENSIONS (L x B)
M1= 0.25 M2=0.05 M3=0.50 M4=0.10

E OF COL.2	L x B OF FOOTING	T OF FOOTING	K	f2 Hz
3E6	2.5 x 1.5	0.5	1E5	5.09
"	4.0 x 3.5	"	"	5.67
"	8.0 x 7.0	"	"	5.90

TABLE-3

VARIATION OF FOOTING THICKNESS (T)
M1= 0.25 M2=0.05 M3=0.50 M4=0.10

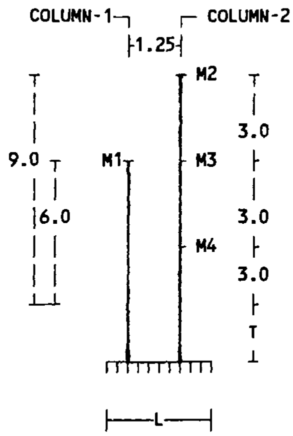
E OF COL.2	L x B OF FOOTING	T OF FOOTING	K	f2 Hz
3.0E6	2.5 x 1.5	0.25	1E5	2.29
"	"	0.50	"	5.09
"	"	1.00	"	8.57

TABLE-4

VARIATION OF MODULUS OF SUBGRADE REACTION (K)
M1=1 M2=5 M3=10 M4=15

E OF COL.2	L x B OF FOOTING	T OF FOOTING	K	f2 Hz
3.0E6	2.5 x 1.5	0.5	3.0E6	1.0
"	"	"	1.0E5	0.8
"	"	"	1.0E3	0.2

TABLE-5



COLUMN DATA		
	COLUMN-1	COLUMN-2
WIDTH	0.5	1.5
DEPTH	1.5	1.0
E	1.0E6	1.0E6

FOOTING DATA	
B x L	4.0x3.5
T	5.00
E	1.0E6
K	1,00,000

MASS DATA				
MASS	CASE-1	CASE-2	CASE-3	CASE-4
M1	20.0	200.0	200.0	200.0
M2	200.0	20.0	200.0	200.0
M3	200.0	200.0	20.0	200.0
M4	200.0	200.0	200.0	20.0

NOTE: * ALL UNITS IN T,M,SEC & Hz

CASE-1

MODE NO	INDIVIDUAL FOOTING COLUMN-1	INDIVIDUAL FOOTING COLUMN-2	COMBINED FOOTING
	FREQUENCIES		
1	0.52	0.31	0.31
2		1.61	0.52
3		4.10	1.61
4			4.10

CASE-2

MODE NO	INDIVIDUAL FOOTING COLUMN-1	INDIVIDUAL FOOTING COLUMN-2	COMBINED FOOTING
	FREQUENCIES		
1	0.16	0.51	0.16
2		2.32	0.51
3		5.38	2.32
4			5.38

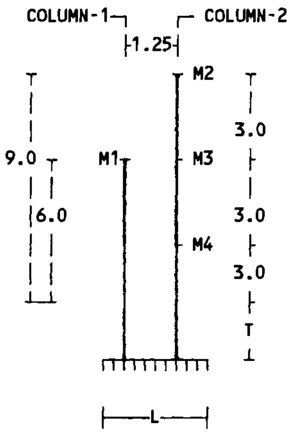
CASE-3

MODE NO	INDIVIDUAL FOOTING COLUMN-1	INDIVIDUAL FOOTING COLUMN-2	COMBINED FOOTING
	FREQUENCIES		
1	0.16	0.34	0.16
2		1.90	0.34
3		9.80	1.90
4			9.80

CASE-4

MODE NO	INDIVIDUAL FOOTING COLUMN-1	INDIVIDUAL FOOTING COLUMN-2	COMBINED FOOTING
	FREQUENCIES		
1	0.16	0.31	0.16
2		2.11	0.31
3		9.76	2.11
4			9.76

TABLE-6



COLUMN DATA		
	COLUMN-1	COLUMN-2
WIDTH	0.5	1.5
DEPTH	1.5	1.0
E	1.0E6	3.0E6

FOOTING DATA	
B x L	2.5x1.5
T	0.5
E	1.0E6
K	1000

MASS DATA				
MASS	CASE-1	CASE-2	CASE-3	CASE-4
M1	1.0	15.0	10.0	5.0
M2	5.0	1.0	15.0	10.0
M3	10.0	5.0	1.0	15.0
M4	15.0	10.0	5.0	1.0

NOTE: * ALL UNITS IN T,M,SEC & Hz.

CASE-1

MODE NO	INDIVIDUAL FOOTING COLUMN-1	COLUMN-2	COMBINED FOOTING
	FREQUENCIES		
1	1.00	0.2	0.2
2		10.80	1.7
3		30.9	10.80
4			30.9

CASE-2

MODE NO	INDIVIDUAL FOOTING COLUMN-1	COLUMN-2	COMBINED FOOTING
	FREQUENCIES		
1	0.2	0.3	0.2
2		17.0	0.7
3		48.0	17.0
4			48.0

CASE-3

MODE NO	INDIVIDUAL FOOTING COLUMN-1	COLUMN-2	COMBINED FOOTING
	FREQUENCIES		
1	0.3	0.2	0.2
2		15.6	0.6
3		79.2	15.6
4			79.2

CASE-4

MODE NO	INDIVIDUAL FOOTING COLUMN-1	COLUMN-2	COMBINED FOOTING
	FREQUENCIES		
1	0.4	0.2	0.2
2		12.6	0.8
3		71.5	12.6
4			71.6