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Using Shear Walls in Minimizing the Torsional Coupling Effects of Asymmetrical Multistory Buildings Subjected to Earthquake Excitations

Prof. Dr. Adnan Falih Ali
Civil Engineering dept. University of Baghdad
Baghdad, Iraq

Majed Ashoor Khalaf
Civil Engineering Dept.
University of Basrah
Basrah, Iraq

***Abstract*— A U-Shape six-story reinforced concrete building with and without shear walls have been analyzed using SAP2000, ETABS and ANSYS software packages under an excitation of El Centro earthquake. The analyses showed the torsional coupling effects that raised from the non-symmetrical horizontal plan of the building when it subjected to lateral excitation and then how to eliminate or minimize these effects by using proper shear walls of selected properties in specific locations of the building. The results of the first analyses of the MRF building without shear walls have shown that torsion is the dominant mode of vibration due to nonsymmetry of the building. The second analyses carried out after addition of selected shear walls in a manner to coincide the center of mass of the building on its center of rigidity have shown a great minimization of these torsional coupling effects under excitation of earthquakes.**

Keywords—Multistory; Nonsymmetry; Torsion Coupling; Shear Walls; Earthquakes

I. U1 BUILDING DESCRIPTION

The U-Shape six-story reinforced concrete building of 43.2×43.2m in plan and 24.5m in height is shown in Fig. 1. The height of the ground story is 4.5m and for the other five typical stories is 4.0m, measured from beams centers. The main horizontal span is 7.2m in both directions. All the 56 per story columns of 500×500mm cross sections, beams of 600×300mm, and slabs of 200mm thickness. The building modeled as fixed supported at the base and the damping ratio considered as 5%. The material properties are summarized in Table I.

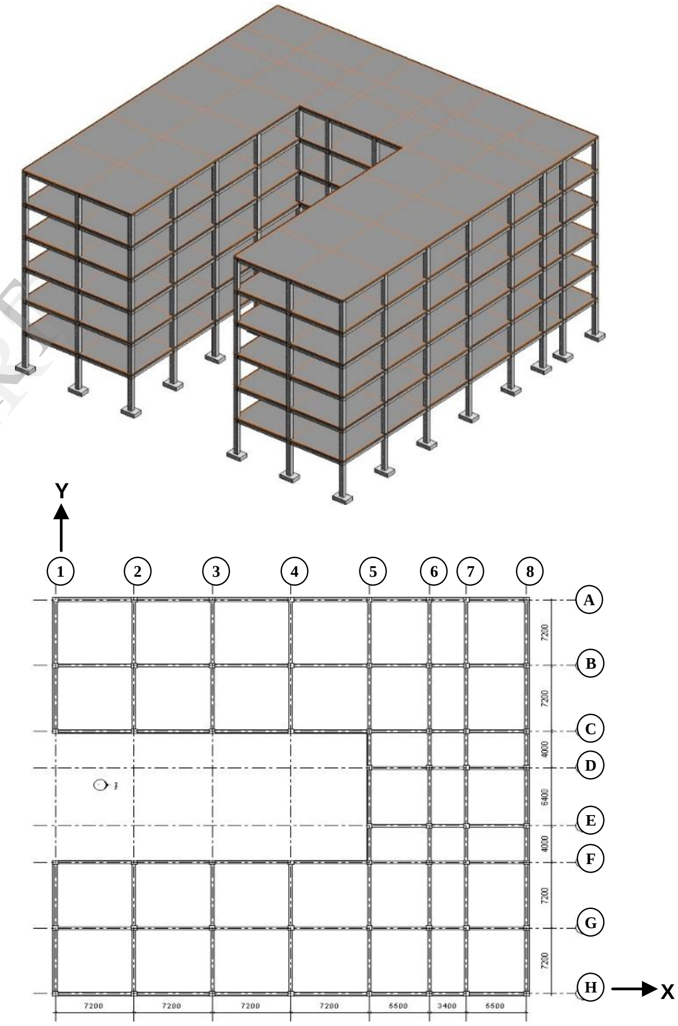

Fig. 1. The 3D and plan views of the U1 building

TABLE I. MATERIAL PROPERTIES OF U1 BUILDING IN N-MM-SEC UNITS

Material	E	Poisson Ratio	Mass/V	Grade
Concrete	24,860	0.2	2.403E-09	F'c=27.5
Steel	200,000	0.3	7.849E-09	Fy=414

II. MODAL ANALYSIS OF U1 BUILDING

The 3D modal analysis of U1 building by three different software have shown that the torsion modes are dominated on this building behavior, and it is noticed that there is no pure lateral mode in y direction. The first 12 modes shapes and frequencies are summarized in Table II.

TABLE II. U1 BUILDING MODES IN SAP2000, ETABS AND ANSYS

Mode	**f (Hz)**		
	SAP2000	**ETABS**	**ANSYS**
1	0.955-R*	0.963-R	0.921-R
2	1.016-X	1.025-X	0.998-X
3	1.075-R	1.084-R	1.060-R
4	2.900-R	2.924-R	2.844-R
5	3.070-X	3.099-X	3.062-X
6	3.250-R	3.279-R	3.256-R
7	3.630-R	3.651-R	3.608-R
8	4.570-R	4.599-R	4.527-R
9	4.945-R	4.990-R	4.997-R
10	5.192-X	5.244-X	5.324-X
11	5.489-R	5.540-R	5.657-R
12	6.126-R	6.171-R	6.173-R

* X and Y denote to modes in the two horizontal directions and R for rotation about Z-axis.

III. TRANSIENT TIME HISTORY ANALYSIS OF U1

The left hand side (LHS) and right hand side (RHS) corner displacements of the roof of the building are investigated through transient time history analysis of the building subjected to a base excitation of the El Centro 1940 earthquake in y-direction by using the three software.

Figure (2) shows the acceleration time history of the earthquake whereas Figures (3) and (4) show separately the lateral displacement of LHS and RHS corners of the roof of the building in y-direction using SAP2000, ETABS, and ANSYS.

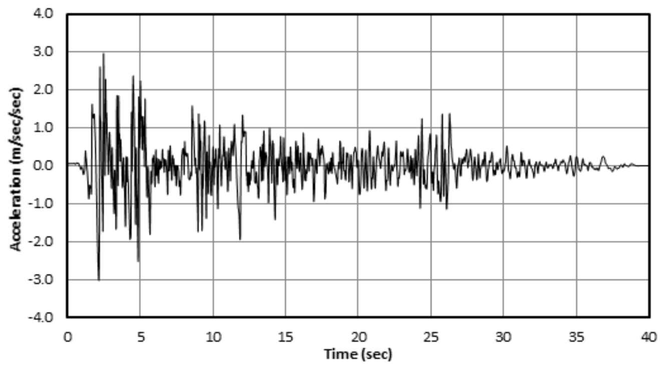

Fig. 2. Acceleration time history record of El Centro 1940 earthquake

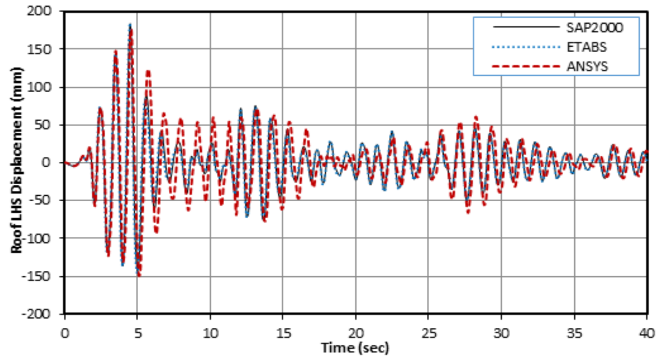

Fig. 3. Roof LHS corner displacement in y-direction using three software

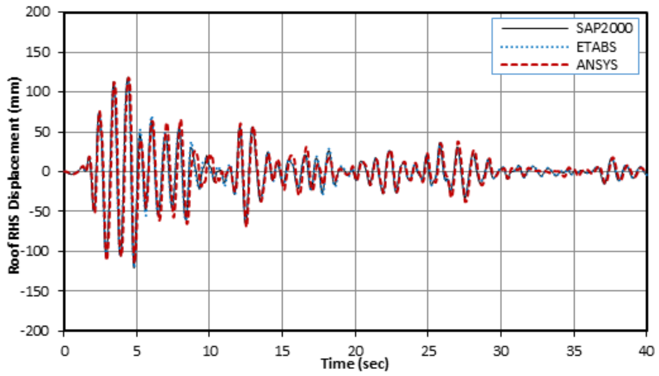

Fig. 4. Roof RHS corner displacement in y-direction using three software

To emphasize the difference in displacement between the LHS and RHS corners, Fig.5 shows both displacement response on the same graph using SAP2000 solution.

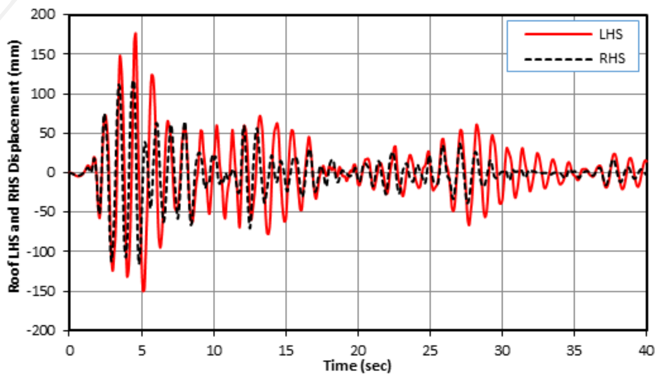

Fig. 5. Roof LHS and RHS displacement using SAP2000

Fig.5 shows that the left corner vibrates in higher amplitude and lower frequency than the right corner. Although the general view of Fig.5 does not show much difference in amplitudes, the important fact is that the two corners of the building are vibrating out of phase along the whole time history. This out of phase motion makes the maximum difference to be 186.6 mm at the instance 5.2 sec when the left corner deflect -147.8mm back and the right corner deflect 38.8mm forward. This will clearly cause a considerable torsion on the different members of the building. The importance of this difference in displacement between the two sides of the building comes from it represent a different type of motion that add a new torsional stresses to the columns, and more importantly it adds a new bending moments to the beams of the building in their weak axes, where these beams are normally not designed for such type of bending.

This difference is presented more clearly in Fig.6 that show the absolute difference in the displacement of LHS and RHS of the roof of the building along the whole time history.

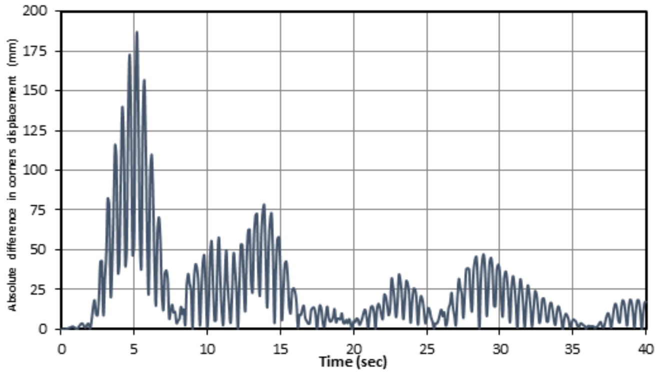

Fig. 6. Absolute difference between LHS and RHS displacement

From the frequency point of view, a Fourier amplitude spectrum analysis have been done for the two corners response using Fast Fourier Transform as presented in Fig.7.

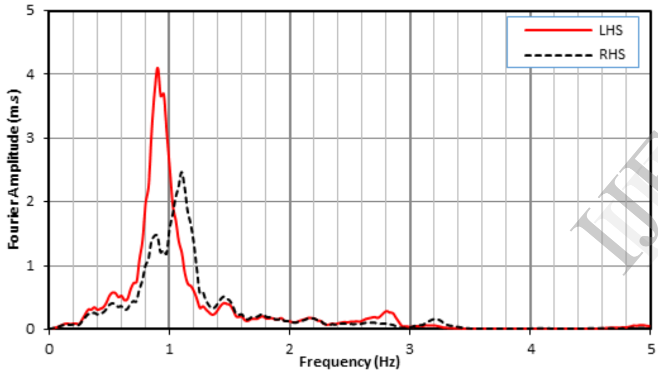

Fig. 7. Amplitude spectrum of LHS and RHS displacement response

Fig.7 shows that the left corner of the building is the softer as it dominantly vibrates at 0.902Hz, while the right corner is the stiffer and dominantly vibrates at 1.103Hz.

IV. U2 BUILDING

The Building U2 is representing a suggestion for eliminating or minimizing the torsional effects of U1 building by adding shear walls of specific properties at specific locations in the plan of the building.

After choosing the location of two shear walls in the weaker LHS legs of the building, several trials of changing their cross sections have been made to reach to the optimum cross sections that can equilibrate the mass and rigidity of the building for both sides. The resulted shear walls are of 1000×300mm cross sections.

Figures (8) through (10) show the 3D and plan views of the resulting U2 building with the shear walls locations.

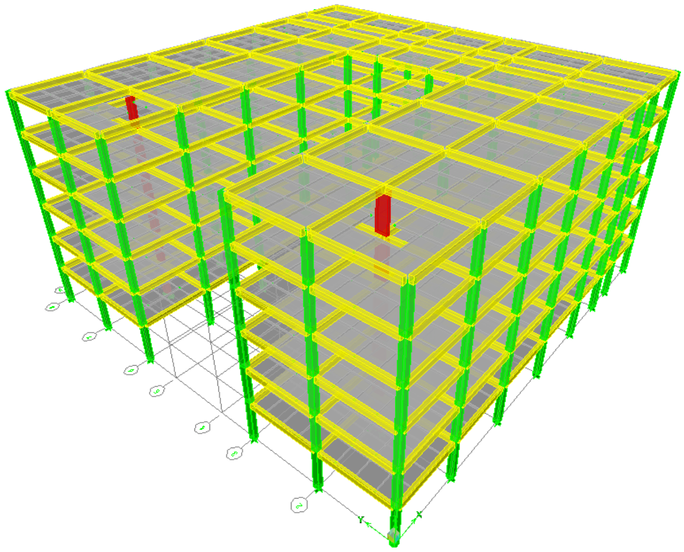

Fig. 8. ETABS 3D model of U2 building

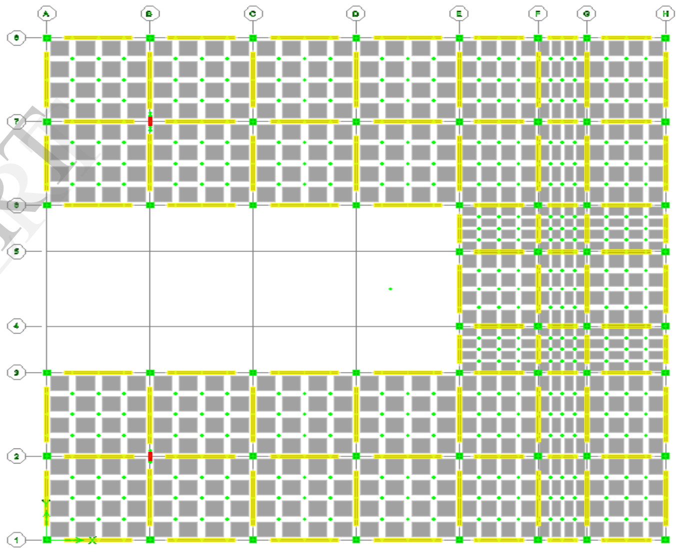

Fig. 9. ETABS plan view of U2 builing

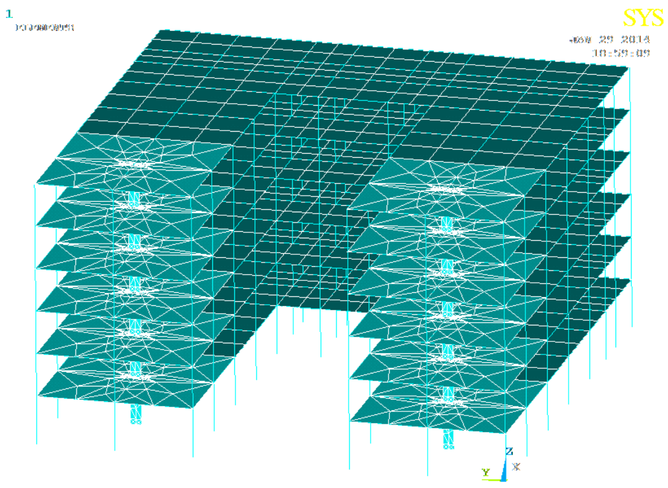

Fig. 10. ANSYS 3D model of U2 building

V. MODAL ANALYSIS OF U2 BUILDING

Table III summarize the results of modal analysis of U2 building using the three software.

TABLE III. U2 BUILDING MODES IN SAP2000, ETABS AND ANSYS

Mode	f (Hz)		
	SAP2000	ETABS	ANSYS
1	1.002-X*	1.015-X	0.921-R
2	1.039-Y	1.062-Y	0.998-X
3	1.078-R	1.098-R	1.060-R
4	3.028-X	3.069-X	2.844-R
5	3.176-Y	3.232-R	3.062-X
6	3.279-R	3.359-R	3.256-R
7	3.665-Y	3.693-Y	3.608-R
8	4.876-Y	4.986-Y	4.527-R
9	5.123-X	5.190-X	4.997-R
10	5.419-R	5.488-R	5.324-X
11	5.656-R	5.829-R	5.657-R
12	6.974-R	7.220-R	6.173-R

* X and Y denote to modes in the two horizontal directions and R for rotation about Z-axis.

The table shows that the addition of shear walls have caused a nearly pure lateral modes in y-direction and have delayed the torsional mode in a similar way faced in symmetrical buildings [1].

VI. TRANSIENT TIME HISTORY ANALYSIS OF U2 BUILDING

As in the previous case of U1 building, a time history analysis have been carried out for the U2 building. The figures below show the two roof corners displacements resulted from the three software implemented in the study.

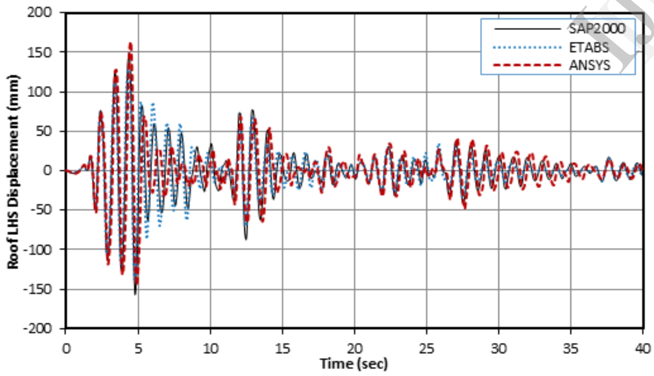

Fig. 11. Roof LHS displacement in y-direction using the three software

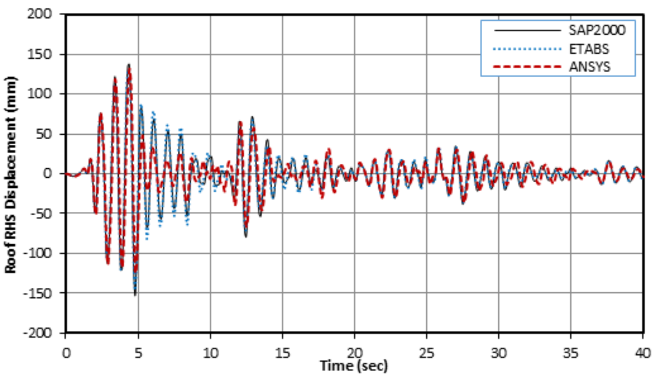

Fig. 12. Roof RHS displacement in y-direction using the three software

Fig.13 shows both LHS and RHS displacement of the building on the same graph, which are nearly, coincides on each other. This figure reveals that the addition of the shear walls at the proper locations have minimized the torsion effects or nearly eliminated it for this building

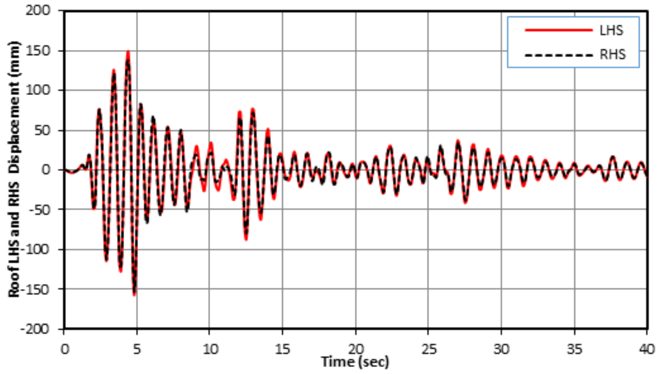

Fig. 13. Roof LHS and RHS displacement using SAP2000

Figures (14) to (16) show the absolute difference in displacement between the LHS and RHS of the building within the time history of response. In these figures, the solution of SAP2000 and ETABS show a minimal maximum difference of less than 25mm, whilst the ANSYS solution shows larger difference of a maximum of 75mm.

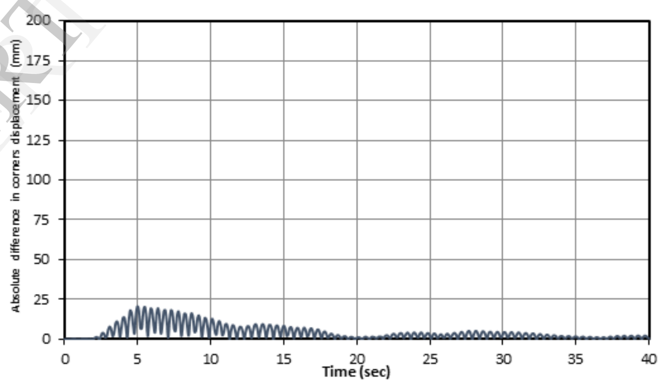

Fig. 14. Absolute difference between LHS and RHS displacement using SAP2000

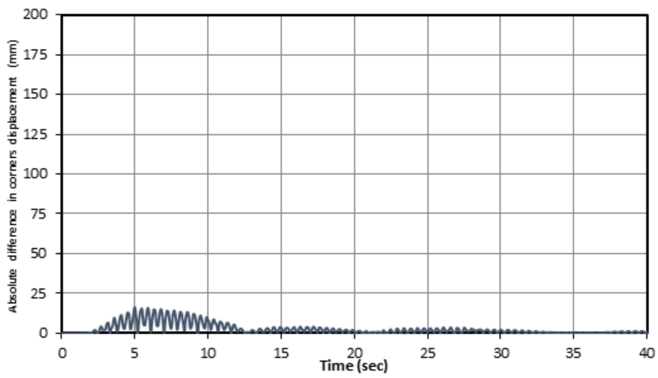

Fig. 15. Absolute difference between LHS and RHS displacement using ETABS

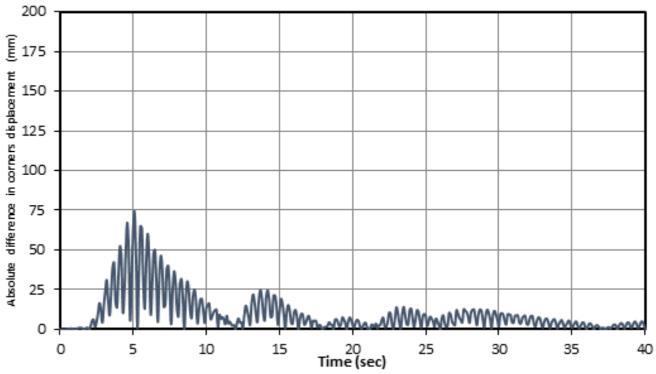

Fig. 16. Absolute difference between LHS and RHS displacement using ANSYS

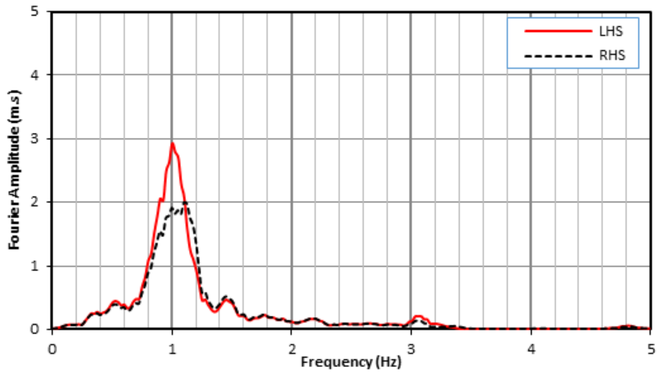

Fig. 18. Amplitude spectrum of LHS and RHS displacement response using ANSYS

Figures (17) and (18) show the frequency of vibration for both corners of the building. As in time history analysis, SAP2000 and ETABS solutions showed minimum difference in frequency, while ANSYS solution shows some difference in frequency between the LHS and the RHS of the building.

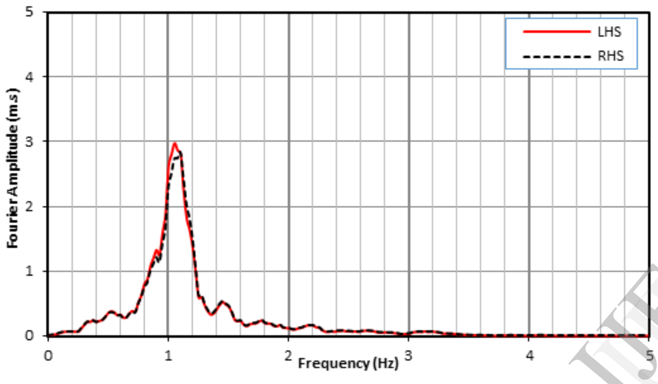

Fig. 17. Amplitude spectrum of LHS and RHS displacement response using SAP2000

VII. CONCLUSIONS

- The shear walls are very efficient structural elements for multistory reinforced concrete buildings subjected to earthquakes or other lateral excitation. They can do dual action, the first one is stiffening the MRF building in resistance to lateral loading, and the second, they can equilibrate the distribution of mass and rigidity of the building especially for non-symmetrical horizontal plans and then can eliminate or minimize the torsional coupling effect of the lateral response.
- The three used software of SAP2000, ETABS, and ANSYS in general have shown comparable results in both modal and transient time history analyses for both U1 and U2 buildings, however, the ANSYS results showed slightly bigger differences than the other two software and that because of finesse of meshing and different types of elements used in modeling.

REFERENCES

[1] Adnan, F. A. and Majed, A. K. (2014) "Multistory Buildings as Band Pass Filters for Earthquake Excitations", IJERT, Vol. 3, Issue 10, October-2014.