https://doi.org/10.15623/ijret.2018.0708007 Received: 28-05-2018, Accepted: 09-07-2018, Published: 30-07-2018

EXPERIMENTAL INVESTIGATION OF SEISMIC PERFORMANCE OF BUILDING FRAME CONSIDERING SOIL STRUCTURE INTERACTION (SSI)

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Abstract

In recent decades, SSI has been given much attention in both research and practice. The two reasons are its important effect on the response of buildings in earthquakes and second is its complexity. Present experimental study aims to evaluate the seismic performance of building frames under the fixed base conditions and flexible base conditions, on scale-down experimental steel model prepared using similitude laws. Three prototype RC building frames G+3, G+5 and G+7 are considered. The building frames considered are square in plan with single bay in both directions. The time history test (El-Centro) is conducted to know the acceleration of the test model. The acceleration v/s time, velocity v/s time and displacement v\s time plots are obtained for all the accelerometers. Study reveals that SSI effect is structure specific and input motion specific. Therefore during Earthquake depending upon frequency content of motion certain classes of buildings are subjected to damage

Keywords: *Soil Structure Interaction, Fixed Base, Flexible Base, Time History Etc.*

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1. INTRODUCTION

During theoretical analysis, certain set of assumptions regarding idealization of the material; boundary conditions etc. are required to be made to simplify the analysis to simulate the field conditions. However, these are not always true representation of what is happening in practice or field. It is observed that well engineered structures are also subjected to distress during earthquake. This happens due to the limitations in the analysis due to certain simplified assumptions. Therefore, in order to investigate the realistic behavior and to identify the various causes of distress in the structure, experimental study needs to be carried out which always gives a valuable insight with respect to limitations of various assumptions made while carrying out theoretical analysis of structures and the physical behavior of the structure.

Present experimental study aims to evaluate the seismic performance of building frames under the fixed base conditions and flexible base conditions, on scale-down experimental steel model prepared using similitude laws. The theory of similitude includes a consideration of condition under which the behavior of two separate entities or systems (model and prototype) will be nearly similar. Similitude is a tool to establish the sufficient and necessary condition of similarity between models and prototype.

1.1 Scaled-Down Model

Generally, a structural model is any structural element or assembly of structural elements built to a reduced scale with respect to prototype structures for testing, using laws of similitude. The results of the prototype structure are obtained by extrapolating the results of scaled down model using the similitude laws. Thus the performance of prototype structure can be predicted by carrying out the study on scaled down model.

1.2 Prototype RC Building Frame Considered for the Analysis

For the present study three building frames are considered that are G+3, G+5 and G+7. Details of the building frames are given below,

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Table -1: Properties of building frames

Sr. No	Contents	Description		
1	Structure	OMRF	OMRF	OMRF
2	No. of stories	G+3	G+5	G+7
3	Storey Height	3.5 m	3.5 m	3.5 m
4	Grade of Concrete	M 25	M 25	M 25
5	Grade of Steel	Fe415	Fe415	Fe415
6	Bay width	4 m.	4 m.	4 m.
7	Slab thickness	0.15 m	0.15 m	0.15 m
8	Size of Column	0.45m x 0.3m	0.40m x 0.25m 0.45m x 0.45m	0.45m x 0.3m 0.55m x 0.50m
9	Size of Beam	0.4m x 0.23m	0.4m x 0.23m	0.4m x 0.23m
10	Floor finish	0.6 KN/m²	0.6 KN/m²	0.6 KN/m²
11	Live load	4 KN/m²	4 KN/m²	4 KN/m²
12	Seismic Zone	III	III	III

1.2.1 Scale Factor

Due to size limitation of shake table, the plan dimension of model is set as 0.32m. Thus, the C/C distance between two columns is set as 0.32 m leading to a linear scale factor, of 4.0/0.32 = 12.5. Therefore, Scale Factor (SL) =12.5

Employing geometric scaling factor of 1:12.5 as explained above height, length, and width of the structural model are determined to be, 1.120 m, 0.32 m and 0.32 m, respectively. The scaling relationship between natural frequency of the model (*fm)* and natural frequency of the prototype (*fp) is:*

$$fm/ fp = S_L^{1/2}$$

$$= 3.54$$

frequency of the prototype structure is fp = 1.4792 Hz. The required frequency of the model (fm) *is*

$$= 1.4792 \times 3.54$$

$$=5.24 \text{ Hz.}$$

The density of the model (ρm) should be equal to the density of the prototype (ρp).

Density of the prototype structure (ρp) is determined as follows:

ρp= mass of prototype/volume of prototype
= 59140/(14×4×4)
=264.01 Kg/m³

Therefore the mass of the structural model (Mm) is estimated as:

$$Mm = \rho m \times Vm = 264.01 \times (1.12 \times 0.32 \times 0.32)$$
$$=30.27 \text{ Kg}$$

The dimensions of column and slab of scale down steel model is derived in such a way that the weight of model nearly equals to 30.27 Kg as required by simulated laws. Considering all above the details of G+ 3 scale down steel model is worked out. Similar calculations were done for G+5 and G+ 7 steel models and the details of all scale down models are presented in Table 2.

Table 2: Geometric and material properties of scale down model

Sr. No	**Contents**	**Description**		
1	No. of stories	G+3	G+5	G+7
2	Storey Height	280mm	280mm	280mm
3	Grade of Steel	Fe250	Fe250	Fe250
4	Bay width	320mm	320mm.	320mm
5	Slab thickness	4mm	3mm	3mm
6	Size of Column	10mm X 10mm	12mm X 12mm	12mm X 12mm
7	Size of Plinth Beam	10mm X 10mm	12mm X 12mm	12mm X 12mm

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2. EXPERIMENTAL SETUP ON SHAKE TABLE

An experimental study is carried out in order to validate the theoretical soil-structure interaction response. Two base conditions i.e. "Fixed-base" and "Flexible-base" are taken into account for the SSI evaluation process. The laboratory set up is developed for both fixed base condition and flexible base condition.

2.1 Fixed Base Condition

The fixed-base response of the scale down steel model is investigated by securing the foundation directly to the platform of the Shake Table. There are 4 numbers of accelerometers used to acquire the data. Accelerometer no. 1 is at bottom of Shake Table (Actuator), no. 2 and 3 are at slab level and accelerometer no. 4 is at roof level of scale down model. The experimental setup and placements of accelerometers are shown in Figure 1.

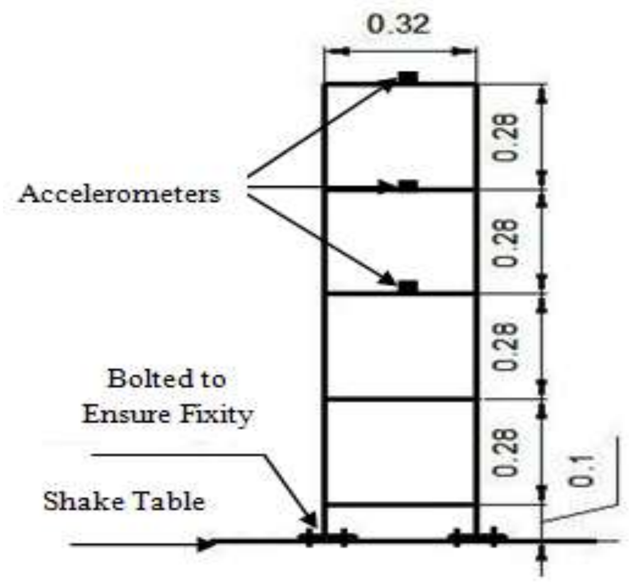

Fig -1: Details of Scale down Steel Model

Fig-2: Model Fixed On Shake Table

2.2 Flexible Base Condition

To simulate soil structure interaction condition in the laboratory a container made of steel plates is used as shown in Figure 3. This container is used to hold the soil mass beneath the foundation. The container is mounted on shake table.

The finite soil mass is considered based on convergence study, with boundary far beyond a region where structural loading has no effect. This is assumed to be at a lateral offset of two times width of the building on all four sides and depth equal to 3 times the width of building. As per this guideline soil block of 1.6x1.6 m in plan is required. However, considering limitation of Shake Table, container of size 1.5x1.5x0.7 m is used.

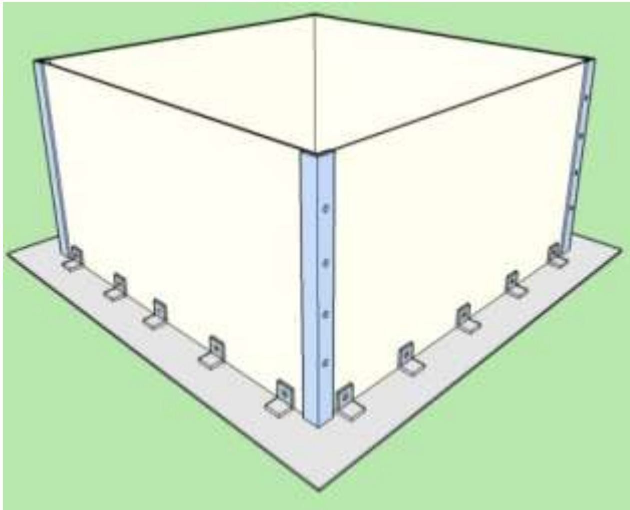

Fig -3: Isometric View of Steel Tank

Fig- 4: Setup of Flexible Base

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3. SOIL USED FOR STUDY

Locally available soft soil is use for the study. Various index properties, strength properties and elastic constant of soil are determined in the laboratory as per the codal procedure.

Table -3: Properties of Soil

Sr. No.	Name of Test	Results
1	Specific Gravity	2.806
2	Compaction Properties	
	Maximum dry density (KN/m^3)	19.2
	Optimum Moisture Content (%)	14%
3	Strength Parameters	
	Soil Internal Frictional Angle (Ø) in degrees	21
	Cohesion 'C'(KN/m^2)	12
4	Atterberg's Consistency Limits	
	Liquid Limit (%)	40%
	Plastic Limit (%)	28.26
	Shrinkage Limit (%)	22.115
5	Particle Size Distribution Analysis	
	% of sand	29%
	% of gravel	71%
6	Unit weight (KN/m^3)	16
7	Classification of Soil	GW(Well-graded gravel)
8	Modulus of elasticity 'E' (KN/m^2)	50000
9	Poisson's Ratio 'μ'	0.3

4. INPUT DATA TO SHAKE TABLE EL-CENTRO TIME HISTORY

To know the performance of building, it is practiced to use time history of various earthquakes. The time history used for experimental study is Imperial Valley, California, 19th May 1940 04:36 UTC (local 05/18), which has Magnitude 7.1

5 .RESULTS AND DISCUSSION

5.1 Comparison of Fixed Base and Flexible Base Condition

In present work, a comparison is made between building frames resting on fixed base and flexible base to understand the effects of SSI. The structures are analyzed to study the dynamic parameters such as acceleration, velocity and displacement. Time history plots of G+3 building for fixed and flexible base condition are shown below. The plots are responses at roof level. In the same way all buildings are analyzed and responses are taken at different stories.

5.1.1 Plots for Fixed Base Condition

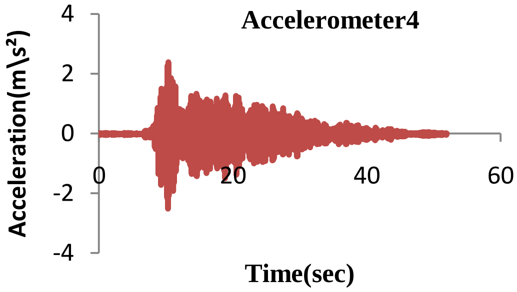

Chart-1: Acceleration Vs Time (fixed base)

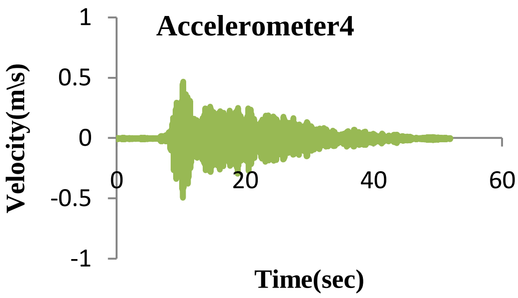

Chart-2: Velocity Vs Time (fixed base)

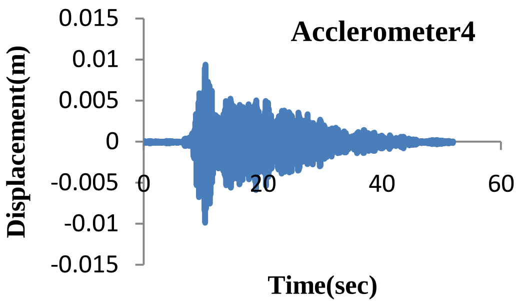

Chart-3: Displacement Vs Time (fixed base)

5.1.2 Plots for Flexible Base Condition

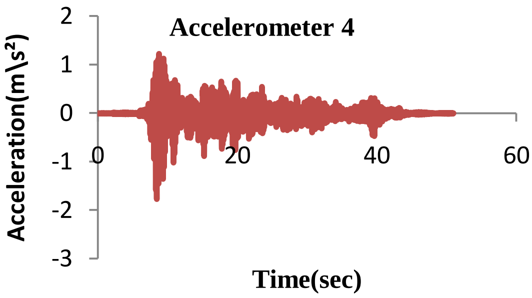

Chart-4: Acceleration Vs Time (flexible base)

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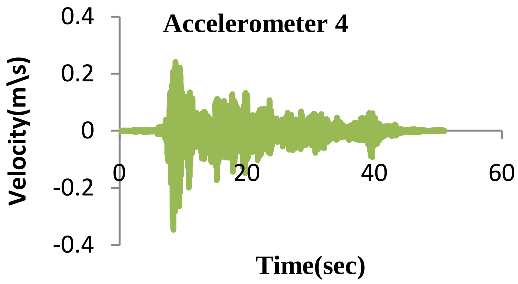

Chart-5: Velocity Vs Time (flexible base)

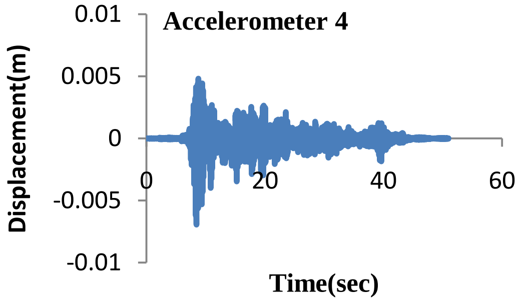

Chart-6: Displacement Vs Time (flexible base)

The results are discussed to highlight the effect of acceleration on fixed and flexible base. The results are presented for G+3, G+5 & G+7 building frames. Those are discussed below.

5.2 Comparison of G+3 Building Frame

5.2.1 Comparison between Maximum Acceleration Velocity & Displacement of Fixed & Flexible Base Condition

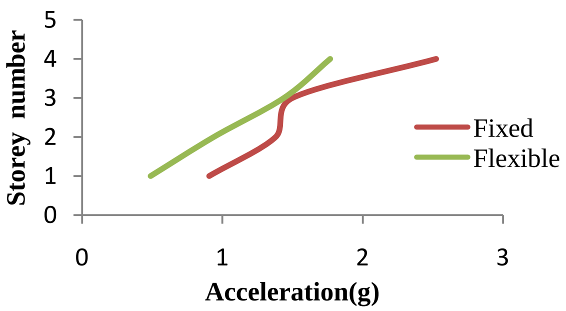

Chart-7: Variation of Maximum Acceleration (G+3)

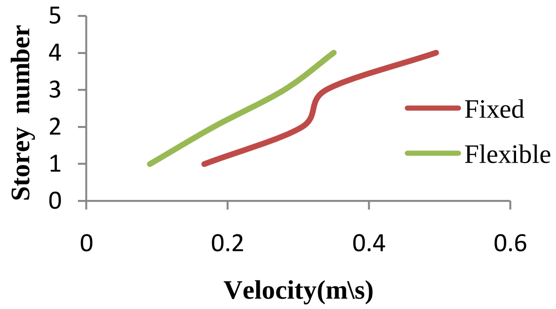

Chart-8: Variation of Maximum Velocity (G+3)

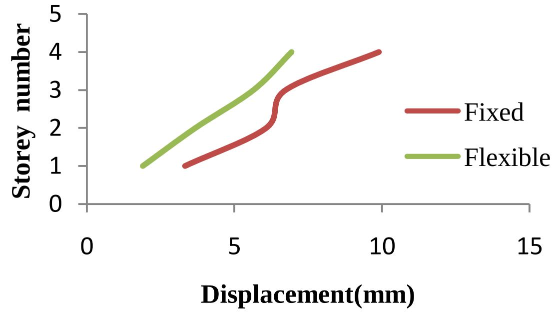

Chart-9: Variation of Maximum Displacement (G+3)

5.3 Comparison of G+5 Building Frame

5.3.1 Comparison between Maximum Acceleration Velocity & Displacement of Fixed & Flexible Base Condition

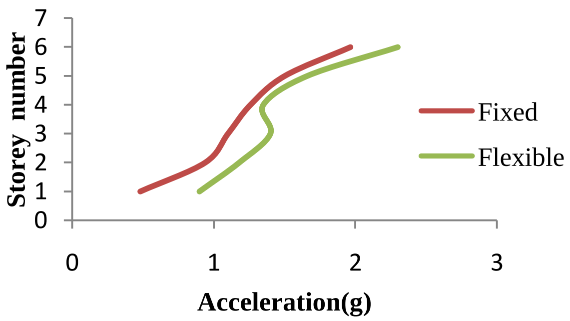

Chart-10: Variation of Maximum Acceleration (G+5)

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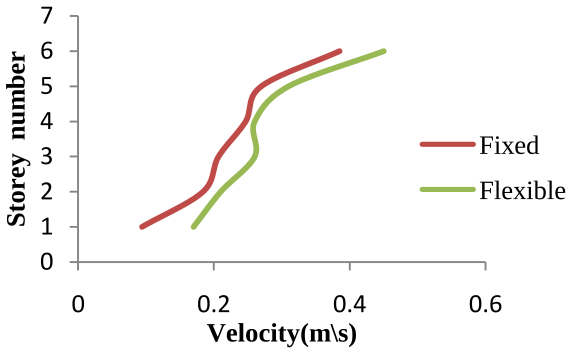

Chart-11: Variation of Maximum Velocity (G+5)

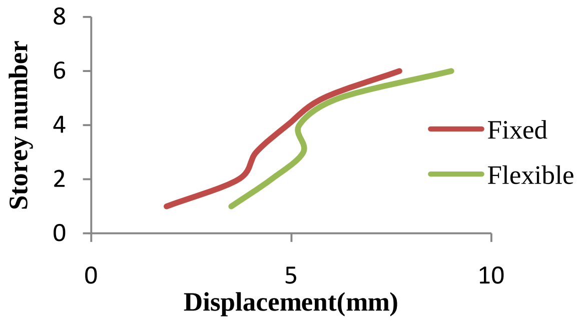

Chart-12: Variation of Maximum Displacement (G+5)

5.4 Comparison of G+7 Building Frame

5.4.1 Comparison between Maximum Acceleration Velocity & Displacement of Fixed & Flexible Base Condition

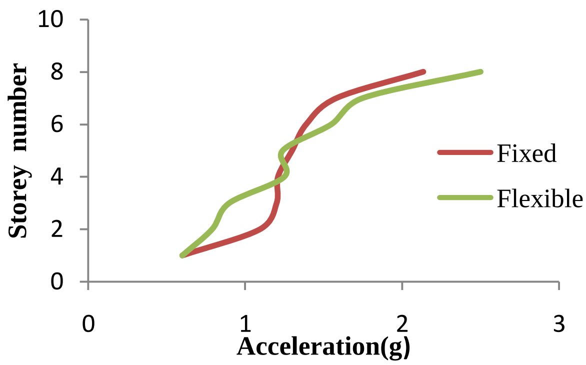

Chart-13: Variation of Maximum Acceleration (G+7)

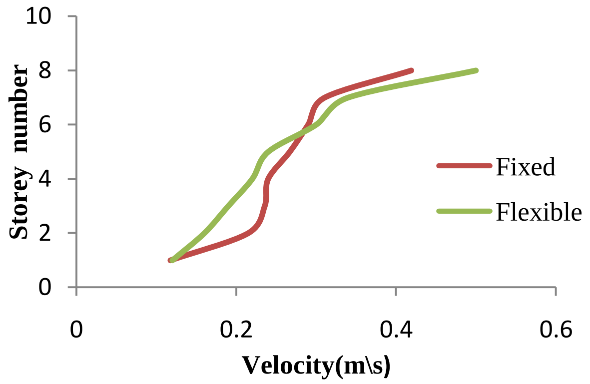

Chart-14: Variation of Maximum Velocity (G+7)

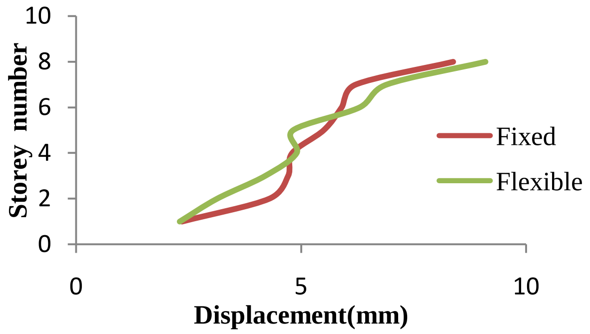

Chart-15: Variation of Maximum Displacement (G+7)

6. CONCLUSION

The test is conducted on el-Centro time history. The response of structure such as acceleration, velocity and displacement at all floor level of all building frame is determined for fixed and flexible base condition. The results obtained are presented in pervious chapter based on these observations following conclusions are drawn.

1. For all building frames it is observed that acceleration, velocity and displacement goes on increasing from ground level to roof level.
2. The rate of increase is observed relatively mild up to 3rdstorey (in case of G+5 building), up to 5thstorey (G+7building) there onwards rate increases up to roof level.
3. In case of G+3 building SSI effect is not significantly observed as the parameters for SSI are lesser than fixed base condition.
4. In case of G+5 building SSI effect is significantly observed as response for SSI is higher than fixed base condition.
5. In case of G+7 building SSI effect shows mixed kind of response. Up to 4thstorey SSI effect is not significant. Beyond this up to roof level SSI effect is significantly observed.
6. Study reveals that SSI effect is structure specific and input motion specific. For El-Centro time history and for given building configuration under consideration G+5 building is severely affected than G+3 and G+7.

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7. Therefore during Earthquake depending upon frequency content of motion certain class of building are subjected to damage .The SSI effect plays important role in the performance of building frames.
8. The present study advocates that all the structures shall be analyzed considering SSI effect for specific site response spectra.
9. The SSI study is carried out on a GW type of soil. The results presented are for this soil only. In case of change in soil separate study shall be carried out.

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