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Flexible Cladding Connection on SAC 3-Story Building

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Abstract: **The paper presents findings from a research done to find if flexible non-linear spring materials help to reduce earthquake forces on SAC (storey steel structures). Tests were run for inelastic and elastic materials on the OpenSees software to find the behaviour of the materials and the difference in simulated and calculated values. Three categories of material that had flexible non-linear spring properties were selected and the tests were run with the El Centro earthquake excitation model. Test results showed that the material Hys 6 absorbed energy of up to 50% and the moments of members did not exceed the max moment. Recommendations are made to further test and study the material for applications.**

Keywords: **Flexible Cladding Connection, SAC 3-Story Building, Earthquake.**

I. INTRODUCTION

Structural Association of California (SAC) along with Federal Emergency Management has developed certain standard designs for welded steel structural elements of RCC beams and other load-carrying members (SAC, 1994). These standards are developed to resist earthquakes and other seismic activity in the California area, and to make the structures resist earthquakes (Malley, 1998). SAC has released a number of design advisories and test results for structural designers in the California region to follow to design safe structures. SAC-3 refers to designs for a 3-storey building (Behmanesha et al., 2016). This paper presents a study of SAC-3 model. Traditionally, cladding systems for buildings are not load-carrying members (Goodno, 1992). They are used for aesthetic, temperature retention, as a barrier against rain and snow and other functions, and use as passive earthquake-resistant components is under study (Sivakumaran, 1988). This paper investigates the possibility of using cladding systems to reduce the load on the main structure under seismic loads. The paper will examine if appropriately designed flexible connections between the primary structure and the cladding can provide any advantages to the primary structure and absorb some of the seismic load.

II. ELASTIC AND INELASTIC ANALYSIS

According to Sekulovi´ and Danilovi´ (2004), non-elastic components such as concrete move into elastic behaviour when they are stressed beyond the permissible limits. Materials are selected based on their ability to move into the range of elastic behaviour without failing. Therefore, design on non-redundant components such as braces, walls, and columns are done for the elastic state, otherwise the structure will collapse. The load-carrying capacity is determined by the load-carrying capability and connection flexibility.

Li (2010) conducted a simulation using OpenSees software on a SAC-3 building model. OpenSees, an acronym for Open System for Earthquake Engineering Simulation, is a software system developed by researchers at the University of California, Berkeley and helps in carrying out stress leading and design of structures to withstand earthquakes (OpenSees 3, 2019). For the simulation, Li (2010) used inelastic yielding fibre elements, and for non-yielding elements, elastic elements were used. Two-node frame element was considered as an elastic element and it was given six degrees of freedom for each node. This element was taken from the software library. A simple 2-D cantilever I-beam was designed. For the test, the base support was fixed on the left end and a maximum force of 50 kilo pound per square inch (ksi) was applied to the other end until the deflection was 100 inches. The induced moments from the test were noted for the deflection. Next, an inelastic 128-fibre element that had strain hardened was applied with the same test forces and the moments were noted for the deflection (Li, 2010). Graphs of deflection and moments of the inelastic and elastic beams were then drawn and illustrated in Figure 1

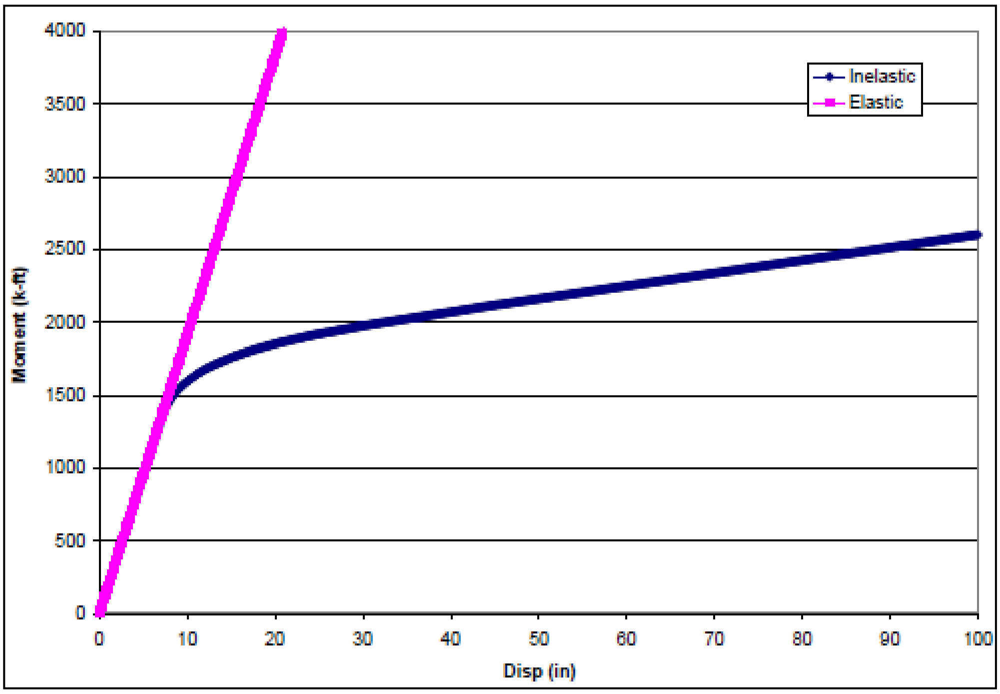

Figure 1: Plot of inelastic and elastic beam deflection (Li, 2010)

As seen in the figure, inelastic beam displacement increases rapidly from 1500 kilo feet force, indicating that the component can fail. From the above tests, the deflection and moment relation is given by the formula:

$\Delta = (ML^2)/ (3SI)$

Where:

L is the beam length taken as 432 inches for the test

M is the moment in kilo inches

E is the elastic modulus of the beam and considered as 29,000 ksi

Δ is the deflection of the beam in inches

I is the moment of inertia along the axis at 4930 $inches^4$

Calculations were done for the above values and the calculated results were about 0.6%, indicating that the test was accurate.

III. MODIFICATIONS ON THE SAC 3-STOREY MODEL

The objective of the test was to find in claddings absorbed some of the forces. Accordingly, the inelastic model used in the above test was rebuilt with rigid claddings (Li, 2010). Eigen value tool was used to compensate for the geometric linearity. Behaviour of the beam under elastic and inelastic condition was used to model the SAC 3-storey model. To reduce computation and time for simulation, parts of the beam with moment less than My were used to model the elastic section, the rest were used for the inelastic sections. The inelastic and elastic models were administered the El Centro earthquake simulation for a duration of 40 seconds each. The model is based on the El Centro quake of 1940 in USA that had a magnitude of 7.0 on the Richter scale. The total time for the quake as 40 seconds, hence the time set for the testing is 40 seconds. Other models based on different earthquakes such as the San Fernando, Loma Prieta, Big Bear, and others are available. However, the model uses the El Centro quake since it had the highest magnitude, the shocks lasted the longest, and it has excitation at the structural fundamental period. The partial inelastic mode had 35 nodes and 27 structural elements. The results showed that ten elements retained their elastic with rigid cladding connection, 17 elements showed moments greater than My, and these were modelled as inelastic fibre elements. Hardening effect was considered for the inelastic member modelling and the moment on eight elements was more by Mp. The behaviour indicates damage and failure of the elements. The peak storey drift allowed for each storey was different, but they were within 0.025. Behaviour of the members is given in table 1. Results were calculated and tabulated for the SAC 3-Storey model without claddings, elastic model without cladding, and partial inelastic model with flexible and rigid claddings.

Table 1: 1 Behavior of cladded elements (Li, 2010)

Column 1 (W14X257)		M_u (k-ft)	M_y (k-ft)	M_p (k-ft)	Yielded	Elasticity
Element	111	1953.6	1729.2	2033.3	Yes	Inelastic
	121	1065.9			No	Elastic
	131	1953.6			Yes	Inelastic
Column 2 (W14X311)						
Element	112	2533.6	2108.3	2511.1	Yes	Inelastic
	122	2027.4			Yes	Elastic
	132	2533.6			Yes	Inelastic
Column 3 (W14X311)						
Element	113	2538.3	2108.3	2511.1	Yes	Inelastic
	123	2044.5			No	Elastic
	133	2538.3			Yes	Inelastic
Column 4 (W14X257)						
Element	114	1977.2	1729.2	2033.3	Yes	Inelastic
	124	1099.3			No	Elastic
	134	1977.2			Yes	Inelastic
Column 5 (W14X68)						
Element	115	373.1	429.2	478.9	No	Elastic
	125	102.6			No	Elastic
	135	373.1			No	Elastic
Beam 1 (W33X118)						
Element	221	1766.8	1495.8	1733.3	Yes	Inelastic
	222	1700.8			Yes	Inelastic
	223	1768.4			Yes	Inelastic
Beam 2 (W30X116)						
Element	231	1593.3	1370.8	1577.8	Yes	Inelastic
	232	1562.3			Yes	Inelastic
	233	1606.5			Yes	Inelastic
Beam 3 (W24X68)						
Element	241	696.7	641.7	737.8	Yes	Inelastic
	242	678.5			Yes	Inelastic
	243	694.9			Yes	Inelastic
Beam 4 (W21X44)						
Element	224	0	340	397.8	No	Elastic
	234	0			No	Elastic
	244	0			No	Elastic

IV. NON-LINEAR SPRINGS MATERIALS AS FLEXIBLE CLADDING CONNECTIONS

Li (2010) ran a test to examine the effect of using non-linear spring materials as flexible cladding connectors. In related studies, Dal Lago et al. (2018) present studies on using dissipative force connectors with a steel plate in W-shape to fix cladding panels. Experiments were run to find the hysteretic characteristics of the devices. The devices were successful in absorbing the seismic loads in simulation. Pinelli et al. (1992) ran tests to see the effects of ductile cladding connection between cladding and the main structure when the structure was subjected to seismic load. A testing machine was used and the results were recorded. The authors reported that the cladding material sheared in both orthogonal directions without transferring any axial stress. The system can be used to create systems that resist earthquakes. In the study, Li (2010) investigated material for the hysteretic behaviours using OpenSees. Hysteretic material classified as Pinching4, Steel02, and others was selected. Pinching4 this material shows a pinched load deflection characteristic when cyclic loading is applied. For each of these materials, certain parameters were defined such as force and deformation points on the positive and negative response area, ratio of deformation for loading, strength, and other parameters. Simulations were run to calculate and plot the hysteresis loop with multiple degradations. Results from the experiments are given in the next section.

V. RESULTS OF SAC 3-STORY MODEL WITH DIFFERENT SPRING PROPERTIES

As mentioned in the previous section, three groups of materials were selected as connectors and simulation tests were run with the El Centro model of earthquake. Materials Pinchings4 and Steel02 indicated that there is low reduction in base shear, whilst the deflection of maximum differential connections decreased by 3.75 inches. This deflection is the relative connection between the cladding and the building. The three components had maximum moments that were more than Mp. Steel02 material had a behaviour that showed a reduction of the maximum base shear and this was 1049.6 kilo Newton, and none of the members had a moment that was more than Mp (Li, 2010). Results of all materials are illustrated in table 2

Table 2: Results of all spring materials (Li, 2010)

Connection types	Rigid	Pinching 4.11&Steel02halfloop	Steel02 Hloop5	Hys.3	Hys.4	Hys.5	Hys.6
Max. Base shear (k)	1118.2	1077.9	1048.6	1062.6	1068.7	1070.5	1065.3
Number of members exceeded M_p	8	3	0	0	2	1	0
Max. differential connection deflection (in.)	N/A	3.75	5.65	4.67	3.07	3.97	3.65

As seen in the above table, for the Hysteretic components, Hys3 and Hys6, all members where within Mp and deflection of maximum differential connection decreased to 3.65 inches from 4.67. At the same time, the base shear that the maximum level for the two materials decreased by 5% from the inelastic material. Overall, it is evident that the Hys6 had the best behaviour to reduce the SAC-3 response to control deflection. In addition, it is evident that the maximum deflection between the structure and the cladding with Hys 6 was lowest for all the three floors. The assessment is that amongst all the test samples Hys6 shows the top performance in reducing the connection deflection and in reducing the response.

VI. CONCLUSIONS

The paper used the OpenSees simulation model to study the effect of El Centro earthquake excitation model on flexible cladding on the SAC 3-storey model. Elastic and inelastic behaviour with cladding was studied and very small differences were seen between calculated and simulated values. Next, three non-linear spring materials categories were selected as connectors between the structure and the cladding. Amongst the material, it was observed that material Hys 6 showed significant decrease in the number of members that were greater than Mp. The hysteretic energy absorbed by Hys 6 was up to 50%. The recommendation is that more research needs to be undertaken to find how these materials behave and the manner in which they can be used to design quake-resistant steel structure.

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