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Assessing the Effect of the Position of the Cavities on the Inner Plate of the Steel Shear Wall under Time History Dynamic Analysis

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***Abstract*—**The seismic forces caused by the waves created in the depths of the earth during the earthquake hit the structure and cause the building to vibrate. Creating large seismic forces will cause low-strength sections in the structure to suffer extensive surface damage. The use of new steel shear walls in steel structures has caused the strength of the building and its main members (columns) to increase due to the reduction and depreciation of seismic forces during earthquakes. In the present study, an attempt was made to evaluate a type of steel shear wall that has regular holes in the inner sheet by modeling the finite element model with Abacus software. The shear wall of the steel plate, measuring 6000 × 3000 mm (one floor) and 3 mm thickness, was modeled with four different pores with a cross-sectional area. The shear wall was dynamically subjected to a time history of 5 seconds by three accelerators, El Centro, Imperial Valley and Kobe. The results showed that increasing the distance between the geometric center of the hole and the geometric center of the inner plate in the steel shear wall (increasing the R_{CS} index) caused the total maximum acceleration to be transferred from the perimeter of the hole to horizontal and vertical beams. The results also show that there is no direct relationship between R_{CS} index and total acceleration in steel shear wall and R_{CS} index is separate from the peak ground acceleration value of earthquake.

***Keywords*—**Hollow Steel plate shear wall, time history analysis, finite element method, Abaqus Software.

I. Introduction

DURING an earthquake, the structure undergoes oscillating movements under the influence of forces released from the depths of the earth, which can cause irreparable damage to various members of the building if a large-magnitude earthquake occurs. The creation of new components in the earthquake energy dissipation elements in a building will increase the possibility of increasing the structural capacity during the earthquake and increase the life and financial safety factor during the construction and operation of the building. Steel plate shear walls are commonly used as structural shear systems in parts of the structure that have large design loads and small space [1]. For the past four decades, the steel plate shear wall (SPSW) has been used as a side-by-side system in steel structures, especially high-rise buildings, in order to increase its strength in buildings. Increasing the thickness of the plate, using hardeners on one or both sides of the shear wall, etc. is done, which is expensive. Also, the use of welding in the hardener weakens the shear wall. As a result, new solutions, especially the creation of holes in the inner plate of the shear wall, are of great interest to structural designers and executors [2]-[4]. Mu and Yang looked at the conditions for opening a two-story steel shear wall with Abacus software, and the results showed that creating a regular opening on both sides of the steel wall increased the maximum stress and force created by one side. The link connects the two middle sections and the columns [5]. Ashrafi et al. evaluated and compared the effect of horizontal and vertical waves on the inner plate of the steel shear wall, and the results showed that the capacity and formation of the steel shear wall in the vertical wave state was higher [6]. Chan et al. evaluated the effect of hole diameter on the inner plate of the steel shear wall and the results showed that increasing the hole diameter caused very little plastic deformation on the inner plate and increased stress in the horizontal beam [7].

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II. Methodology

A. Materials

Steel shear wall modeling was performed in Abacus software with ST37 steel. The mass density, elastic modulus and Poisson's steel coefficient are 0.000078, 200000 and 0.3, respectively. The steel part of the steel is based on the normal plastic model and in the form of a line passing through two points provided to the software, including (0, 340) and (0.1 and 440), which in each coordinate is (Yield Stress, Plastic Strain).

B. Geometry and Cross Section of the Element

The final model is based on a combination of three components, including a vertical element, a horizontal element, and a recessed internal cavity element. Also, the dimensions and specifications of the elements are presented in Table I. The inner plate has a rectangular cross section with a length and width of 6000 mm and 3000 mm, respectively (parameters A and B in Fig. 1).

The thickness of the recessed (hollow) inner plate element is 3 mm. A hole with a square cross section of 300 mm and 4 pieces was created in this element. The cavities are placed in four different modes in the shear wall (total areas are equal in four modes). The process of increasing their distance to the geometric center of the inner plate is regularly increased.

In order to evaluate the effect of the distance between the geometric centers of the cavity and the inner plate in the steel shear wall, a proposed index called R_{CS} index has been introduced in this study, the value of which is presented for each model in Table II.

TABLE I
SPECIFICATIONS OF VERTICAL AND HORIZONTAL ELEMENTS IN THE SHEAR WALL OF PERFORATED STEEL PLATE

Element title	Moment of inertia	The length	The length of the lower wing	The lower wing thickness	The thickness
Horizontal	500	1000	460	44	20
Vertical	200	440	280	20	18

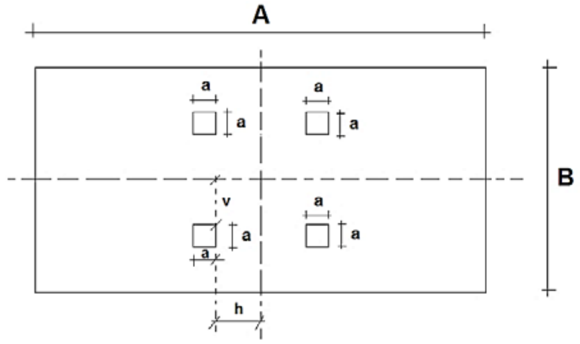

Fig. 1 Schematic modeling of perforated inner plate in steel shear wall shear

TABLE II
NAMING SOFTWARE MODELS AND PROVIDING THEIR GEOMETRIC CHARACTERISTICS

Row	Model title	length	Width	H (mm)	V (mm)	Rcs
1	SPSW1	a = 6000	b = 3000	0	0	R_{CS1}
2	SPSW2	a = 6000	b = 3000	300	300	R_{CS2}
3	SPSW3	a = 6000	b = 3000	600	600	R_{CS3}
4	SPSW4	a = 6000	b = 3000	900	900	R_{CS4}

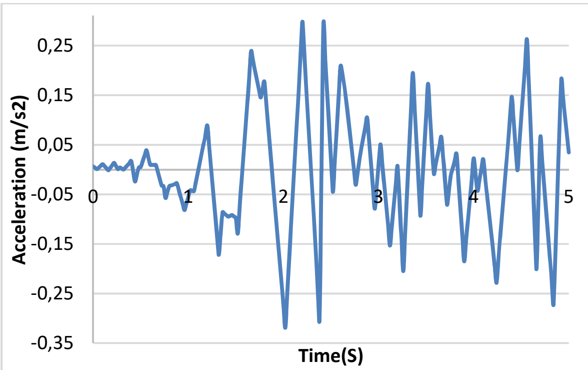

Fig. 2 El Centro earthquake diagram (Acceleration-time)

C. Mesh and Support

The size of the mesh in the recessed plate element of the steel shear wall is 100 mm. The mesh on the entire shear wall of the steel plate is FREE and linear. Two types of support, including clamping (alignment in all three directions of x, y, and z) and articulated (alignment in the direction of z), were defined in the modeling, which are respectively; 1) the contact point of the shear wall to the ground and 2) the contact point of the shear wall to the horizontal element was assigned.

D. Loading

The loading was done as Dynamic Explicit and using three accelerometers of El Centro, Imperial Valley and Kobe. The acceleration-time diagram of these three earthquakes is shown in Figs. 2-4. The quake was concentrated at the upper and left upper points of the shear wall.

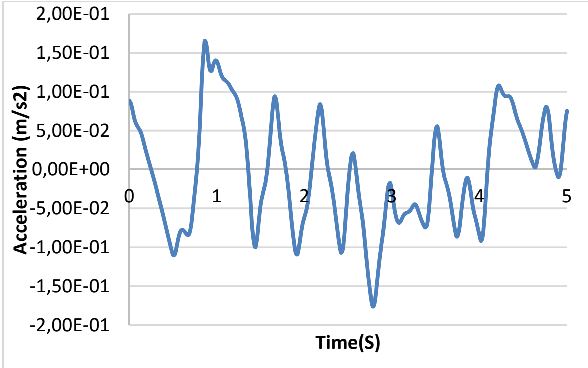

Fig. 3 Imperial Valley earthquake diagram (Acceleration-time)

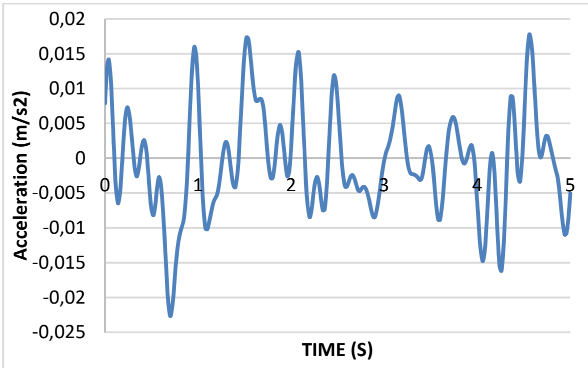

Fig. 4 Kobe earthquake diagram (Acceleration-time)

III. PRESENTING AND ANALYZING THE RESULTS

A. El Centro Earthquake

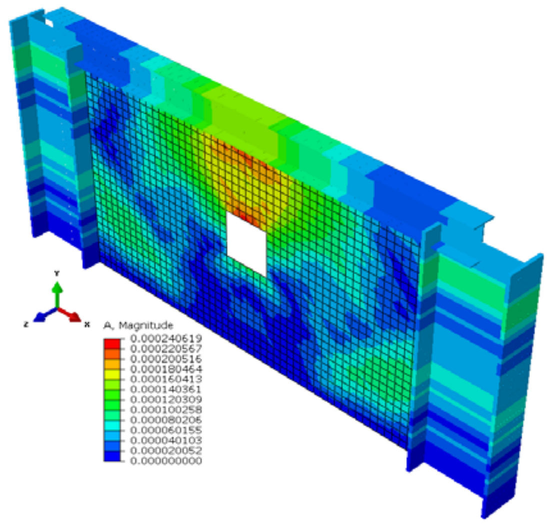

Fig. 5 Acceleration in SPSW1 model under El Centro earthquake

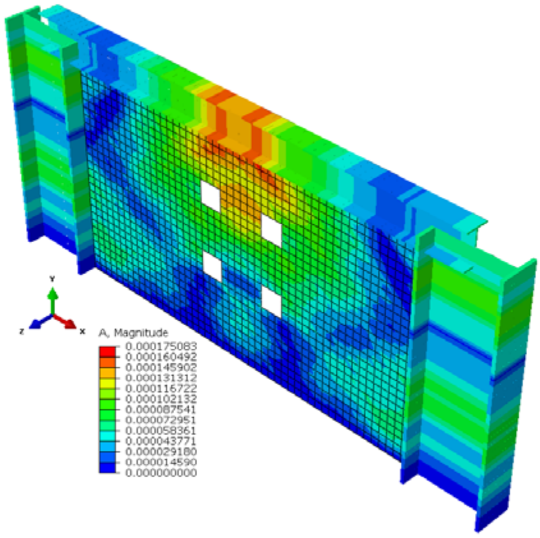

Fig. 6 Acceleration in SPSW2 model under El Centro earthquake

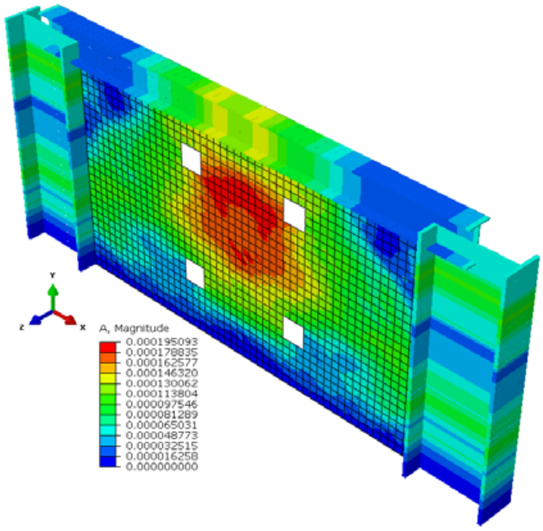

Fig. 7 Acceleration in SPSW3 model under El Centro earthquake

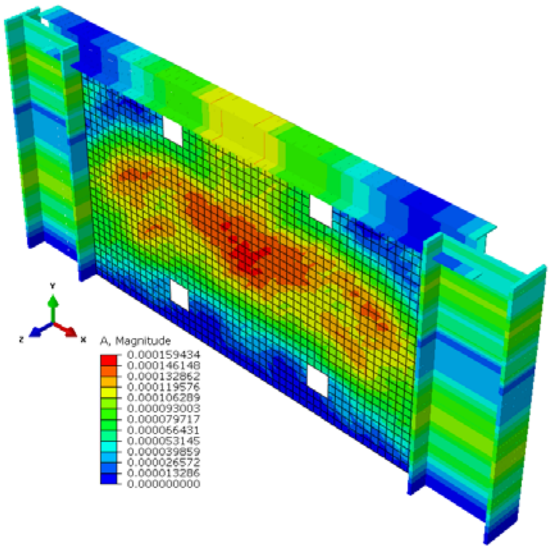

Fig. 8 Acceleration in SPSW4 model under El Centro earthquake

As the RCS index increased, it was observed that the maximum rate of acceleration was changing, so that the lowest acceleration rate occurred in the SPSW4 model, which is 0.000159434 MPa. This decrease is equal to 33%, 8.9% and 37%, respectively, compared to SPSW1, SPSW2 and SPSW3 models. The results showed that with increasing RCS index, the acceleration was gradually transferred from around the hole (SPSW1 model) to the horizontal beam (SPSW2 model) and then to the inner part of the cavity.

B. Imperial Valley Earthquake

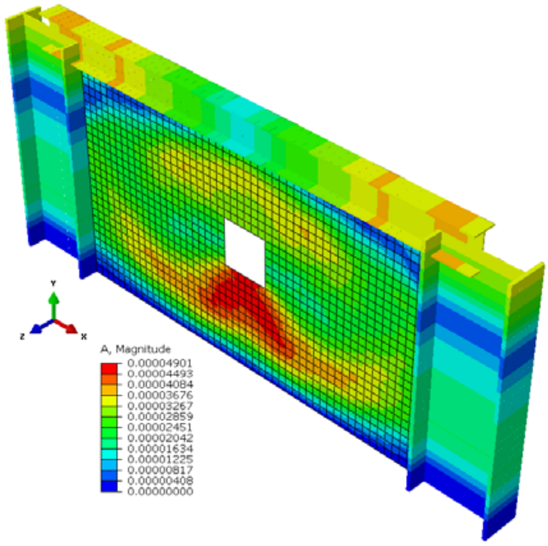

Fig. 9 Acceleration of SPSW1 model under Imperial Valley earthquake

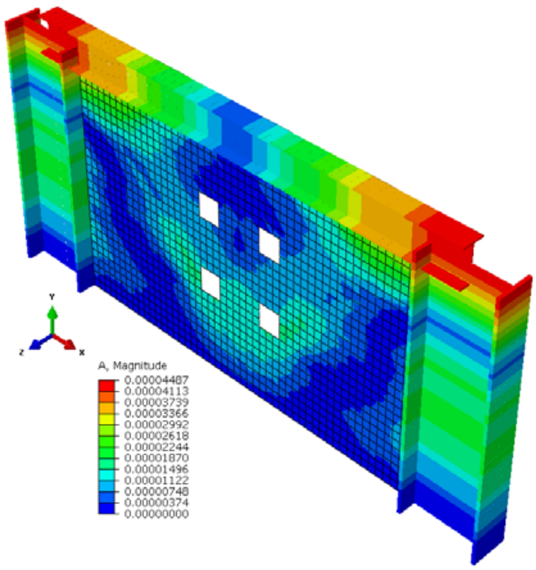

Fig. 10 Acceleration of SPSW2 model under Imperial Valley earthquake

With the increase in the RCS index, it was observed that the acceleration rate was changing and the highest and lowest acceleration levels were created in SPSW1 and SPSW4 models with the values of 0.00004901 MPa and 0.00004373.0

MPa. The reduction in acceleration in the SPSW4 model compared to the SPSW1, SPSW2 and SPSW3 models is 10.7%, 2.5% and 7.2%, respectively. The results showed that the increase in RCS index caused the maximum acceleration around the hole in the SPSW1 model to be transferred to the connection areas and the horizontal beam, and these areas will be under more pressure, which caused the compressive forces to be removed from the inner plate.

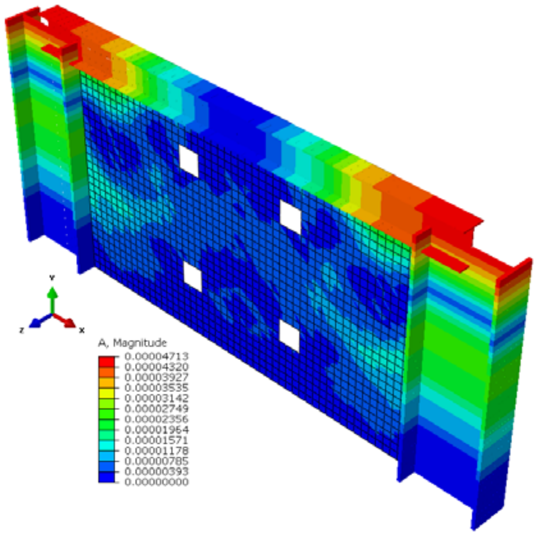

Fig. 11 Acceleration of SPSW3 model under Imperial Valley earthquake

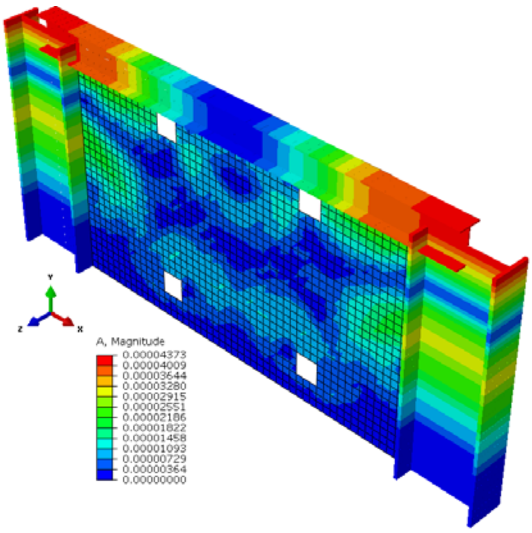

Fig. 12 Acceleration of SPSW4 model under Imperial Valley earthquake

C. Kobe Earthquake

The results showed that the increase in RCS caused the acceleration to change and the acceleration in the SPSW4 model to have the lowest value equal to 0.000000430 MPa. This decrease is 96%, 15.5% and 32%, respectively, compared to SPSW1, SPSW2 and SPSW3 models. It can also be seen that the increase in the RCS index caused the maximum acceleration from around the cavity to the vertical and horizontal beams to be independent, which has increased the strength of the steel shear wall.

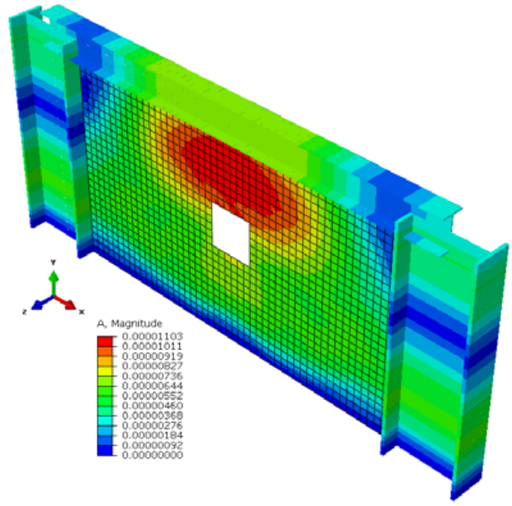

Fig. 13 Acceleration of SPSW1 model under Kobe earthquake

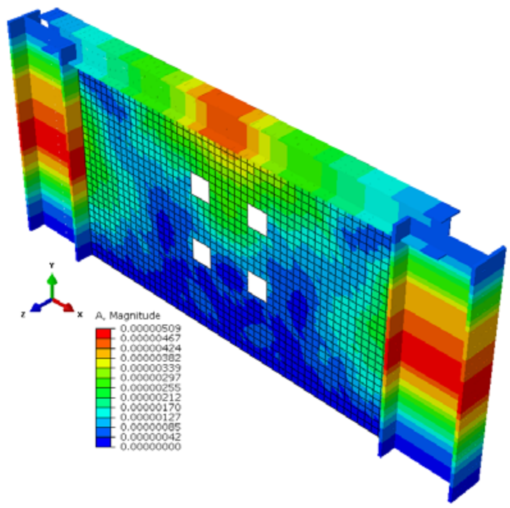

Fig. 14 Acceleration of SPSW2 model under Kobe earthquake

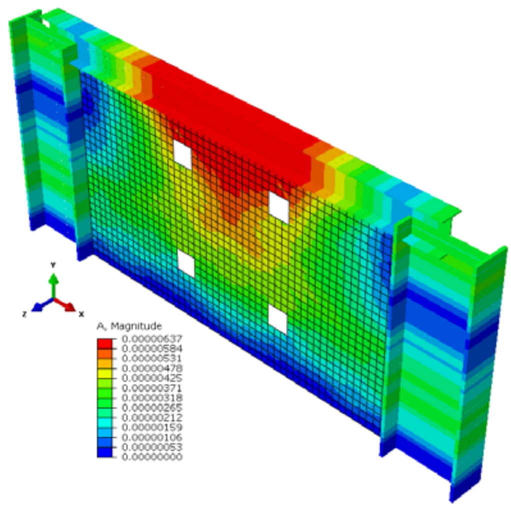

Fig. 15 Acceleration of SPSW3 model under Kobe earthquake

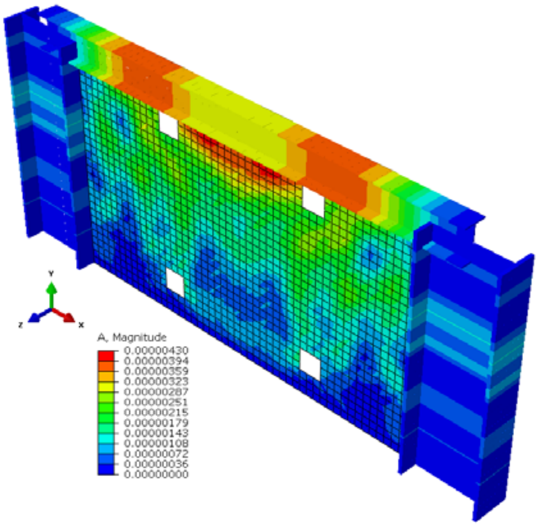

Fig. 16 Acceleration of SPSW4 model under Kobe earthquake

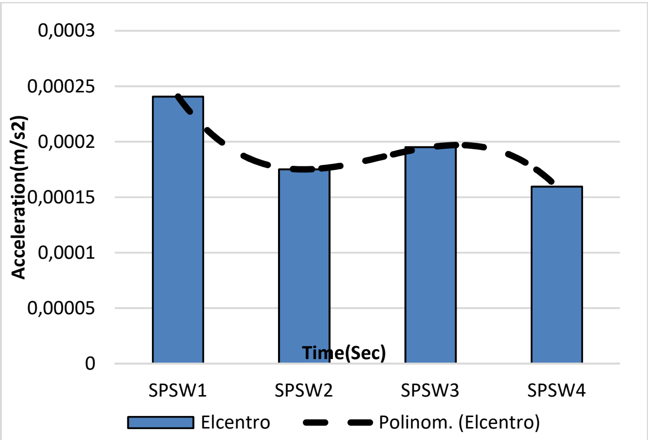

Fig. 17 Maximum Acceleration diagram in SPSW1, SPSW2, SPSW3 and SPSW4 models under El Centro earthquake

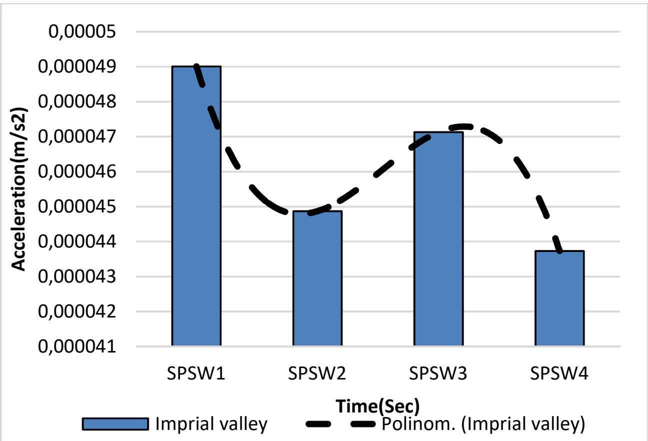

Fig. 18 Maximum Acceleration diagram in SPSW1, SPSW2, SPSW3 and SPSW4 models under Imperial Valley earthquake

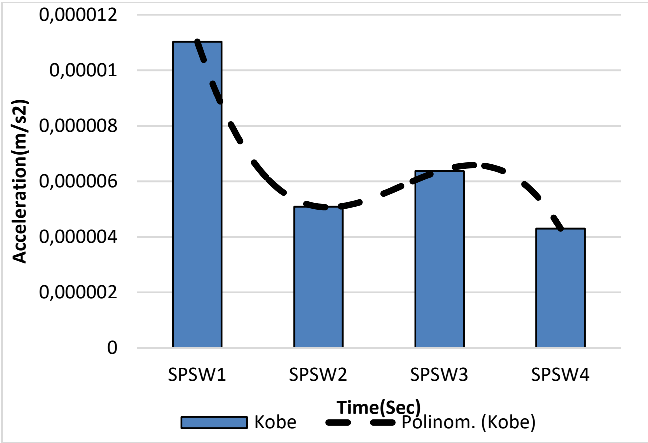

Fig. 19 Maximum acceleration diagram in SPSW1, SPSW2, SPSW3 and SPSW4 models under Kobe earthquake

IV. Conclusion

By evaluating the results of time history analysis, the summary of the final achievements includes the following:

1. The highest total acceleration among the four proposed models is created in the SPSW4 model, which has the maximum R_{CS} index. However, by evaluating the resulting graphs, it can be seen that there is no direct relationship between the R_{CS} index and the maximum total acceleration in the shear wall of the steel plate.
2. In all three earthquakes in the SPSW, the results have a similar trend, indicating that the changes in PGA have not affected the process of creating the results, and that the R_{CS} index per PGA of the probable earthquake is true.
3. With the increase of R_{CS} index, the place of formation of the maximum total acceleration has been transferred from the holes around to horizontal and vertical elements.

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