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Examining the Effective Parameters of Fuse in Seismic Behavior of Low Damage Steel-Braded Frame Systems

Elahe Tajik [1], Abdolreza S. Moghadam [2]*

*[*1] M. Sc. of Structural Engineering, Department of Civil Engineering, University of Science and Culture, Tehran, Iran.*

(E.tajik.h@gmail.com)

[2] Associate Professor, International Institute of Earthquake Engineering and Seismology, Tehran, Iran.

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ABSTRACT

Past earthquakes experiences identifies the need for buildings which are less vulnerable to damage and easier to repair after a major earthquake. In a major earthquake, traditional seismic lateral resisting systems can impose serious damages in structural system, leading to large residual drifts thus non-affordable to repair. Therefore, applying new types of structural systems which is known as low damage systems is promoted in framework of a resilience based design. These systems include components of rocking able frame, replaceable fuses and vertical post tensioning tendons to return the structure to its initial state. This paper, first, determines the effective parameters of the fuse, then their effect on seismic behavior of steel-braced frame are examined. According to the results, fuse can significantly influence the performance of the system and some trends to find its optimum characteristics are identified.

Keywords:

Lateral resisting system, Rocking, Fuse, Post tensioning tendon.

1. Introduction

Designing and constructing of structures that can a) concentrate damage b) be useable after big earthquakes are noticed in recent years. Low damage system is a resisting system with high performance against earthquake. An important class of this system has controlled rocking frames and replaceable fuses that is combination of conventional steel braced frame characteristics and energy dissipating devices. It consists of three parts:

1- Steel frames that remained elastic and can have rocking motion.

2- Vertical post tension tendons for increasing overturning resistance and providing self-centering characteristics that return the structure to its initial state after earthquake.

3- Energy dissipating replaceable elements as fuses that effectively limited forces in base of structure.

Each of these parts have an effective role in behavior of this system [1-2]. Designers use performance based design for structures to prevent huge damages after large earthquakes. In this method designers can design structure for special performance levels. For example if structure is very special and is in a region with high seismicity, it can be designed for operational level which structure doesn't have any damage. Normally, structures are designed based on the life safety in which the structure stability is conserved while it includes low damage. Newly, designers use low damage systems to minimize damages and concentrate them on the special parts that are repairable. Tendons and self-centering characteristic cause structure to return to the own initial state and dissipated earthquake energy by fuses. In this article, seismic behavior of three story steel braced frame with low damage system examined by OpenSEES [3]. Since different parameters can affect the behavior of energy dissipating and steel braced frame, at the first these parameters are introduced and then the effect of change in these parameters on the results is examined.

2. Model

The proposed model includes three story braced steel frame. Initial model has selected from SAC studies [4] and altered to a low damage system therefore all columns can rock. The frame has three bays, the central bay includes energy dissipating fuses, that modeled in the form of cross-bracing at second and third floor and two adjacent bays include diagonal bracing. Along each column, from base to top are post tension tendons. The proposed model in OpenSEES is shown in Figure 1.

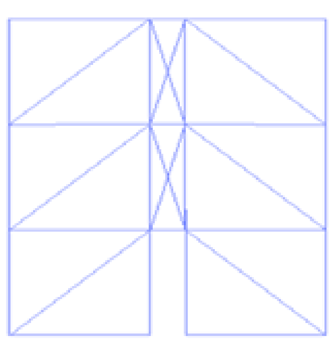

Figure 1. Three Floor Steel-Braced Frame with low damage system modeled in OpenSEES [3].

3. Ground Motions Records and Characteristics

For nonlinear dynamic analyses of the model, seven records have selected. These records include earthquakes with magnitude up to 6. (Table 1) The records consist of events occurred by two mechanisms. One of them is fault failure under shear and the other is failure under pressure. Every records is scaled to acceleration level of 0.6g at T=1 second. This maximum acceleration coincides with the 10% in 50 occurrence probability. The records have been taken from pacific earthquake engineering research center [4]. Furthermore, in this study effects of soil are neglected.

Table 1.The ground motion records.

Record ID	Event	Year	M_w	Station	R	Mechanism	PGA(g)	Rec.length(s)
BM68elc	Borrego Mountain	1968	6.8	El centro Array	46	Strike-Slip	0.057	40
BO42elc	Borrego	1942	6.5	El centro Array	49	-	0.068	40
CO83c05	Coulinga	1983	6.4	Parkfield-cholame5w	47.3	Reverse-oblique	0.131	40
CO83co8	Coulinga	1983	6.4	Parkfield-cholame8w	50.7	Reverse-oblique	0.098	32
IV79cal	Imperial valley	1979	6.5	Culipatria Fire station	23.8	Strike-Slip	0.078	39.5
IV79cc4	Imperial Valley	1979	6.5	Comchella canul	49.3	Strike-Slip	0.128	28.5
IV79chi	Imperial Valley	1979	6.5	Chihuahua	28.7	Strike-Slip	0.27	40

4. Fuse Characteristics

The fuse components should be designed with sufficient ductility and toughness that they can dissipate energy throughout the cyclic loading expected during large earthquakes. Moreover, the fuses should be designed to permit easy replacement in the event they become damaged [5]. One kind of common fuse is thin steel plate (6 mm thick) with butterfly shaped links. Figure 2 shows an example of fuse in low damage system.

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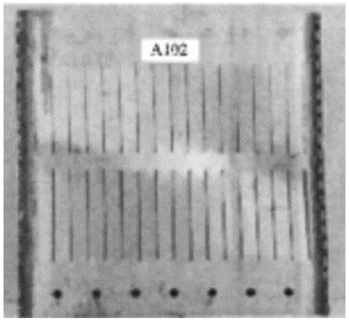

Figure 2. Slotted Steel Fuse [5].

5. Fuse Performance

To dissipate seismic energy and assure ease of repair after a damaging earthquake, modular shear panels can be used as fuses in the lateral resisting system. During maximum considered event these shear panels may undergo shear deformations as large as 7-12% strain depending on the geometry of the system. To achieve the large shear deformations, very ductile innovative shear panel systems must be explored. The shear panels are fastened between the frames. By positioning the fuses in the center and allowing both frames to uplift, the strain in the fuse is doubled. This concentrates damage at the fuse, simplifying system repair after an earthquake. As the fuses are located in the central bay, a smaller central bay causes a lower fuse strain. [5-6]. Effective parameters of fuse that have examined in this study are: (Figure 3)

1. Yield strength **(Fy)**
2. Elasticity Module: slope of line D **(E)**
3. Post capping slope, as a ratio of the initial stiffness **(alpha cap)**
4. Pinching parameter-displacement factor **(alpha pinch)** (pinches at zero strain=0 and pinches at last maximum displacement=1)
5. Pinching parameter-force factor **(beta cap)** (pinches at zero force=0 and pinches at last maximum force=1)
6. Strain in plastic region **(delta cap)**
7. Residual strength: ratio of strength point C to strength point A **(Resid.)**

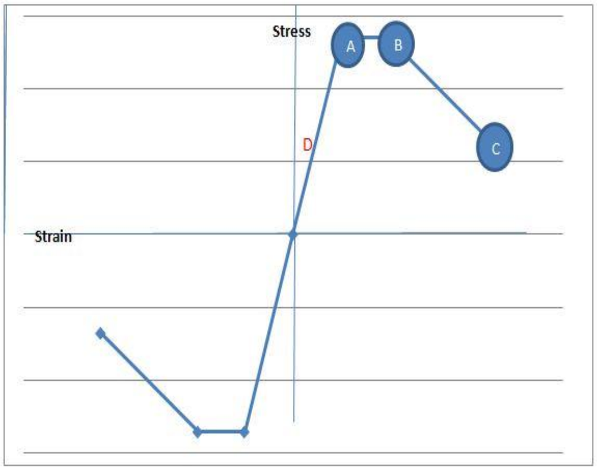

Figure 3. Stress-Strain curve for fuse panel**.**

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6. Analyses Results

For examining effects of parameters on the behavior of fuse and steel braced frame, following steps have been followed: At first, seven records of earthquake with magnitudes up to 6 have been taken from PEER database [7] and the steel braced frame with low damage system subjected to these records has been analyzed. Outputs include tension and compressive axial forces of columns in the first floor, uplifts, drifts, horizontal and vertical accelerations of floors. All the results and diagrams are average of maximum responses. In continue, each of effective parameters has been increased or decreased while other parameters are constant, and with that values the system has been run and outputs are compared with the original system. The original values of these parameters have been taken from experiments that Medina and et.al. had done in Stanford university. (Table 2) Complement report of these experiments have been brought from NEEShub [8-9].

Table 2.Original Values of Effective Parameters on Fuse.

Effective Parameters on Fuse	F_y (kN)	E	alpha cap	alpha pinch	beta cap	delta cap	Resid.
	54	200	-0.02	0.5	0.5	0.26	0.5

7. Effects of Each Parameter

The first parameter is yield strength. For examining the effects of this parameter on behavior of frame, yield strength has been assumed as Fy, Fy/2 and Fyx2 and for each case outputs consist of tension and compressive axial forces of columns in the first floor, uplifts, drifts, horizontal and vertical accelerations of floors have been calculated. Average of maximums has been shown in Table 3. The results are normalized to results of original case and shown in Figure 3.

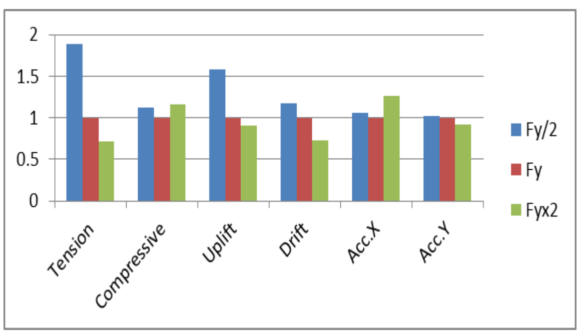

Figure 3. Effect of difference in yield strength parameter on frame behavior.

According to the Figure 3, results are generally sensitive to change in yield strength. Next parameter is elasticity module of fuse material. For examining effect of this parameter on behavior of steel braced frame with low damage system, the 3condition of E, E/2 and Ex2 is assumed. Average of maximums has been shown in Table 3. Again, the state of system has been run with original value of elasticity module (E) is taken as the base for comparing with other cases and the results are shown in Figure 4.

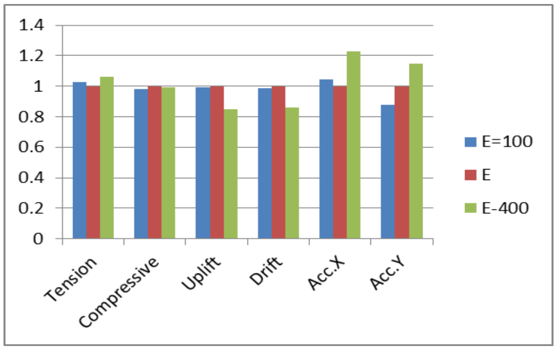

Figure 4. Effect of elasticity module on frame behavior.

According to the Figure 4, horizontal and vertical accelerations of floors are increased when elasticity module was Ex2. This increase in accelerations can cause non structural damages. Other parameter that is effective on energy dissipating, is the ratio of cap point slope to initial slope which is stiffness.(alpha cap). For examining of this parameter, three states for system have been considered and separately. Average of maximums has been calculated and shown in Table 3. The case that system has been run with original value of alpha cap is base for comparing with the two other states (alpha cap/2 & alpha cap x2). According to the results, when this parameter is equal to a value of alpha cap/2 , the horizontal and vertical accelerations extremely increased. An important point is increasing accelerations again, when this parameter is alpha capx 2. Other outputs show only marginal changes in behavior of frame compared with the base case. Next parameter is pinching parameter depending on displacement factor. (alpha pinch) This parameter is between 0 and 1 that in experiments by Medina [8] is taken as 0.5. For examining this parameter, boundary values of 0 and 1 has been taken and the models are analyzed and the results compared with base state, alpha pinch=0.5.(Table 3) Next parameter is pinching parameter depending on force factor (beta cap). This parameter is between 0 and 1 that in this study the original amount is assumed as 0.5. The frame analyzed for original amount and boundary amounts (other parameters are constant) (Table 3). According to the results, when this parameter is equal to lower limit the frame has more sensitivity in compared with base state. Accelerations of stories about 1.5 times and uplifts about 1.3 times have been increased. Other parameter that is effective in low damage system is strain of plastic region (delta cap). Analyzing of three story steel braced frame with low damage system was done for three states of original, half and 2 times of original value. Average of maximums has been calculated for mentioned outputs and results of that have been brought in Table 3.According to Figure 5, vertical and horizontal accelerations of stories and compressive axial forces of columns increased by changing amount of this parameter. Whereas increasing or decreasing of this parameter resulted in increasing of accelerations and because of this increasing nonstructural components damages, amount of this parameter be advised that be close to original amount.

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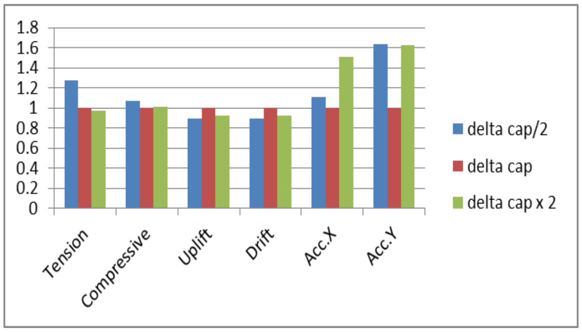

Figure 5. Effect of different values of delta cap parameter on frame behavior.

The last parameter that is effective on fuse energy dissipating is residual strength. This parameter has been assumed as a ratio of residual strength to yield strength. The frame is analyzed for cases equal to 0.25, 0.5 and 1.The results are normalized with the outputs of residual strength which is equal to 0.5. The summary of results has been brought in Table 3. According to the Figure 6, when this parameter is half of original amount behavior of system is sensitive extremely, and vertical and horizontal accelerations of stories are increased about 250%. In this circumstance, amounts of tension and compressive axial forces of columns and uplift have been increased about 40% to the ratio of original state. When the ratio of residual strength to yield strength is halved, assuming that yield strength is constant, it means that residual strength is halved. So it’s expected that when system strength is reduced amounts of uplift and vertical and horizontal accelerations to increase. Outputs are significantly change by increasing this parameter. So, residual strength is very effective in low damage system.

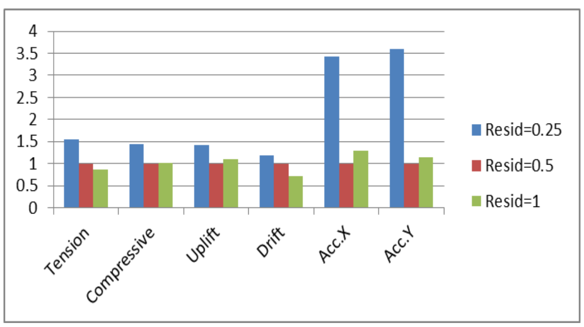

Figure 6. Effect of different values of residual strength parameter on frame behavior.

Table 3. Average of Maximums for Effective Parameters on Fuse.

Parameters	Max ave for axial force (+Tension)	Max ave for axial force (-Compressive)	Max ave for Uplift	Max ave for Drift	Max ave for ACC. X	Max ave for ACC. Y
Fy/2	2357.649 + 89.23%	6072.745 +12.24%	268.877 +57.58%	0.0466 +17.68%	76037 +5.41%	119163 +2.46%
Fy	1245.86	5410.3	170.64	0.0396	72140	116303
Fyx2	898.648 - 27.87%	6249.085 +15.5%	154.207 -9.63%	0.02858 -27.85%	90903 +26%	107335 -7.71%
E/2	1282.48 + 2.94%	5316.142 -1.74%	169.13 +0.88%	0.039 -2.07%	75350.43 +4.45%	102239 -12.09%
E	1245.86	5410.3	170.64	0.04	72140.3	116303
Ex2	1323.78 + 6.25%	5368.81 -0.77 %	144.56 +15.28%	0.034 -12.5%	88706.62 +22.97%	133437 +14.7%
alpha cap/2	1439.691 + 15.56%	5565.058 +2.86%	157.612 -7.64%	0.03579 -9.62%	138716.6 +92.29%	267268.8 +129.81%
alpha cap	1245.86	5410.3	170.64	0.0396	72140.3	116303.01 43
alpha cap x 2	1394.7099 +11.94%	5609.977 +3.7%	155.318 -8.98%	0.0331 -16.17%	92650.85 +28.43%	121617 +4.57%
alpha pinch=0	1029.471 -17.37%	5411.1129 +0.01%	159.502 -6.53%	0.0311 -21.55%	74068 +2.67%	111226 -4.37%
alpha pinch	1245.86	5410.3	170.64	0.0396	72140.3	116303
alpha pinch=1	1404.942 +12.77%	5470.887 +1.11%	165.045 -3.28%	0.0337 -15.11%	81311 +12.7%	113279 -2.59%
beta cap=0	1286.33 + 3.25%	5720.865 +5.74%	223.897 +31.21%	0.0456 +14.99%	107393 +48.86%	187537 +61.2%
beta cap	1245.86	-5410.3	170.64	0.0396	72140.3	116303
beta cap=1	1139.7517 -8.51%	5182.798 -4.21%	178.2306 +4.44%	0.0282 -27.87%	65908.3 -8.63%	114723 -1.36%
delta cap/2	1582.2391 + 26.99%	5782.798 +6.88%	153.259 -10.18%	0.0353 -11%	80122.2 +11%	189826 +63.2%
delta cap	1245.86	-5410.3	170.64	0.0396	72140.3	116303
delta cap x 2	1208.7278 -2.98%	5475.005 +1.2%	158.056 -7.37%	0.0365 -7.79%	108855 +50.8%	189545 +62.9%
Resid/2	1937.8213 +55.5%	7740.91 +43.07%	242.685 +42.23%	0.0467 +17.85%	247157.4 +242.6%	417825 +259%
Resid	1245.86	-5410.3	170.64	0.0396	72140.3	116303
Resid x 2	1071.3793 -14%	5442.2571 +0.5%	188.7105 +10.6%	0.0286 -27.87%	92586.72 +28.35%	133964 +15%

8. Conclusions

According to the studies and experiments that have been done, low damage structural system has a better performance in large earthquake compared with common structural systems. Dissipating energy has an important role in these systems. If fuses can be designed to dissipate more earthquake energy, it's expected that these systems can show better performance. In this article, effective parameters on behavior of fuse are introduced and examined. According to the results, yield strength, alpha cap and delta cap shouldn't be changed and increased from their original amounts. Amount of elasticity module parameter should not be increase from the original amount. Beta cap parameter shouldn't decrease from the original amount. Changes of alpha pinch parameter didn't have remarkable effect. Last parameter is residual strength that the frame is sensitive to its changes. It's better that amount of this parameter neither reduced from the original amount nor significantly increased. Within these limits, it's expected that this frame with low damage system can have the best performance in large earthquake.

9. References

[1]- Eatherton, M., Hajjar, J., Ma, X., Krawinkler, H., and Deierlein, G., 2010, **Seismic Design and Behavior of Steel Frames with Controlled Rocking—Part I: Concepts and Quasi-Static Subassembly Testing**, Structures Congress, 1523-1533.

[2]- Roh, H. and Reinhorn, A., 2010, **Nonlinear Static Analysis of Structures with Rocking Columns**, Journal of Structural Engineering,136(5), 532–542.

[3]- OpenSees, Open System for Earthquake Engineering Simulation, http://opensees.berkeley.edu/

[4]- Pacific Earthquake Engineering Research Center, 2006, Strong Motion Database,August 25, 2006, < http://peer.berkeley.edu/smcat/index.html>.

[5]- Hall, K., Eatherton, M., Hajjar, J., 2010, **Nonlinear Behavior of Controlled Rocking Steel-Framed Building Systems with Replaceable Energy Dissipating Fuses**, NSEL Report Series.Report No. NSEL-026.

[6]- Hajjar, J. F., Eatherton, M., Ma, X., Deierlein, G. G., and Krawinkler, H., 2010, **Seismic resilience of self-centering steel braced frames with replaceable energy-dissipating fuses—Part I**, Joint Conf. Proc., 7th Int. Conf. on Urban Earthquake Engineering, Tokyo Institute of Technology, Japan, 1071–1078.

[7]- Gupta, A., and Krawinkler, H., 1999, **Prediction of seismic demands for SMRFs with ductile connections and elements**, SAC Background Document, Report No. SAC/BD-99/06.

[8]- Medina.R., 2002, Seismic Demands For Nondeteriorating Frame Structures and Their Dependence on Ground Motions, Ph.D. thesis, Stanford University.

9. https://nees.org/