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EMPIRICAL EQUATION FOR EVALUATION OF STOREY DISPLACEMENT CONSIDERING SOIL STRUCTURE INTERACTION

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Abstract

The incorporation of soil structure interaction effect in the analysis is complex and time consuming. In this work an attempt is made to derive an empirical equation to evaluate storey displacement under the influence of SSI effect using the results of storey displacement obtained from fixed base condition. An attempt is also made to check the accuracy of empirical equation by comparing the results with the incorporation of soil structure interaction effect using elastic continuum model. The results obtained from empirical equation are compared with the elastic continuum model using application software SAP2000. Study reveals that the empirical equation is reasonably correct and can be used to estimate storey displacement of mid rise building frames considering soil structure interaction. Thus the complexity involved in the SSI modeling may be reasonably substituted using simple empirical equation.

Keywords: - *soil structure interaction, fixed base, flexible base, storey displacement etc.*

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1. INTRODUCTION

In recent decades, soil-structure interaction has been given much attention in both research and practice. The main reason is its important effect on the response of buildings in case of earthquakes. The second is its complexity. The researchers have quantified the effect of interaction behavior and established that, there is redistribution of forces in the structure and soil mass. Hence, structures and their supporting soils should be considered as a single compatible unit.

2. STUDY FORMULATION

In this study structural responses of mid rise building frames under soil structure interaction are determined. Five types of mid rise moment resisting plane frames of G+5, G+7, G+10, G+12, G+15 storey buildings are considered. After knowing the structural mass of the building base shear of building is calculated and distributed at each storey.

The frame sections are modeled and analyzed employing Finite Element Method adopting SAP2000 software under two different base conditions (a) fixed base, (b) flexible base (considering soil structure interaction). The results are in terms of the maximum storey displacement at each storey level of the building. With the results a comprehensive empirical relationship is evaluated to determine the lateral storey of mid rise building frames.

The size of Beam is kept same throughout i.e = 0.4mX0.25m

The sizes of columns are shown in table below,

Table 1: Sizes of columns

Building	Storey	External column	Internal column
G+5	1 to 5	0.45mX0.25m	0.525mX0.3m
G+7			
	1 to 4	0.625mX0.35m	0.675mX0.45m
	5 to 8	0.6mX0.25m	0.6mX0.3m
G+10			
	1 to 3	0.625mX0.35m	0.675mX0.45m
	4 to 7	0.6mX0.253m	0.6mX0.3m
	8 to 11	0.45mX0.23m	0.525mX0.3m
G+12			
	1 to 4	0.8mX0.425m	0.875mX0.525m
	5 to 9	0.6mX0.425m	0.8mX0.425m
	10 to 13	0.525mX0.3m	0.575mX0.375m
G+15			

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	1 to 3	0.8mX0.425m	0.825mX0.525m
	4 to 7	0.6mX0.425m	0.8mX0.425m
	8 to 11	0.525mX0.3m	0.575mX0.375m
	12 to 16	0.3mX0.23m	0.4mX0.23m

A typical plane frame having 5 bays and 5 stories is shown in the fig. below,

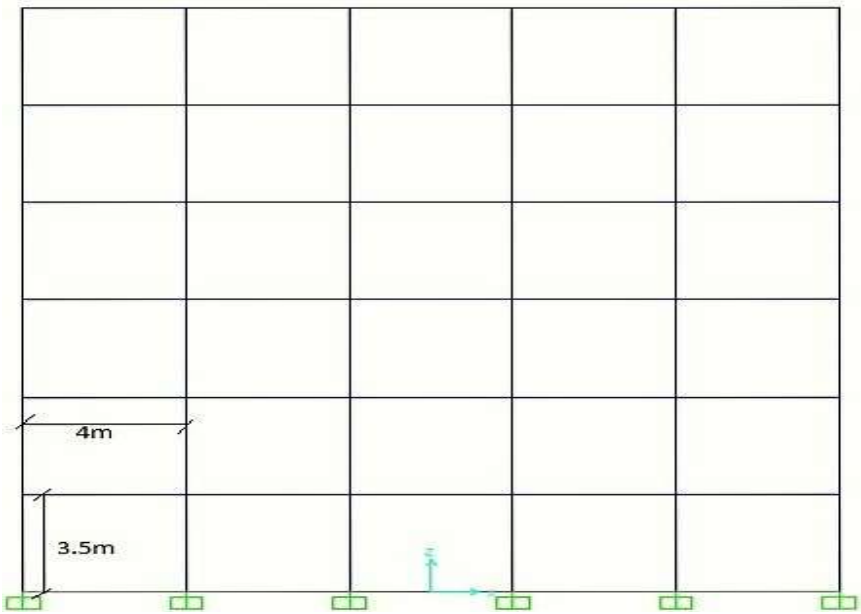

Fig 1: G+5 storey plane frame

Plane frame is considered for the analysis. Two base conditions used for the analysis of the building firstly fixed base and secondly flexible base. For flexible base modulus of elasticity is taken as 70000N/mm^2, Poisson's ratio is 0.4 and density of soil material is taken as 20N/mm^2. For soil structure interaction bed rock depth is kept 30m. Also convergence study is done for G+5 building to define particular mesh size for the flexible base condition.

2.1 Convergence Study

Meshing of the soil mass plays an important role in the soil structure interaction considering elastic continuum model. Following is the typical figure of elastic continuum model using SAP2000 software.

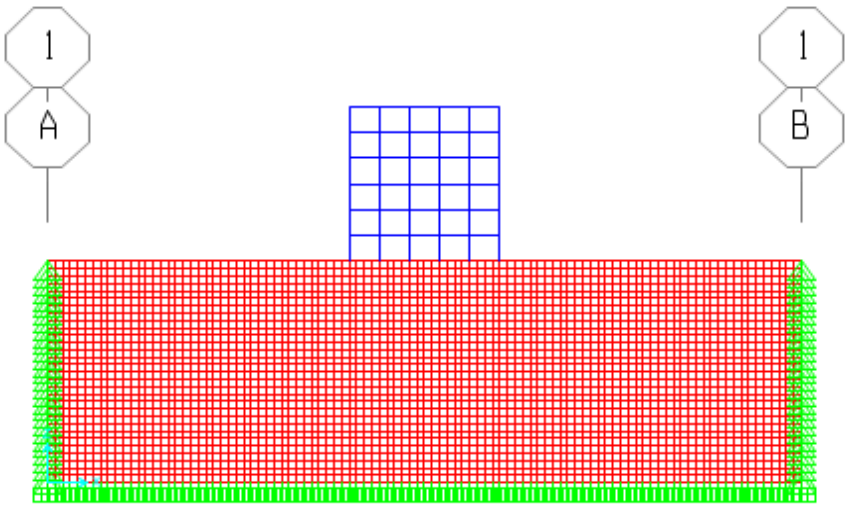

Fig 2: G+5 building frame with flexible base condition

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The width of the soil mass is kept 5 times the width of the building and bed rock depth is kept 30m. As we consider the soil mass have infinite boundary in all lateral direction, that's why hinges are provided in the SAP software in that direction. While after 30m the soil mass is considered as fixed base.

The area of soil is divided in five ways as mentioned below in table,

Table 2: Convergence study

Trial No.	Top storey displacement (mm)
1	8.98
2	9.33
3	9.61
4	9.81
5	9.92

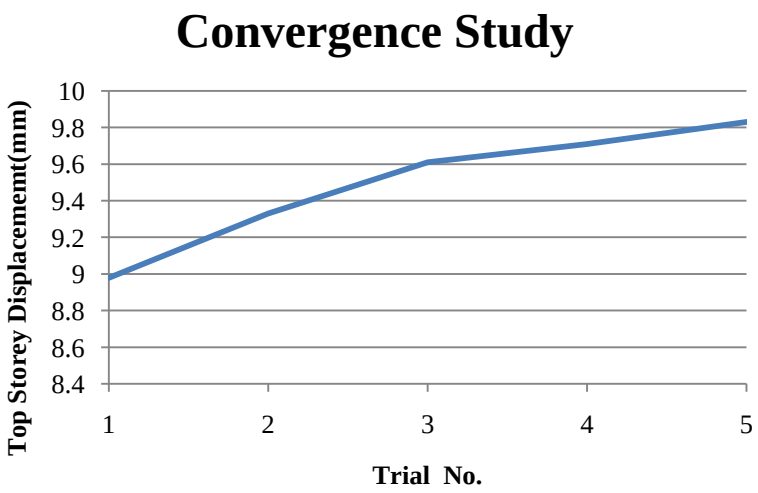

Chart 1: Graph of convergence study

The displacements of top storey goes on increasing rapidly up to area divided in size of 1mX1m i.e. (100X30) and after this mesh size it goes smoothly in increasing order. So after third mesh size it does not reflect so much change in the displacement of the top storey, so we keep the mesh size 1mX1m and divide the area in 100X30.

3. EMPIRICAL EQUATION

To analyze mid rise building frames an empirical equation is developed by Dr. S. Hamid Reza Tabatabaiefar, Behzad Fatahi and Bijan Samali. By applying this equation one can get directly the value of lateral storey displacement.The equation is derived as following,

$$\frac{d\tilde{\imath}}{di} = \left(1 + \frac{h^2 hs Estr}{\lambda \rho Vs^2 B^3}\right)$$

Where,
dĩ = lateral storey deflection at (i) level under the influence of SSI
di = lateral storey deflection at (i) level for fixed base condition
h = height of structure
hs = bedrock depth
Vs = shear wave velocity
Estr = modulus of elasticity of structural material
ρ = density of soil
B = foundation width
λ = model parameter
Lateral storey displacements considering soil structure interaction is calculated using the results of lateral storey displacement having fixed base condition. Height of the structure and foundation width is variable for different structures. Shear wave velocity and density of soil depends on type of soil considered for the analysis. The model parameter like λ can be calculated with the regression analysis.

4. RESULTS AND DISCUSSION

Results obtained from software analysis and empirical equation are compared and shown in following table,

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Table 3: storey displacement in mm for G+5 building

G+5	Fixed	Flexible(ECM)	Flexible (Emp. Eq.)
1	6.5	34.5	16.4
2	17.1	48.9	43.2
3	27.7	62.2	70
4	37.2	74.7	94
5	44.2	86.1	111
6	48.2	96.1	122

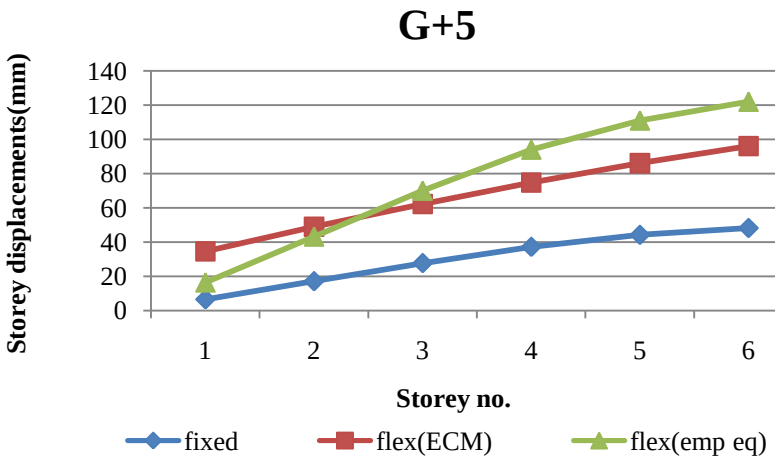

Chart 2: comparison of results of G+5 building

- For G+5 building, up to 3rd storey empirical equation shows lesser results as compared to elastic continuum model, after that the results of empirical equation are on higher side than that of elastic continuum model

Table 4: storey displacement in mm for G+7 building

G+7	Fixed	Flexible(ECM)	Flexible (Emp. Eq.)
1	4.4	41.6	19.6
2	13.2	60.6	42.3
3	23.3	79.3	69.3
4	33.6	97.4	94.2
5	43.9	115.3	125.4
6	52.6	132.4	152.7
7	58.9	148.3	171.6
8	62.7	163.1	182.4

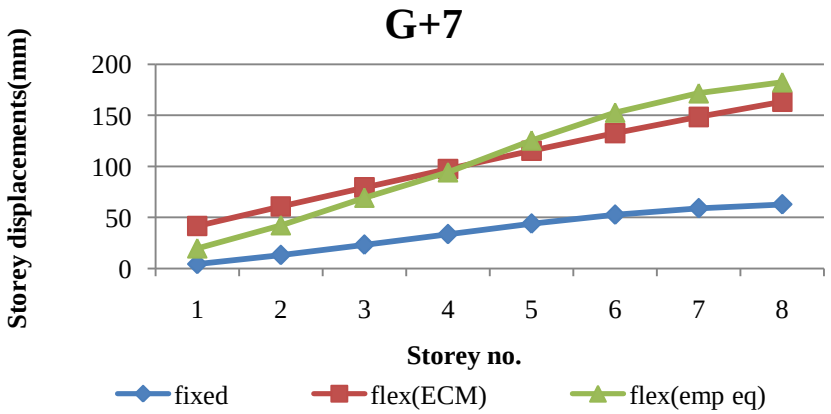

Chart 3: comparison of results of G+7 building

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- For G+7 building, up to 4th storey empirical equation shows lesser results as compared to elastic continuum model, after that the results of empirical equation are on higher side than that of elastic continuum model

Table 5: storey displacement in mm for G+10 building

G+10	Fixed	Flexible(ECM)	Flexible (Emp. Eq.)
1	5.1	51.9	14
2	15.5	78.1	42.8
3	27.9	104.1	77
4	40.8	130.5	112.7
5	53.7	156.7	148
6	67	182.6	187
7	79.3	207.9	219
8	90.3	235	249
9	104.2	260.6	287
10	113.8	284.2	314.3
11	118.7	305.5	327.8

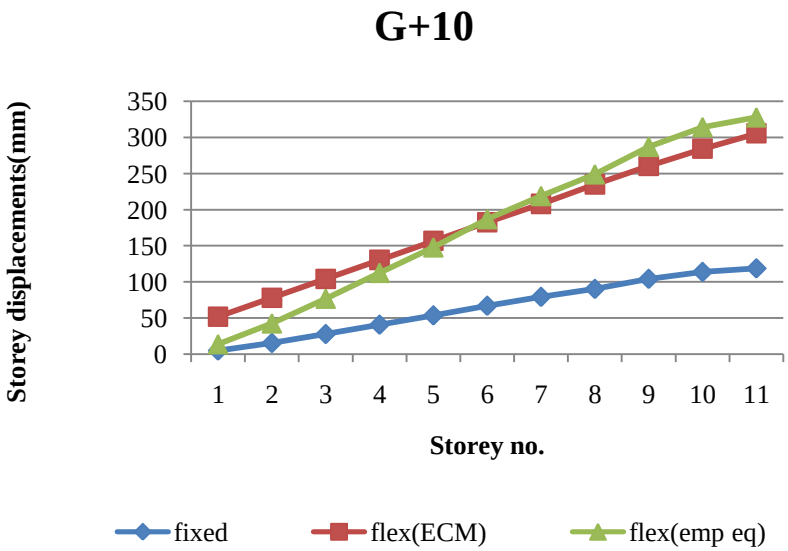

Chart 4: comparison of results of G+10 building

- For G+10 building, up to 6th storey empirical equation shows lesser results as compared to elastic continuum model, after that the results of empirical equation are on higher side than that of elastic continuum model

Table 6: storey displacement in mm for G+12 building

G+12	Fixed	Flexible(ECM)	Flexible (Emp. Eq.)
1	3.7	64.8	18.5
2	12	98.5	63.4
3	22.8	132.8	98.7
4	34.7	166.6	135.7
5	47.5	200.1	173.2
6	60.2	233.4	198.4
7	72.6	266.4	228.6
8	84.2	298.7	252.1
9	94.9	330.7	278.3
10	105.2	362.1	318.5

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11	113.4	393.1	342.3
12	119.1	422.8	326.2
13	122.7	450.8	368.5

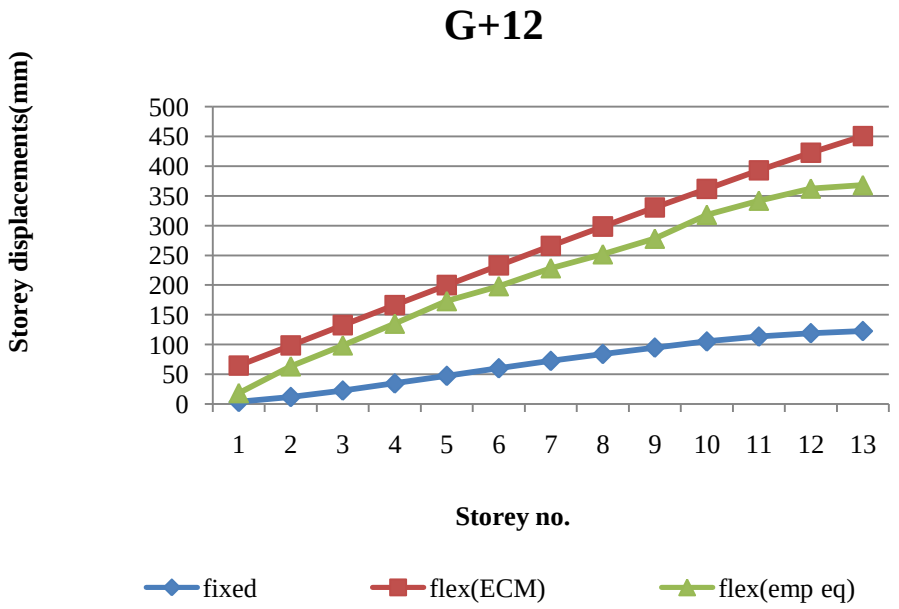

Chart 5: comparison of results of G+12 building

- For G+12 building, Flexible base results calculated by empirical equation are on lesser side as compared to results calculated by elastic continuum model.

Table 7: storey displacement in mm for G+15 building

G+15	Fixed	Flexible(ECM)	Flexible (Emp. Eq.)
1	4.1	76.6	11.9
2	13.6	119.1	39.6
3	25.9	162	75.3
4	39.8	204.6	115.7
5	54.3	247	157.9
6	69.5	289.1	202
7	84.7	331.1	246
8	99.5	372.8	289
9	114	415	332
10	128.9	456.6	374.9
11	142.6	497.6	414
12	154.8	538	450
13	165.5	580.4	481
14	178.5	621.1	519
15	187.4	659.6	545
16	192.1	696.1	559

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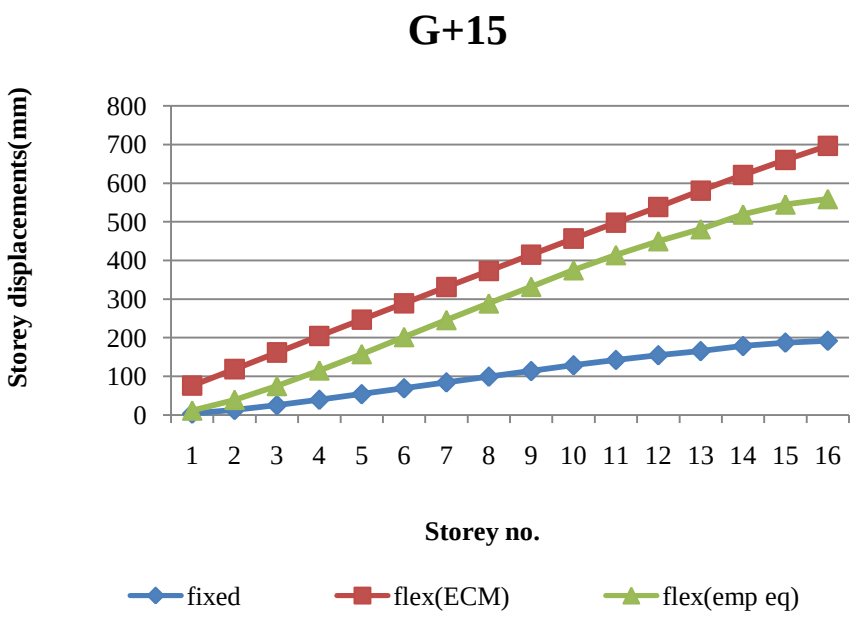

Chart 6: comparison of results of G+15 building

- For G+15 building, Flexible base results calculated by empirical equation are on lesser side as compared to results calculated by elastic continuum model.

5. CONCLUSION

5.1 Introduction

Soil structure interaction effect is dominantly observed in the results. The empirical equation is used for determining storey displacement of mid rise building frames.

5.2 Conclusion

1. The study reveals that the empirical equation suggested by Dr. S. Hamid Reza Tabatabaiefar, Behzad Fatahi and Bijan Samali reasonably matches with the results obtained by ECM.
2. For G+5, G+7 and G+10 storey buildings the empirical equation gives lesser results than elastic continuum model up to bottom one third height then after responses are reversed. Thereafter, as the storey goes on increasing the results of the empirical equation goes on increasing as comparing to elastic continuum model.
3. The equation is based on properties of soil mass as well as properties of structure. Therefore for study purpose there is a need, to get the input data which is case specific.
4. In case of change in soil parameters study needs to be revised.
5. It is observed that the complex process of SSI analysis can be avoided to estimate storey displacement considering soil structure interaction by using the proposed empirical equation as it gives reasonably accurate results.

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