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Study of Nonlinear Behavior in Steel Shear Connections via Finite Element Modeling

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Abstract: ***Shear-links are the most important part of an eccentrically braced steel frame system and provide fuse in terms of reducing the forces acting on the rest of the members such as columns and braces in the framing system. In this study shear links are modeled and analyzed in finite element program ANSYS Workbench with 3-D elements. The study is attempted to increase strength, reduce weight and produce more economical structures by using elegant member sections. Shear links with different sections are modeled, analyzed and find out optimal section. By grid convergence study finds out the optimal element length needed for the shear links under various loading conditions. Nonlinear analysis of shear links with the influence of unsymmetrical loading is to be carried out and analyze the models with weight and stress parameters.***

Keywords: Steel, eccentrically braced frames, shear links, finite element method

1. Introduction

Eccentrically braced frame is a hybrid system which is a combination of moment resisting frame and concentrically braced frame. With a proper design, ductility of a moment resisting frame and drift control capacity of a concentrically braced frame can be obtained economically through the use of an eccentrically braced frame. An eccentrically braced steel frame is a structural system in which eccentricities are deliberately introduced into the bracing configuration. As a result, the axial forces in the braces are transferred among braces and to columns through shear and bending in a portion of the floor beam called the link. A link in an eccentrically braced steel frame acts as a ductile fuse. During overloading of the structure the links are designed to yield and dissipate large amounts of input energy while inhibiting brace buckling .While conventionally designed Eccentrically Braced Frames provide sufficient strength, stiffness and ductility for buildings, the ductile action is achieved through plastic deformation of the active link, which can result in permanent deformation and building residual drift. When analyzing a shear link connected to a column, very large elastic moments can be observed at the link end adjacent to column of the link. However, large elastic moments should not be the design load of a link. Previous experimental studies show that a plastic hinge occurs at the end of the link due to the high elastic moments and moment redistributes along the link. Therefore, maximum moment on the link does not reach flexural yield strength of the link before it yields due to shear. Thus, the shear yield strength should be considered rather than flexural yield strength while designing the link.

2. Literature Survey

Engelhardt and Popov (1992)
Performed experiments on long links to investigate their yielding mechanisms and plastic rotation capacity. The experiments are performed with two different sections which are W12x16 and W12x22 and the cyclic loading is applied to the specimens. As a result of 12 experiments the dominant failure mode of the long links were observed to be the fracture of the flange near the column connection.

Prinz and Richards (2009)
The material model used in analysis is calibrated according to the experimental data of Kaufmann et al. (2001) and defined in program using kinematic hardening law. The analyses show the importance of axial forces, flange-web area ratio and link length cross section depth for the shear over strength. They also observed that the tensile axial forces developed due to the restraints, have significant effects on shear over strength.

Della Corte et al. (2013)
They modeled the sections with different end conditions to examine the plastic shear over strength of short links more detailed. They compared the finite element analysis results with the test results obtained from previous studies in the literature. For modeling of the specimens shell elements with 6 nodes are used in finite element program ABAQUS.

Q. Ma, Y. Wang (2014)
A central steel shear link was used in the replaceable coupling beam as a fuse in which all inelastic deformations and damage are supposed to be concentrated. These steel shear links commonly use a built-up shape and have a length ratio shorter than 1.0. Low yield steel is recommended to be used for the shear link to advance yielding and increase inelastic deformation capacity.

3. Objective of the work

Finite element study on yielding mechanism of concentrically braced frames and eccentrically braced frames.3D modeling and analysis of shear links.

4. Finite Element Modelling

Finite element modelling was done in ANSYS 16.0 software.

Table 1: Material data

Property	Value
Volume (mm^3)	7354006
Mass (kg)	57.729
Density (kg mm^{-3})	7849994
Coefficient of thermal expansion (C^{-1})	1199995
Specific heat (mJ kg^{-1} C^{-1})	4340005
Tensile yield strength (Mpa)	250

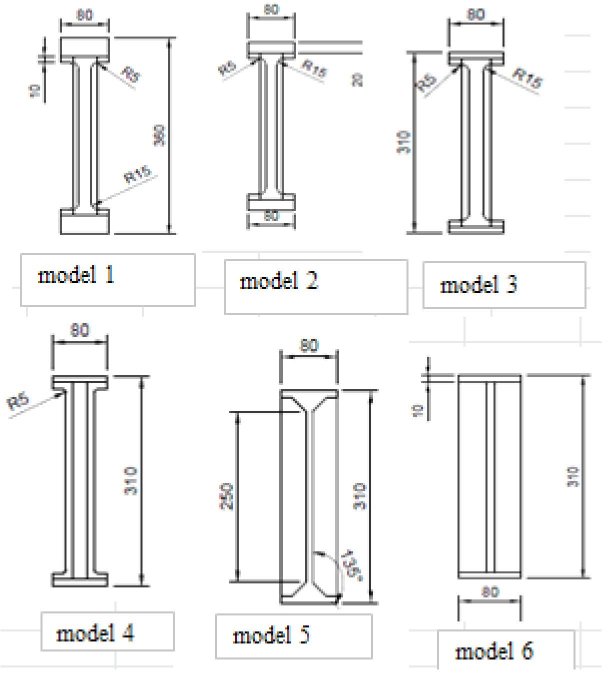
ANSYS Workbench has various analysis systems provided in its toolbox and Static Structural is one of them that suited to the finite element analysis study performed in this Paper. Link elements are modeled by using surface body to simplify model and shorten analysis time.

4.1 Boundary conditions

Modeling of active links fixed support is assigned one end of the link and effect of axial forces on a link that is subjected to cyclic end displacement.

4.2 Modeling of shear links

Seven models are done. Model 1 described as I section with filleted edge with ribs positioning 95 units from each end, Model 2 I section with filleted edge with ribs positioning 95 units from each end with flange thickness 20mm, Model 3 I section with filleted edge with ribs positioning 95 units from each end with flange thickness 10mm,Model 4 I section with rib is modeled with 10mm optimized thickness at the center and 200mm apart, Model 5 I section modeled with flange web and rib has 10mm thickness with ribs apart 140mm and 45 degree chamfered at edges, Model 6 I section modeled with 60mm flange thickness with chamfered at edges. Model 7 I section modeled with flange web and rib has 10mm thickness with ribs apart 190mm and 30 degree chamfered at edges.



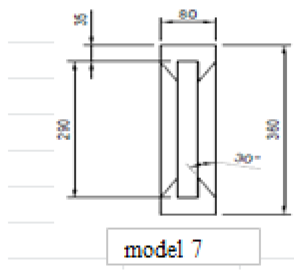


Figure 1: Dimensions of models

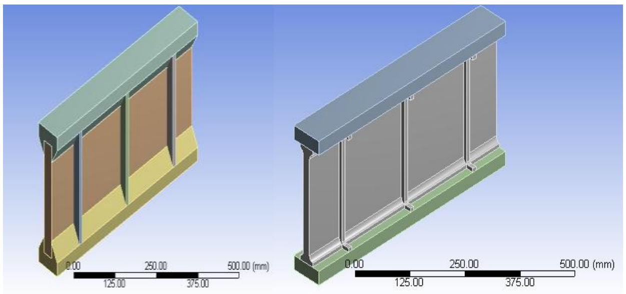


Figure 2: finite element models

5. Results and Discussion

In this study plastic material option is used for the cyclic simulations of steel shear links. To obtain plastic responses accurately load should applied in a series of small incremental load as time steps.

Table 2: Maximum stress and strain obtained in each model

Model	Mass (kg)	Maximum stress (Mpa)	Maximum strain
1	57.729	414.09	0.0020704
2	72.817	405.62	0.0020321
3	38.889	414.3	0.0020715
4	36.413	414.3	0.0020715
5	29.555	414.3	0.0020715
6	25.976	414.3	0.020715
7	83.014	407.68	0.020384

Table 3: Multi linear Isotropic hardening for each model

Stress (Mpa)	Plastic Strain (mm mm^{-1})	Temperature (C)
250	0	0
275	3499997	30
291	5499997	30
355	1749998	30
394	2949998	30
414	0.1049	30
414.3	0.2195	30

I section is a very efficient form for carrying both bending and shear loads in the plane of the web. On the other hand, the cross-section has a reduced capacity in the transverse direction, and is also inefficient in carrying torsion for which hollow structural sections are often preferred. This makes the structure more economical and lighter and in turn again making it even more economical. It exhibit large moment of inertia at same volume as we used in rectangular cross section.

The typical behavior of steel represents a linear elastic range until stress level reaches the yield stress after yielding a strain hardening region. Comparing all the models reduce the weight of I sections increase strength and produce more economical section by using elegant member sections. By modeling found out the optimal element length needed for the shear links under various loading conditions.

6. Conclusion

Accuracy provided by the force based frame finite element under nonlinear conditions is achieved by a single element discretization per member. The use of shell and solid elements necessitate great increase in the number of element discretization. Shell elements are suitable for modeling beams with I-sections with thin flanges, but for rolled or built-up sections with thick flanges, the accuracy attained by shell elements should be investigated carefully and solid finite elements should be preferred. The frame finite element with proposed flange shear strain assumption provides very close match when compared with the solid finite element results for shear-link specimens with thicker flanges.

Cyclic behavior of steel in ANSYS by the use of multi-linear kinematic hardening material model gives very close estimation of the nonlinear behavior of shear-link members. For the presented frame finite element, generalized plasticity material model proposed in literature was employed, and the capability of that material model in reflecting the cyclic behavior of steel has also resulted in overall close estimation of nonlinear response and energy dissipation characteristics of shear-link members.

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