SEISMIC PERFORMANCE EVALUATION OF HYBRID STEEL COUPLING BEAM IN WALL SYSTEM

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Abstract - *shear walls are a major design consideration for resisting earthquake hazards for high-rise buildings. So proper design of shear wall takes a major importance for the buildings in high risk seismic areas. For improving the lateral resistance of shear wall, coupling beam shear wall are nowadays are used, which also have so many disadvantages. Due to its fixity, more crack are forming at the corner of the beam and also it requires large time period for post-earthquake repair works; very costly too. So to improve the seismic resilience, a replaceable steel truss coupling beams is introducing in this paper. Because of the pinned connection, free rotations are allowed; thus moments will be zero at the support and most of the damages will be concentrate on the coupling beam. Cyclic analysis has conducted on RSTCBs by varying different l/d ratios and different truss orientation. A best performed model was selected and push over analysis is conducted on a 11- story prototype structure. Finally the seismic response of the RSTCB structure is compared with the RC coupling beam shear wall structure***.**

***Key Words*: RC coupling beam, RSTCB, pushover analysis, Energy dissipater**

1. INTRODUCTION

Reinforced concrete (RC) buildings often have vertical plate like RC walls called Shear Walls in addition to slabs, beams and columns. These walls generally starts at foundation level and are continuous throughout the building height. Shear walls are like vertically oriented wide beams that carry earthquake loads downwards to the foundation. Shear walls are a major important element that must be provide in medium and high rise buildings in regions of high seismicity and it acts like primary lateral load bearing elements. Instead of providing it as a single solid vertical member, no of beams connected in between the walls, makes it more flexible. So this coupling beams act as a fuse in between the two wall piers and under large earthquake loads the beam will be subjected to more shear deformation. RC coupling shear walls are widely used for the construction over a large period of time. Since this beams are rigidly connected to the two wall piers, the ends of the beams are do not allow any rotation so that more amount of moments will be generate at the ends of the beam and it will also affect the wall pier. Diagonal cracking and sliding cracking are more observe on this case. Moreover, the post-earthquake repair works become more difficult and also it need more time and wants more money.

In order to improve the seismic resilience of the coupling beams, various studies had been conducted and different types of coupling beams were proposed. Replaceable steel truss coupling beam (RSTCB) is a latest innovation in this area. As the name suggest, it is replaceable and it is pinnely connected to the two ends of wall pier. It consist of two chords i.e.; top chord and bottom chord and two energy dissipating element connecting the chords. The main objective of this article is to propose a best former replaceable steel truss coupling beam by varying different l/d ratio for the beam and different orientation of the truss that could be useful for the buildings of high risk seismic area.

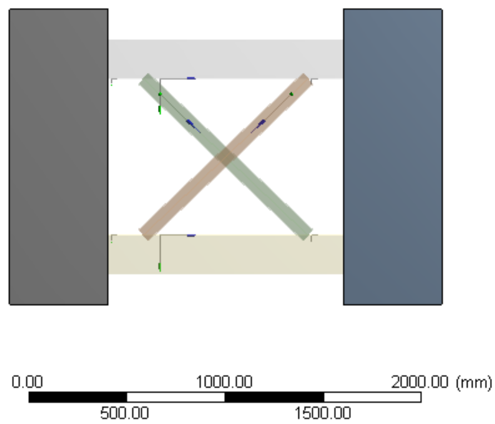

Fig-1: General model of RSTCB

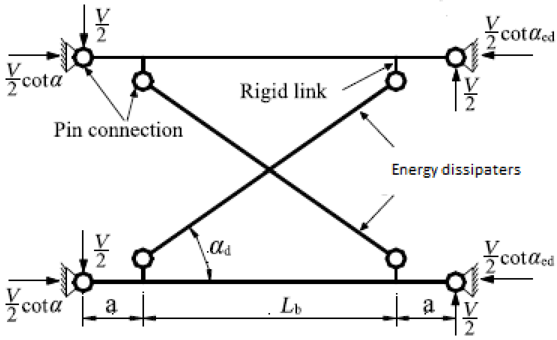

Fig-2: Analytical model of RSTCB([1.] Yong Li, Ye Liu and Shaoping Meng (2018))

a = 180 mm (horizontal distance between the hinge of beam and dissipater)
L_b= 840 mm (horizontal distance between the hinge of dissipater)
H= 800 mm (total height of RSTCB)

2. FINITE ELEMENT MODELLING

2.1 General

In finite element analysis, fine mesh was adopted for accuracy. The finite element model of RSTCBs with different l/d ratios and different truss orientations were prepared using ANSYS 16.1 software.

2.2 Scope

The work is mainly focused on modeling four different RSTCB having 4 different truss orientation i.e.; X type bracing, chevron bracing, eccentric bracing, parallel bracing with 5 different l/d ratios. Former works ([1.] Yong Li, Ye Liu and Shaoping Meng (2018)) are used CFST chords for the beam, RSTCB used in this work is made up of full steel. Cyclic analysis are conducting for every shapes with every l/d ratios.

2.3 Geometry

The RSTCBs with different type of truss orientation and different span to depth ratios are taken for analysis. Each type of trusses are analyzed with each of the ratios. The selected orientation for the trusses are x type bracing, chevron bracing, eccentric bracing, parallel bracing. The top chord and bottom chord are made of ISMB 200 and two energy dissipater is of ISMB 100 respectively. Cross section of shear wall is 500x400 mm.

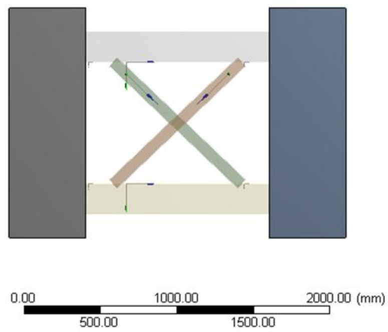

Fig-3: X type bracing coupling beam

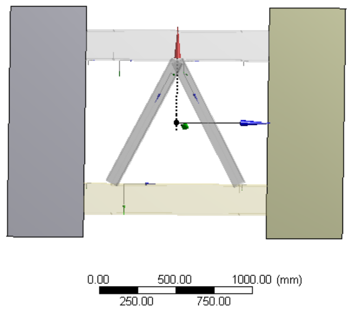

Fig-4: Chevron bracing coupling beam

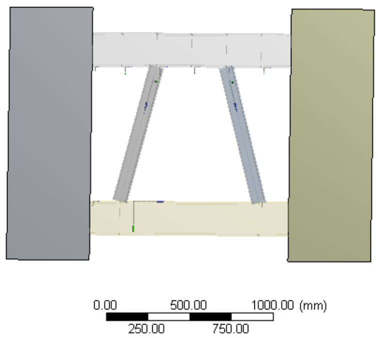

Fig-5: Eccentric bracing coupling beam

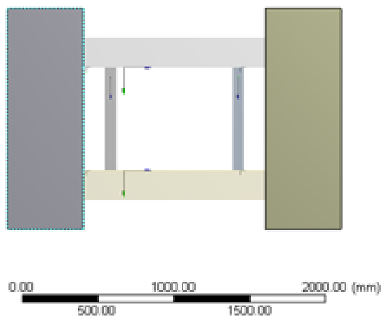

Fig-6: Parallel bracing coupling beam

2.4 Meshing

Finite element analysis is the process of dividing the geometry into finite nodes and elements and solving it for stress and strains and the particular process of discretization is known as meshing. Meshing is the way of communicating the geometry to the FEA solver. In meshing, geometry will be divided into into any one of the following shapes of elements like triangles, quadrilaterals, tetrahedron, quadrilateral pyramid, triangular prism, and hexahedron. and the selection of particular shape of the element depends on the type of analysis and the shape of the geometry.Elements on the mesh of the geometry will only capture the structural response of the system so it is mandatory to understand the impact of element type and mesh quality before solving a problem. Even the density of the mesh can affect the output so it is best to have a more elements.

2.5 Loading and Boundary conditions

Fig-7shows the general boundary conditions of RSTB in a wall . To stimulate the real conditions, coupling beam wall panels is analysed with fixed support at two columns to restrain axial deformation whereas load is applied in one direction. Cyclic loadings were applied upto 6% drift under the guidelines of FEMA(350).

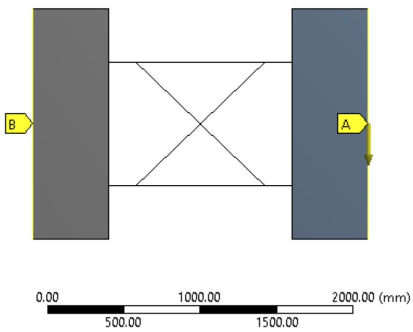

Fig-7: General boundary condition of RSTCB

2.5.1 Cyclic loading

FEMA(350) and ASCE(american council for civl engineering) governs the loading protocol for cyclic loading for siesmic analysis. According to ASCE, a properly designed siesmic structure can withstand upto 4% drift and prevent collapsing. More percentage of drift makes the structure more flexible and safe.

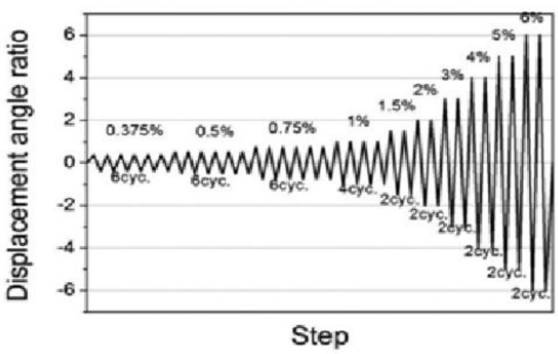

Fig-8: FEMA350 loading protocol ([2.]Sang-Hoonoh, Hae Yong Park, (2016))

Table -1: cyclic analysis results of x brace coupling beam

l/d ratio	step	Displacement (mm)	Load (kN)	drift	failure
X brace 1.33	39	72	889	5% full	6%
X brace 1.43	35	46.5	752.73	3% full	5%
X brace 1.50	39	72	829.34	5% full	6%
X brace 1.56	39	72	800.84	5% full	6%
X brace 1.70	39	72	829.36	5% full	6%

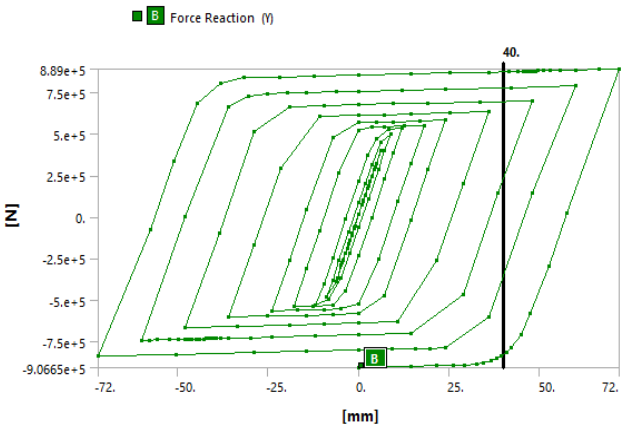

Fig-9 : Hysteric curve of X brace coupling beam

Table -2: cyclic analysis results of chevron coupling Beam

l/d ratio	step	Displacement (mm)	Load (kN)	drift	Failu-re
Chevron 1.33	39	72	519.11	5% full	6%
Chevron 1.43	39	72	519.01	5% full	6%
Chevron 1.50	39	72	516.79	5% full	6%
Chevron 1.56	39	72	513.82	5% full	6%
Chevron 1.70	39	72	509.19	5% full	6%

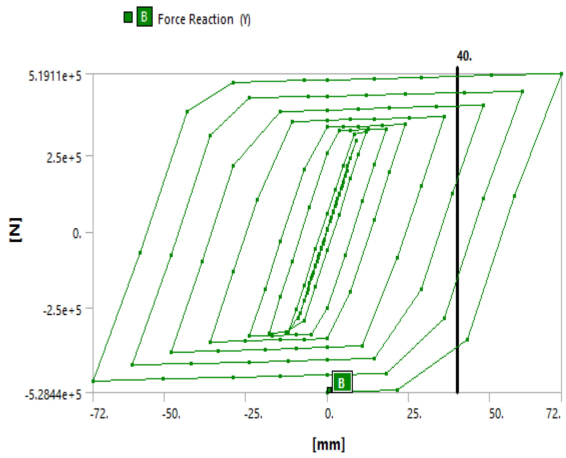

Fig-10: Hysteric curve of chevron brace coupling beam

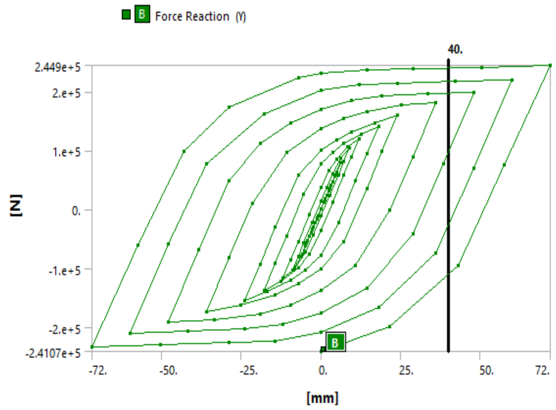

Fig-11: Hysteric curve of eccentric brace coupling beam

Table -3: cyclic analysis results of eccentric brace coupling beam

l/d ratio	step	Displacement (mm)	Load (kN)	drift	failure
Eccentric 1.33	39	72	244.9	5% full	6%
Eccentric 1.43	39	72	238.95	5% full	6%
Eccentric 1.50	39	72	244.77	5% full	6%
Eccentric 1.56	39	72	244.4	5% full	6%
Eccentric 1.70	39	72	238.95	5% full	6%

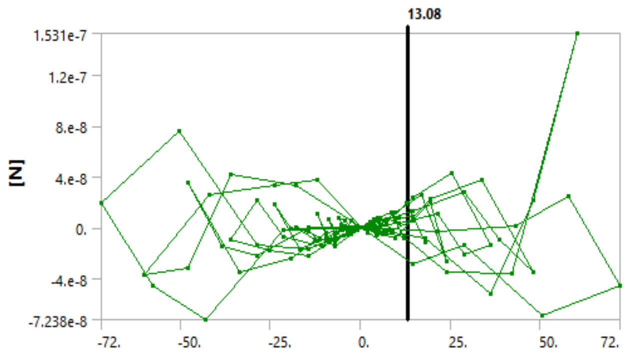

Fig-12: Hysteric curve of parallel brace coupling beam

2.5.2 Result analysis

Results shows that among various geometries of RSTCBs with different l/d ratio, X type bracing shows better performance during cycling loading. It has more load carrying capacity among the various types and it allows full 5% drift and failure occurs at a certain portion of 6% drift.it is also notable that parallel type bracing is not at all a good option for truss orientation, because hysteric curve indicates that, during cyclic loading the two parallel braces were undergo large amount of buckling and cannot withstand a heavy load during an earthquake. For pushover analysis x brace coupling beam with l/d ratio 1.33 is selected.

2.3 pushover analysis

In order to evaluate the seismic performance of RSTCB, an 11-story prototype structure was selected and the plan view of the building is shown in Figure 5.The first story has a height of 5.4 m, and each of the upper stories has a height of 4.2 m resulting in a total height of 47.4 m. Wall piers are identical and have a uniform thickness of 400 mm throughout the height of the building. The dead load including the self-weight of the floor slabs and the live load of each story are 5.5 and 2.5 kN/m^2, respectively. The cross sections for frame beams and frame columns are 250 mm x 700 mm and 700 mm x 700 mm, respectively([3.] Yong Li, Ye Liu and Shaoping Meng, Advances in Structural Engineering 1–13, 2018)

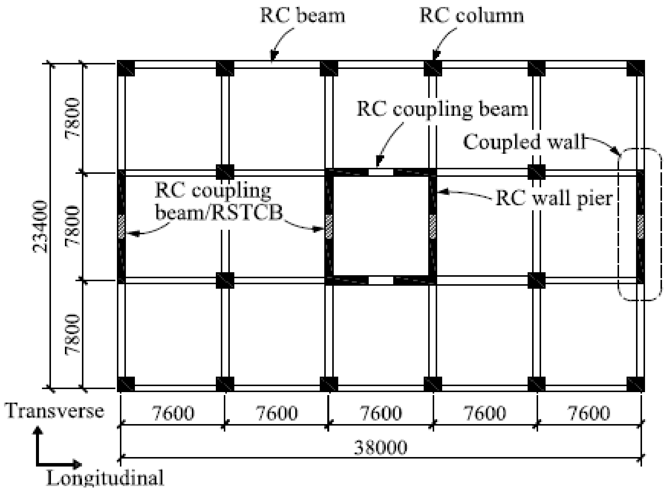

Fig-13: plan view of the building) ([3.] Yong Li, Ye Liu and Shaoping Meng, Advances in Structural Engineering 1–13, 2018

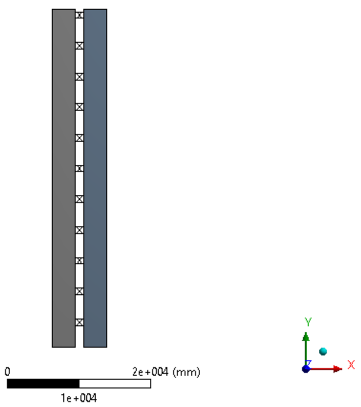

Fig-14: Elevation of the building

Peak ground motion datas of el centro earthquakes are used for the time history analysis. Modal analyses were conducted to know the natural frequency and time period of the structure, max deformation, base shear, directional accelerations were compared between the RC coupling beam structure and the RSTCB structure.

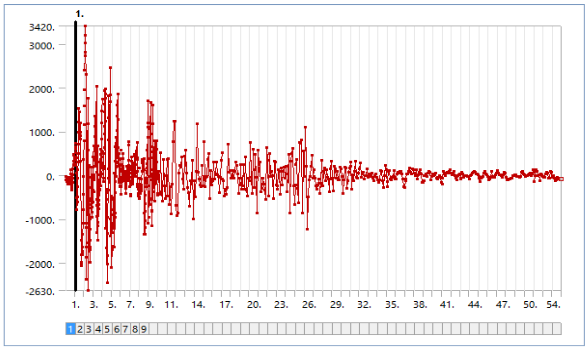

Fig-15: peak ground motion; el centro earthquake

2.3.1 Dynamic result analysis

Test results shows that the frequency of the RSTCB structure is significantly lower than the RC coupling beam structure and also the equivalent stress at wall pier is negligible in the case of RSTCB structure and more stress is concentrated on the energy dissipater. This indicate that the proposed HCW(Hybrid coupling beam) allow more deformation during seismic loading and stresses will be only concentrated in the beam only.

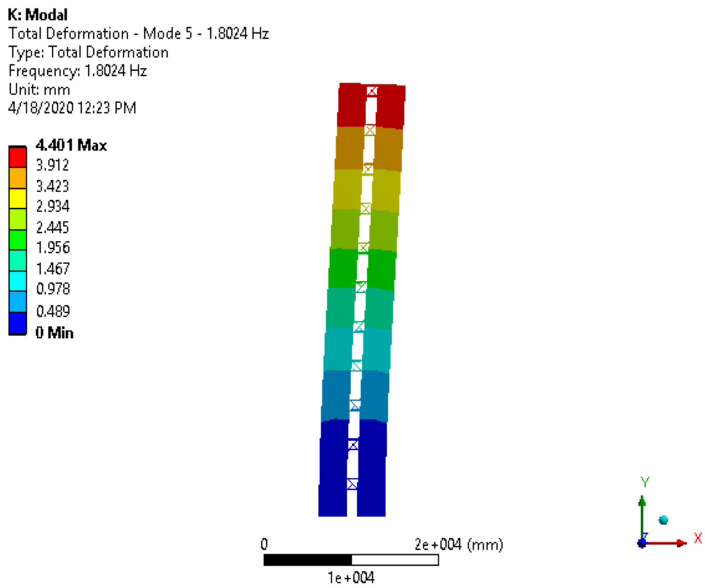

Fig-16: Total deformation of Modal Structure at natural frequency

The natural frequency of the RSTCB structure is found to be 1.8024 Hz.

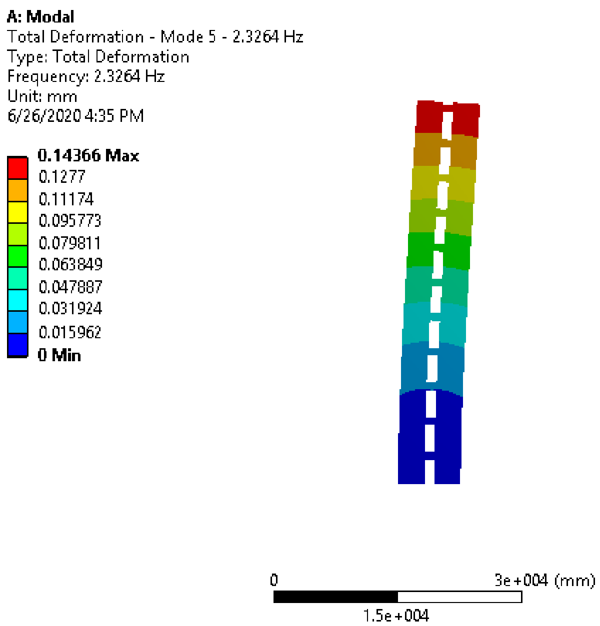

Fig-17: Total deformation of the RC coupling beam structure at natural frequency

The natural frequency of RC coupling beam structure is found to be 2.3264 Hz.

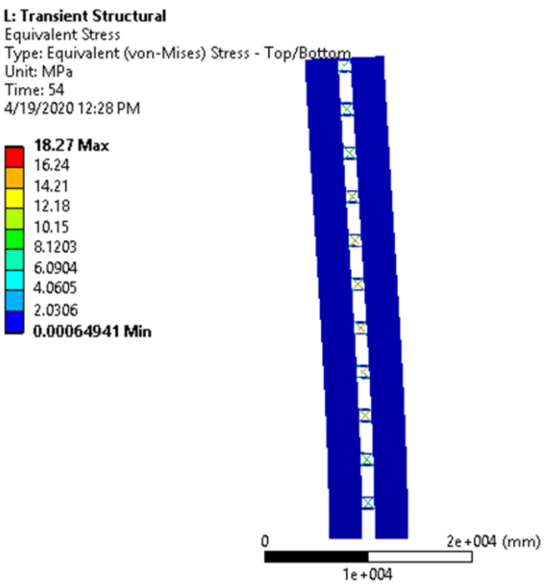

Fig-18: Equivalent stress of the structure with RSTCB

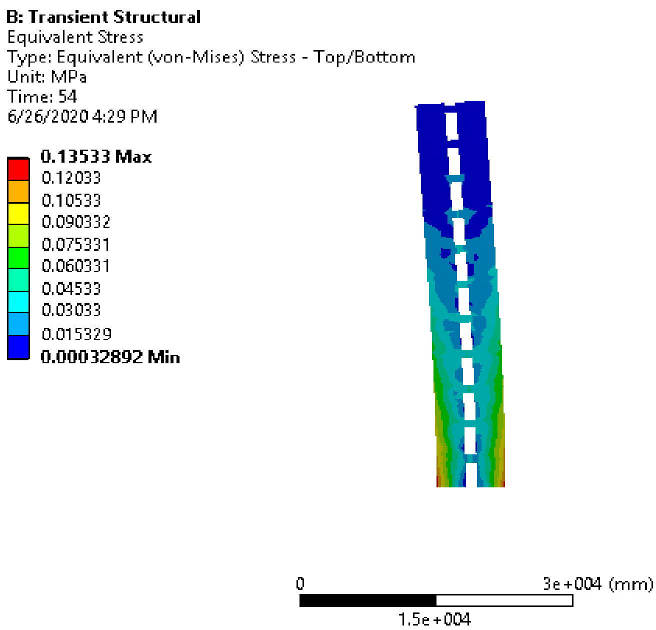

Fig-19: Equivalent stress of RC coupling beam structure

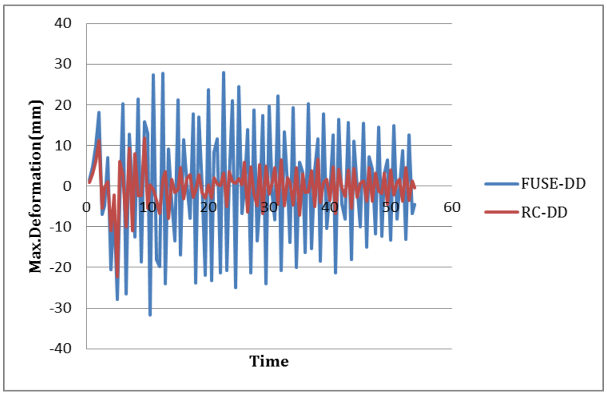

Chart 1: comparison between max. deformation Of two structures

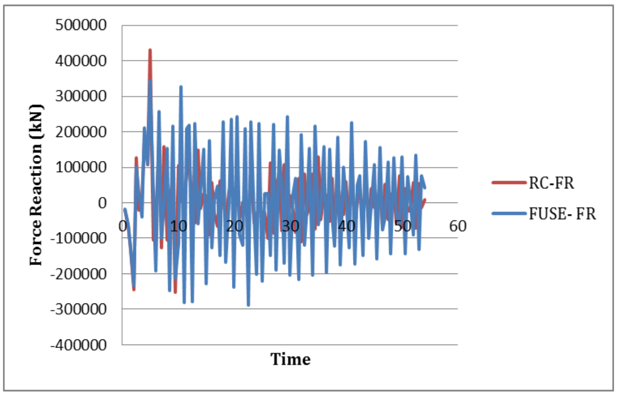

Chart 2: comparison between base shear of two structures

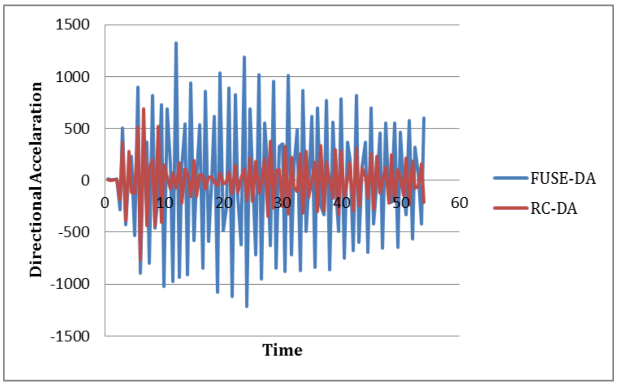

Chart 3: comparison between directional acceleration of two structures

3. CONCLUSIONS

The proposed replaceable steel truss coupling beam can said to be very efficient in terms of lateral load bearing capacity. This type of coupling beam will allow more and more deformation than a conventional RC coupling beam during an earthquake. So more stresses will be concentrated on the energy dissipating segment of the coupling beam (i.e.; more forces will be acting on this segment) and absolutely negligible forces and thereby negligible stresses are transferring to the wall piers. Hence it will make the wall pier safer during an earthquake. Studies show that x type bracings with 1.33, l/d ratio process best performance during seismic loading and also it is notable that the l/d ratio should be kept small for the better performance. The natural time period between the two structures have significant difference which also proves the efficiency of RSTCB. In conventional coupling beam, more load will be carried by the shear walls so the coupling beam have to carry more base shear; but in the case of HCW , due to the provision of shear link deformation will be more thereby stiffness will be reduced, hence base shear will be lower than RC coupling beam structure. However, overall it can said that HCW with replaceable steel truss coupling beam is an efficient idea for the building at high seismic risk.

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