International Journal of Civil and Structural Engineering – IJCSE
Copyright © Institute of Research Engineers and Doctors
Volume 6 : Issue 2 - [ISSN : 2372-3971] - Publication Date: 27 Dec, 2019

Relationship Between Energy Dissipation and Column Uplift in Simple 3D Structure During Dynamic Loading.

Nakhshab Ajaz[1], Assad Rashid[2] and Majid Ali[3]

***Abstract*—There is a new trend to allow uplift in structures to have maximum energy dissipation during strong ground motion. This aspect needs to be studied in detail, particularly in three dimensional structures. To start with, a prototype 3D structure is considered. In this work, a relationship is developed between column uplift and energy dissipation for a 3D prototype structure during harmonic loading. The simple 550 mm high single storey structure consists of a top steel plate (500 mm x 500 mm and 5 mm thickness) with four corner aluminum columns (each having size of 30 mm x 30 mm x 3 mm). The structure will be simulated under harmonic loadings with two options: i. all four columns will be fixed, and ii. three columns will be fixed and fourth one will be allowed to have a maximum uplift of 5 mm. Relative comparison will be made between the two options. Column response and uplift will be measured. Detail discussions will be made on relative response of structures. This study will help in understanding the importance/benefit of allowing uplift in 3D structures.**

***Keywords*—energy dissipation, uplift, dynamic loading, 3D structure, column**

I. Introduction

Earthquakes have been a serious threat to the structural safety. But with the passage of time, as the human intervention in the nature has increased our planet has become more prone to the ground motions. Earthquakes are the natural events that cannot be stopped, but their negative impacts can be minimized using engineering knowledge. According to the study almost 80% of among 1 million deaths turned out to be caused by ten great earthquakes around the world which together affected a small section of the region that was at risk from heavy ground movement [1]. Many minor and major structural damages at local and global level were reported after the 2011 Tohoku-Oki Earthquake [2]. A series of earthquake in Christchurch in 2010 and 2011 reportedly damaged many masonry, concrete and steel structures. Nearly 1700 out of 2400 buildings were knocked down due to the tilting or cracking [3]. Hence an effort is required to reduce loses during future earthquake events. To enable an efficient and cost-effective solution, new construction techniques were investigated by various researchers in last decade [4]. Uplift in structures has evolved as a new mitigation technique. Studies have been made in past to investigate its effect on dynamic characteristics.

[1] Capital University of Science and Technology, Islamabad, Pakistan
[2] Capital University of Science and Technology, Islamabad, Pakistan
[3] Capital University of Science and Technology, Islamabad, Pakistan

To simulate the real earthquake a complex shake table having six degree of freedom is essential, but that is expensive. However, dynamic behavior of structures can also be studied using unidirectional shake table. Baran et al. (2010) developed simple and low cost shake table to study the dynamic behavior of structure on small scale in laboratory [5].

During earthquake events column uplift can dissipate energy due to the flexible connection. Activated forces in structure were observed to have significantly reduced in a single degree of freedom model structure due to uplift [6]. In this study a multi degree of freedom prototype structure was tested under harmonic loading to investigate the energy dissipation due to allowed uplift.

II. Experimental Procedures

A. *Prototype Structure and Uplift Mechanism*

The simple 3D 550 mm high single storey prototype frame structure is shown in Fig. 1. It consists of a top steel plate (500 mm x 500 mm and 5 mm thickness) with four corner aluminum columns (30 mm x 30 mm x 3 mm each). The columns are connected with a base plate through bolts. The base plate acts as a connection through bolts between above structure and shake table.

Moreover, only one column among four is loosened and allowed to have a maximum uplift of 5 mm. The loosened bolts acts a guide as well as restraint at the connection to ensure the translation only in vertical axis i.e. out of the plane and do not slip off horizontally. An enlarged view of allowed column uplift is shown in Fig. 1.

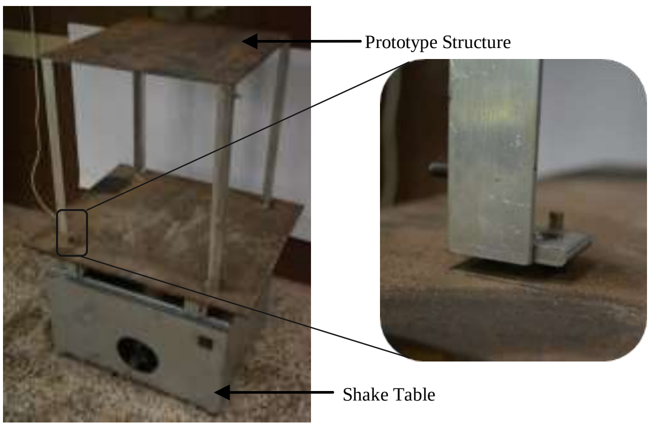


Figure 1. Prototype structure and enlarged view of column uplift

International Journal of Civil and Structural Engineering – IJCSE
Copyright © Institute of Research Engineers and Doctors
Volume 6 : Issue 2 - [ISSN : 2372-3971] - Publication Date: 27 Dec, 2019

B. *Prototype structure on shake table and its instrumentation*

The prototype structure is tested on simple uni-axial shake table in laboratory using two different base conditions i.e. i. all four columns were fixed, and ii. three columns were fixed and fourth one was allowed to have a maximum uplift of 5 mm. Uplift is allowed in only one column through a loosened bolt at the base. The experimental setup for the 3D prototype structure mounted on the shake table along with the details of its instrumentation for response measurement is shown in Fig. 2. Test set up is shown in Fig. 2a and schematic diagram is shown in Fig 2b. The structure was instrumented with the following set of accelerometers:

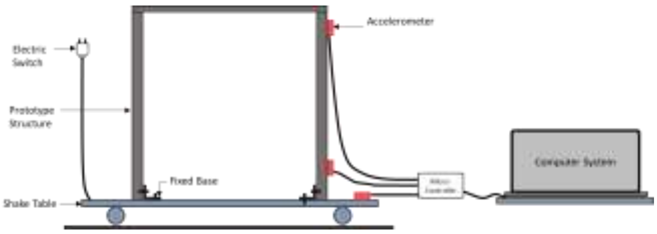
i) one at shake table to record the applied loading;

ii) one at the top of column with uplift to record its response i.e. horizontal displacement;

iii) one at the bottom of same column to record the uplift;

iv) and one at the diaphragm middle to record the structural response against applied loading.

a. Test set up



b. Schematic diagram

Figure 2. Instrumentation of shake table test

C. *Testing*

The simple 3D prototype structure was tested on shake table using two different base conditions under harmonic loading of around 1.25 Hz (i.e. time period 't' of 0.80 s or rotation of 75 rpm). As stated earlier the uplift of column was allowed through the loosened bolt at the column base connection. No additional mass was put on the top of structure due to the pay load limitation of shake table. Though the results would be different with an added mass at the top, replicating more realistic behavior. The only purpose of this testing was to determine the energy absorption due to an allowed uplift in structure. Different tests (i.e. snap back and shake table tests) were performed for structure with fixed base and with allowed uplift. Snap back test was performed to determine the fundamental frequency and damping ratio of structure.

III. Results

A. *Acceleration–Time, and Displacement–Time Histories*

The response of structure is recorded in terms of acceleration-time and displacement-time histories at three of the above mentioned locations. Since horizontal displacement at column top and total energy absorption in structure with fixed base and allowed uplift are the only studied parameters. The response in terms of acceleration–time and displacement–time history during the period of 10 to 20 seconds at column top is sown in Fig. 3. The red dotted line represents the applied loading whereas the green full line shows the response at column top. The recorded acceleration–time histories were fed to a computer program named 'seismosignal' to obtain displacement-time histories.

Since the simple shake table that was developed locally using local resources, is only able to apply precise harmonic loading (i.e. a little variation exists in amplitude of different cycles) the averaged acceleration and displacement of base motion is considered as applied loading.

The time history recorded at the column base provided the column uplift. The enlarged view of 10 seconds record is shown in Fig. 4. It can be seen that the column uplift occurred only once in a cycle i.e. when the structure moved towards the right. A maximum of 2.47 mm uplift was observed during the complete loading time.

B. *Base Shear – Displacement Curves and Energy Dissipation*

The total mass of structure is considered to be lumped at the middle of the diaphragm. Acceleration is recorded at this location. Base shear (Q) is calculated as $\Sigma(m_t\ \ddot{u}_t)$, wherein $\ddot{u}_t$ is the acceleration at the diaphragm middle and m_t is the contributing mass for $\ddot{u}_t$. This approximate base shear calculation is done to obtain base shear-displacement curves. The displacement u at the top is the planar horizontal displacement of structure. Table 1 shows the averaged energy absorption per cycle and total energy absorbed during complete loading duration.

TABLE I. ENERGY ABSORPTION DURING HARMONIC LOADING

Base Condition	Total no. of cycles (n)	Energy Absorption	
		Average Energy absorption in one cycle (kJ)	*Total Energy absorbed (kJ)*
Structure with Fixed Base	75	0.017	1.275
Structure with Uplift	75	0.021	1.575

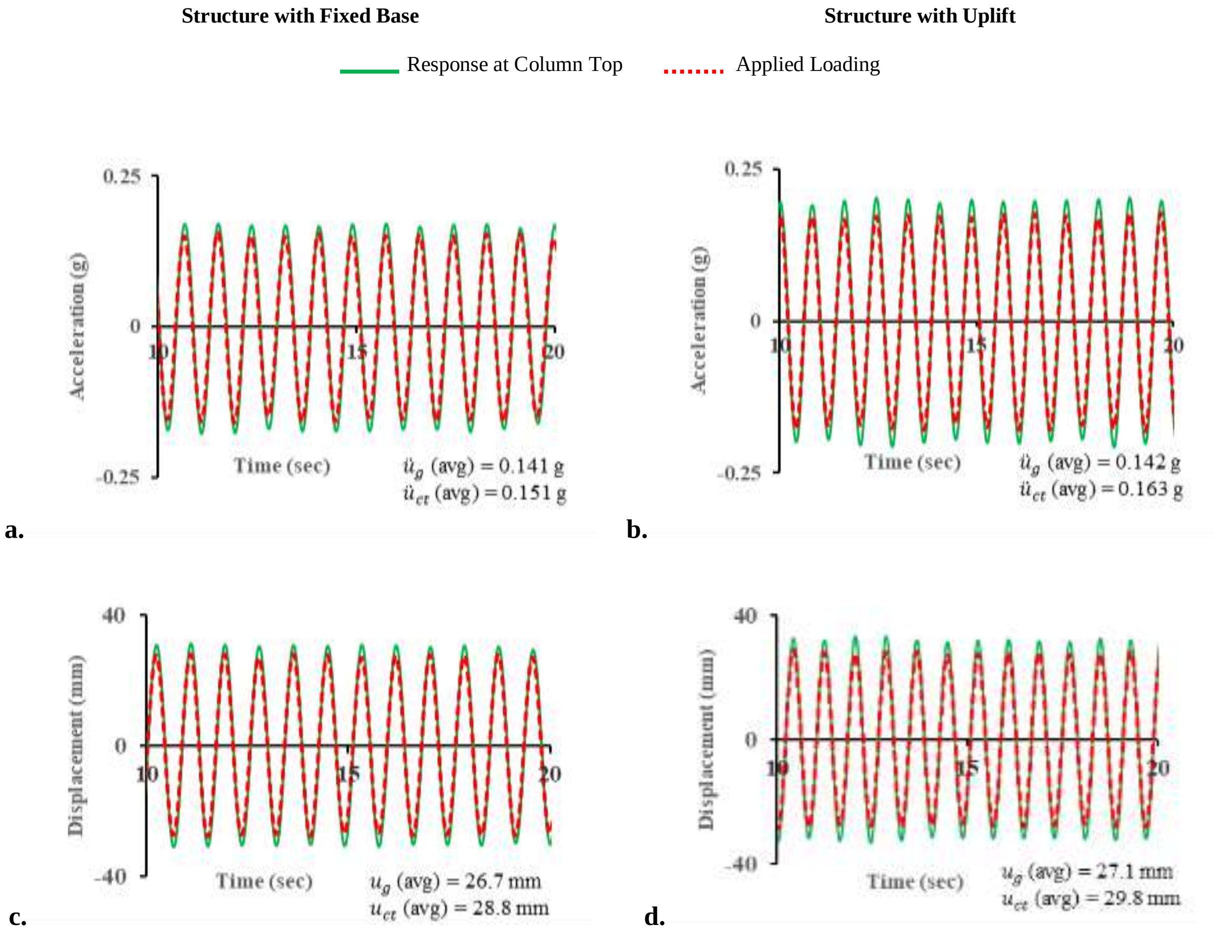


Figure 3. Coulmn response for intermediate 10 seconds
a. Acceleration-time history of SWFB, b. acceleration-time history of SWU, c. displacement-time history of SWFB, and d. displacement-time history of SWU

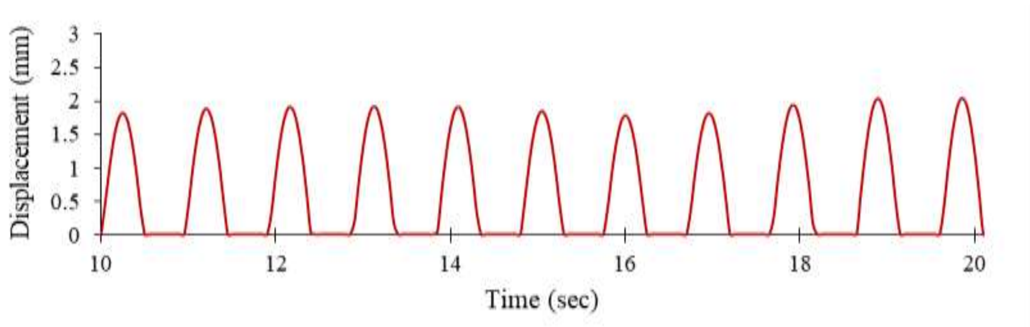
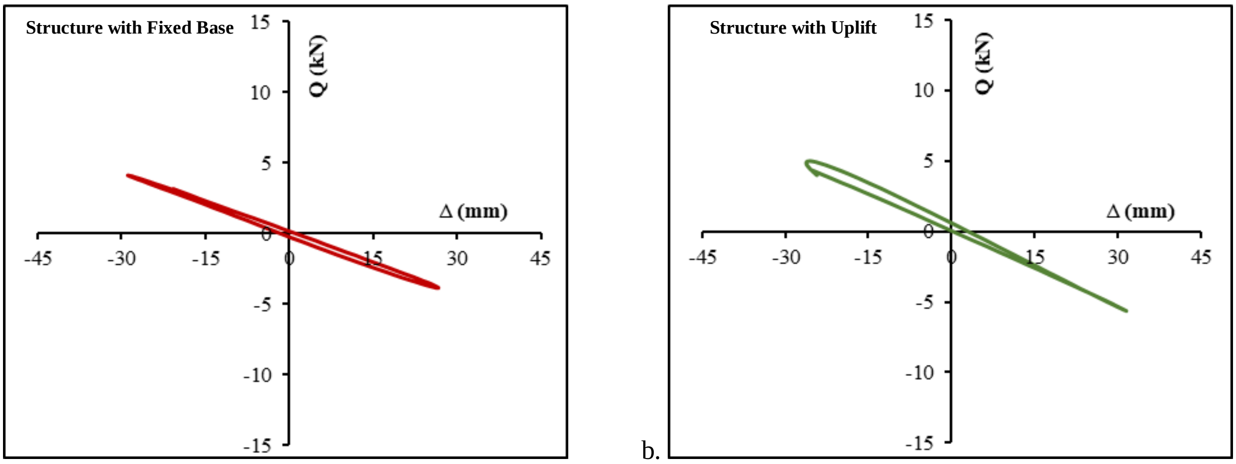


Figure 4. Intermdeiate vertical displacemnt (uplift)-time history for frequency of 1.25 Hz

The wider the loop, more will be the energy dissipated. For this purpose a typical single loop for one complete cycle of loading is considered. The obtained typical curves against harmonic loading for both base conditions are shown in Fig. 5. The energy absorption is observed to have increased in structure with allowed uplift. The loosened bolt provides a capacity to column to translate vertically. This vertical translation is named as column uplift (Up). Figure 4 shows the uplift in column during an intermediate interval of 10 seconds. The uplift in each cycle is observed to have occurred when structure moves opposite to the direction of column with uplift. Relative top displacement occurs with the movement of base.This uplift provides a flexibility at the column-base connection hence the generated energies get dissipated. Area within the loop is calculated using origin software to obtain the energy dissipation in structure. A significant increase in the total amount of energy being dissipated is observed due to the allowed uplift of column in simple 3D structure under the application of harmonic loading.

International Journal of Civil and Structural Engineering – IJCSE
Copyright © Institute of Research Engineers and Doctors
Volume 6 : Issue 2 - [ISSN : 2372-3971] - Publication Date: 27 Dec, 2019



a. b.

Figure 5. Typical base shear (Q)-displacement (mm) curves; a. Structure with fixed base and b. structure with uplift

C. *Fundamental Frequency and Damping Ratio*

The dynamic characteristics of structure such as fundamental frequency and damping ratio bear great significance in structural behavior. To determine these two characteristics of prototype structure under consideration with fixed base (SWFB) and uplift (SWU), snap back tests are performed. Fig. 6 shows results obtained from snap back test with fixed base and allowed uplift. The calculation of approximate fundamental frequency (f_n) and damping ratio (ζ) is done by log decrement method.

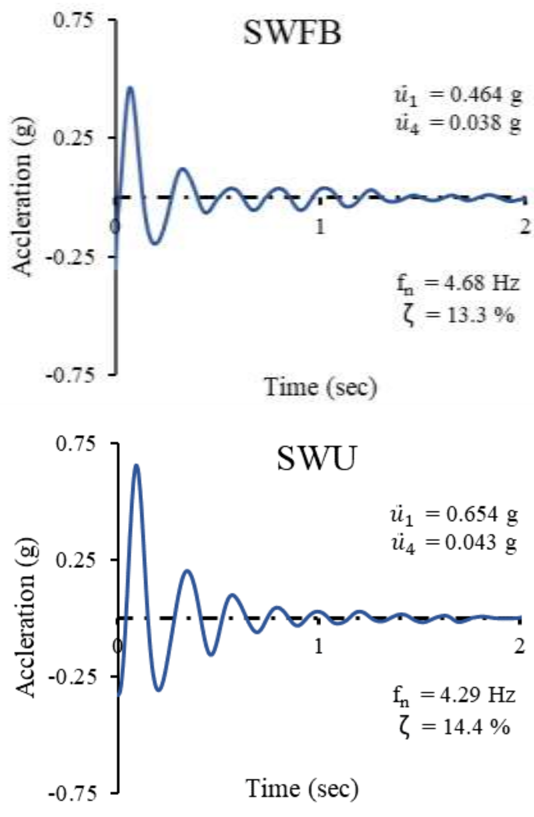


Figure 6. Snap back test: acceleration-time histories for structure tested

IV. Discussions

Precise harmonic loading was applied through locally developed simple shake table for this study. The response recorded at the top of the structure shows a slight increase in horizontal displacement of structure. An increase in horizontal displacement was also observed in SDOF model structure allowed to have uplift, however a decrease in activated forces was observed[6]. The average acceleration and displacement on column top was observed to be 0.151 g, 0.163 g and 28.8 mm, 29.8 mm for SWFB and SWU respectively. That shows an increase of 3.4% in displacement due to uplift. However an increase of 23.5 % energy absorption in structure with uplift was observed as compared to the structure with fixed base. The reduction in fundamental frequency from 4.68 Hz to 4.29 Hz shows an increase in structural flexibility. The significant increase in energy absorption shows a positive potential. So this mechanism should be studied in detail for multi degree of freedom structures.

V. Conclusions

A simple multi degree of freedom single storey prototype structure was studied to investigate the dynamic behavior of structure under harmonic loading particularly the effect of allowed column uplift. A locally made simple shake table was employed in laboratory to apply the harmonic loading. Uplift was only allowed in single column only. Multiple column uplift could also be provided however it was not the goal of current study.

It can be concluded from current study that:

- Column response (i.e. averaged acceleration and displacement) slightly increased in structure with uplift as compared to fixed base.
- A significant increase in energy absorption (23.5%) is observed in structure with uplift.
- A decrease in fundamental frequency while increase in damping ratio of structure with uplift, shows increase in structural flexibility.
- The experimental results are in good agreement with numerical results.

The obtained results from this study shows an impressive effect of allowed uplift in column as column base flexibility. Further precise studies should be conducted to analyze the dynamic characteristics of structure with multiple uplifts in detail. Multi story steel frame structure should also be tested using more complex shake table.

Acknowledgment

The authors would like to offer thanks to every person/department who extended their support throughout this research work, particularly EE department, Engr. Fayaz Khan, Engr. Junaid Farooq and Hassan Ali. The careful review by the anonymous reviewers is also gratefully acknowledged.

References

[1] Spence, R. (2007). Saving lives in earthquakes: successes and failures in seismic protection since 1960. Bulletin of Earthquake Engineering, 5(2), 139-251.

[2] Okazaki, T., Lignos, D. G., Midorikawa, M., Ricles, J. M., & Love, J. (2013). Damage to steel buildings observed after the 2011 Tohoku-Oki earthquake. Earthquake spectra, 29(S1), S219-S243.

[3] Takagi, J., & Wada, A. (2018). "Recent earthquakes and the need for a new philosophy for earthquake-resistant design." Soil Dynamics and Earthquake Engineering.

[4] Elvin, A. and Uzoegbo, H.C., (2011) Response of a full-scale dry-stack masonry structure subject to experimentally applied earthquake loading, Journal of the South African Institution of Civil Engineers, Vol 53, pp 22 -32.

[5] Baran, T., Tanrikulu, A. K., Dundar, C., & Tanrikulu, A. H. (2011). Construction and performance test of a low-cost shake table. Experimental Techniques, 35(4), 8-16.

[6] Qin, X., & Chouw, N. (2010). "Experimental investigation of uplift effect on structures in earthquakes." New Zealand society for earthquake engineering conference, Paper (Vol. 14).

About Author (s):

Nakhshab Ajaz is an final year undergraduate student at Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan

Assad Rashid is an final year undergraduate student at Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan

Majid Ali holds a doctorate degree in Civil Engineering from The University of Auckland, New Zealand and currently an associate professor at Department of Civil Engineering, Capital University of Science and Technology, Islamabad, Pakistan having a more than 14 years of rich teaching, research and professional industry experience