COMPDYN 2015
5th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, V. Papadopoulos, V. Plevris (eds.)
Crete Island, Greece, 25–27 May 2015

# THE EFFECT OF STEEL SLIT PANELS IN RETROFITTING WEAK BUILDINGS

**F. Jamshidzadeh[1], and B. Mohebi[2]**

[1] Faculty of Engineering
Imam Khomeini International University, Qazvin, Iran. Postal Code: 34149-16818
e-mail: ff.jam.4@gmail.com

[2] Faculty of Engineering
Imam Khomeini International University, Qazvin, Iran. Postal Code: 34149-16818
mohebi@ENG.ikiu.ac.ir

**Keywords:** Steel Slit Panel (SSP); Nonlinear Static Analysis; Seismic Rehabilitation; retrofitting.

**Abstract.** *Due to the importance of Retrofitting and researches done about it, and the importance of selecting a good lateral resisting system, this paper is going to use Steel Slit Panel to retrofit available buildings and see its effect. This is a new system suitable for high seismic region. Some benefits of this system are its ductile behavior and ability to dissipate energy, architectural flexibility, simple fabrication and installation and its easy replacement. In this research the SSP's nonlinear behavior and their effects on retrofitting buildings are studied using nonlinear static analysis and Guidelines for seismic rehabilitation. At first the panel has modeled and analyzed in a finite element software individually and its nonlinear behavior derived to be used in the nonlinear analysis. Then weak structures and retrofitted structures with this panel have modeled and analyzed in analytical software using nonlinear static analysis and the results have compared. This panels will greatly improve the behavior of the structures. The stress ratio of the elements after retrofitting is in allowable ranges and has greatly improved. And also after retrofitting the Performance Level was improved and the life safety was obtained.*

## 1 INTRODUCTION

Earthquake is one of the greatest hazard of nature. Its impact is sudden and there is little or no time to get ready against damages.

One of the way of preventing the disaster caused by earthquake is to reduce the seismic risk by retrofitting existing buildings. The first step to retrofitting the structures is to strengthen and stiffen them by adding a lateral load resisting system, such as braces, shear walls and etc [1].

Selecting a good system especially in bays with openings (doors, windows, etc) is important and sometimes difficult.

The Steel Slit Panel-Frame is a new resistant system for seismic regions. Its main members are beams and columns that are simply connected and the Steel Slit Panels (SSPs) that are bolted to the beams at the top and bottom of the bays.

The SSPs has a pair of vertical stiffeners at the edge of them and are designed to resist all lateral load [2].

At first in 1969, Muto has studied on the slitted reinforced concrete walls by goal of utilizing elements that would yield at specific regions [3].

In 1991 Whittaker et al. studied the ADAS elements. It also shares the same concept of dissipating energy through yielding of steel.

The steel wall with slits were discussed in 2000 and 2003 by Hitaka and Matsui. It is similar in concept to the SSPs but there are two differences between them: 1) height to with ratio; 2:1 and 2) resisting the entire base shear [4].

McCloskey studied the behavior of SSPs in 2006. He worked on different parameters of the SSPs (b/t, α, m). He also verified formulas presented by Hitaka and Matsui for the SSPs. He presented formulas for failure mechanism of the SSPs. McCloskey also suggested the use of edge stiffeners and studied ways of reducing the gravity loads demands in SSPs [2].

Deierlein et al. in 2007 studied on Self-Centered braced frame that also uses steel plates with slits to dissipate energy [5].

After all Gustavo Cortes with his Professor Judy Liu studied experimental and analytical models of SSPs.

The SSP is a steel plate with vertical slits cut in rows that form a series of flexural members –called links- in it. Under lateral deformations each link behaves as a beam in double curvature. They reach to their plastic moment capacity at both ends.

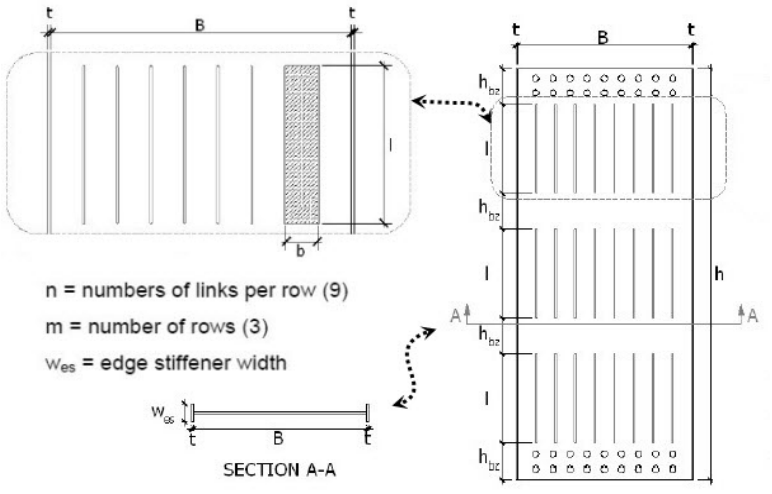


Figure 1: SSP parameters [6].

The parameters to define the geometry of an SSP are B, the width of the panel, h, the height of the panel, t, the thickness of the panel and the edge stiffeners, l, length of the links, b, width of the links, b, m, the number of rows in one panel, n, the number of the links in a row and $h_{bz}$ the height of a band zone that is between the rows of links [2].

There are three types of SSP, T1, T2 and BR panels shown in Figure 2. They are different in their geometry parameters and their behavior [7].

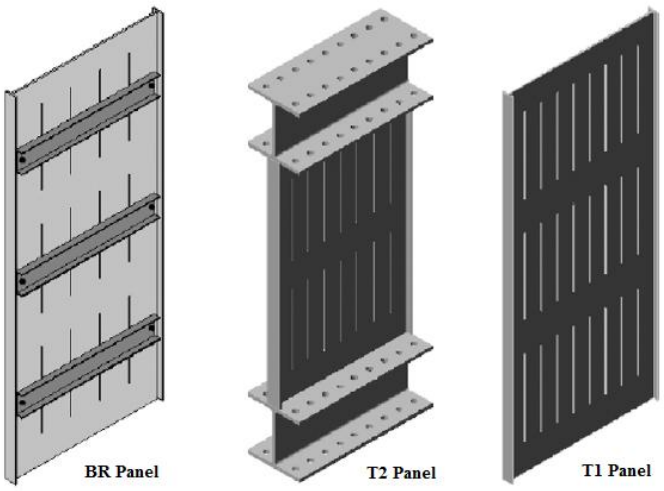


Figure 2: SSP panels [7].

α, β and b/t are three important parameters that are need to considered for ductile behavior of the panels. α (l/b) should be between 2.5 and 5.0. β (ml/h) should be between 0.65 and 0.85. And b/t ratio should be between 10 and 15 [2].

Ductility; Architectural flexibility; Simple fabrication and installation and replacing the panels are some benefits of the Steel Slit Panels. And the easy replacing of the panels makes it possible to use them in retrofitting deteriorated structures.

In this paper it is going to use T1 panel to retrofit available buildings and discuss its effect on the buildings' behavior.

## 2 RETROFITTING A WEAK BUILDING WITH SSP

### 2.1 Existing weak building

The existing weak building has three stories. In both X and Y axles moment resisting frames are used as lateral resisting system in the building. The stress ratio of some elements of the building is shown in Figure 3.

As it is obvious, the stress ratio is more than allowable ratio. In nonlinear static analysis the Life Safety Performance Level was not obtained. Figure 4 represent the deformed shape of the one of the frame in target displacement in pushover analysis.

Because of the importance of this building it was decided to retrofit it by adding a lateral resisting system. But the problem choosing one was the existence of openings in most bays. That is why we thought about Steel Slit Panels. So we tried to use T1 panel to retrofit this building. Analysis Software was used to analyze and design the structure [8].

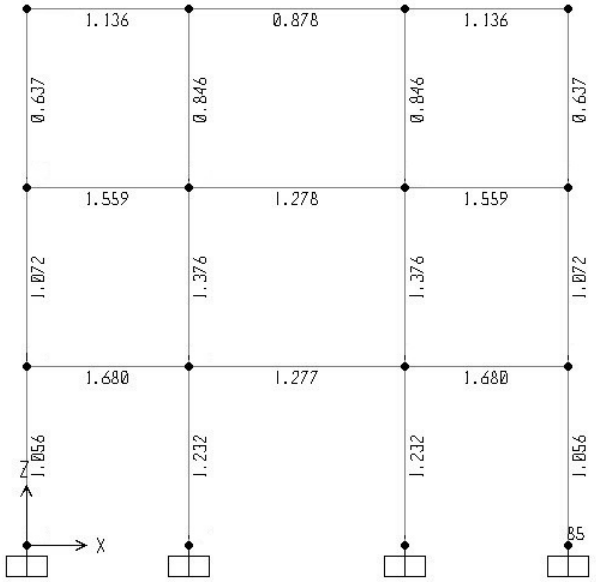


Figure 3: The stress ratio of weak building (beams and columns).

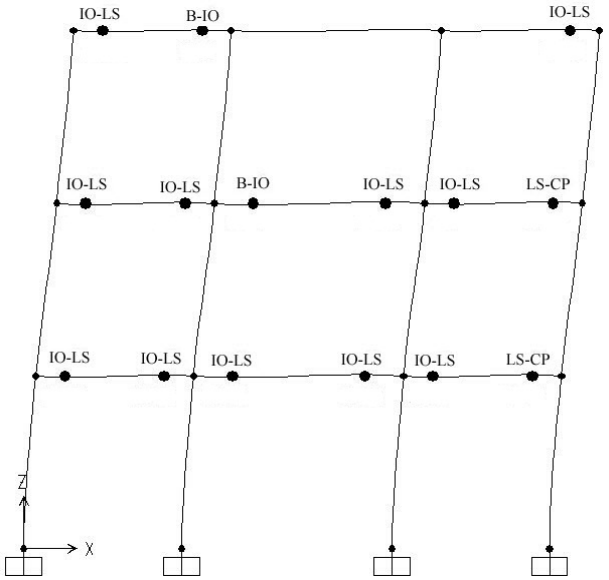


Figure 4: Deformed shape of the Frame 4 in target displacement for weak building.

## 2.2 Retrofitting existing weak building

As said before due to the existence of openings in most bays the selected lateral resisting element to retrofit this building was T1 panel of SSPs. This panel's parameters are represent in Table 1.

| m | n | B | h | t | b | l | β | α | b/t |
|---|---|---|---|---|---|---|---|---|---|
| 3 | 9 | 59.375 | 130 | 0.5 | 6.375 | 32 | 0.72 | 4.9 | 12.8 |

Table 1: T1 panel Parameters (inch).

In X direction, one panel was used in middle bay of the frames from top to bottom of the frames. In Y direction one panel was used in edge bays of the frame from top to bottom. To define SSP behavior, the results of FEM model in Finite Element software [9] was used.

The 1/3 scale of this panel, according to Gustavo Cortes' study, was analyzed in Finite Element software, Figure 5.

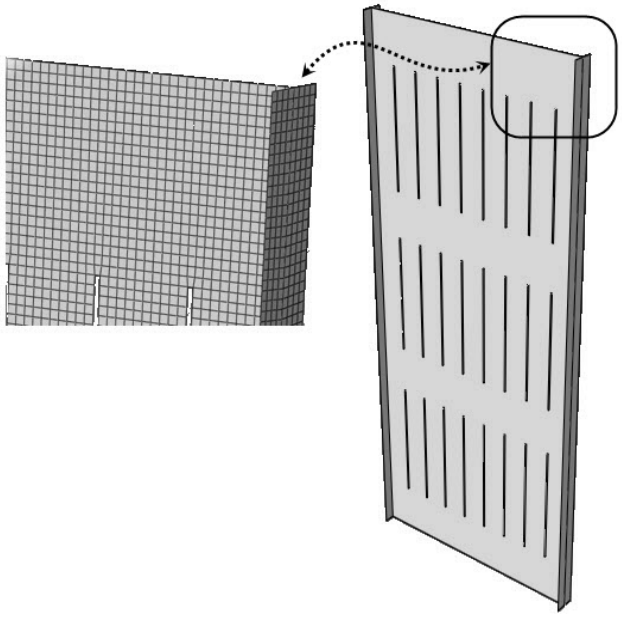

Figure 5: T1 panel model in FE Software.

After adding SSPs to the building its behavior was greatly improved. The stress ratio of the beams and columns are shown in figures 7. As it is clear the stress ratios are in allowable limit.

The life safety level was obtained in all beams and columns. The deformed shape of one of the frame in the target displacement is shown in figure 8.

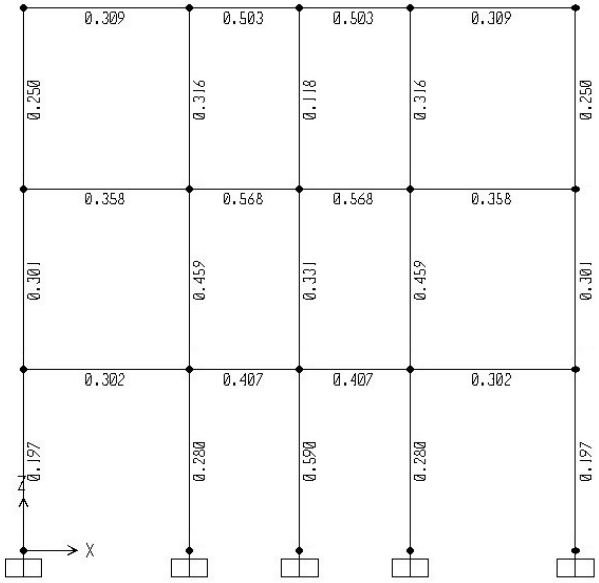


Figure 7: The stress ratio of retrofitted building (beams and columns).

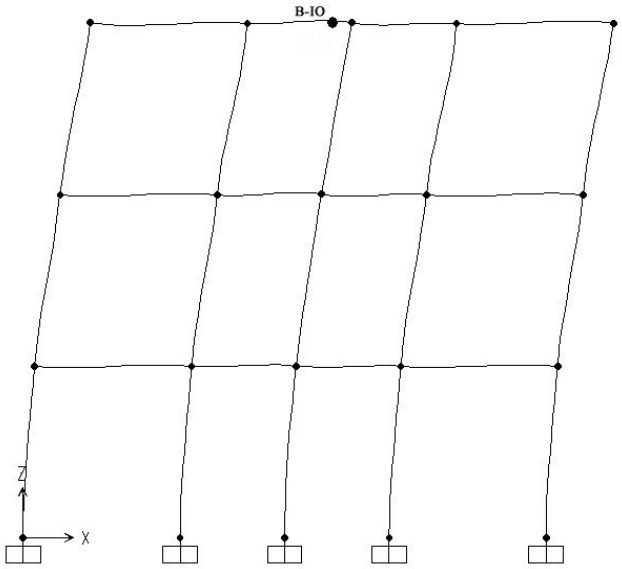


Figure 8. Deformed shape of the Frame in target displacement for retrofitted building.

## 3 CONCLUSIONS

From the results shown in figures it is obvious that SSP panel added to the building has improved the stress ratio of the elements. The stress ratio after retrofitting is in allowable ranges and has greatly improved.

And also it is clear that in the initial structure the Life Safety Performance Level was not secured but after retrofitting it was improved and the life safety performance level was obtained.

## REFERENCES

[1] *Handbook on retrofit seismic building*, Central Public Works Department & Indian Building Congress, Aplril, 2007.
[2] G. Cortes and J. Liu, *Experimental evaluation of steel slit panel-frames for seismic resistance*, Journal of Constructional Steel Research 67, 181-191, School of Civil Engineering, Purdue University, 2011.
[3] Martinez-Rueda JE. *On the evolution of energy dissipation devices for seismic design*, Earthquake Spectra, EERI 2002; 18(2): 309-46.
[4] Hitaka T, Matsui C, *Experimental study on steel shear wall with slits, Journal of Structural Engineering*, ASCE 2003; 1299(5):586-95.
[5] M.R. Eatherton, J.F. Hajjar, G.G. Deirelein, H. Krawinkler, S. Billington, and X. Ma. *Controlled Rocking of Steel-Framed Buildings with Replaceable Energy Dissipated Fuses. The 14th World Conference on Earthquake Engineering*, Beijing, China, October 12-17, 2008.
[6] G. Cortes, *Steel Slit Panel Frames for Lateral Resistance of Building*, Dissertation submitted to the Factually of Purdue University, 2009.
[7] G. Cortes and J. Liu, *Steel slit panel configurations, The 14th World Conference on Earthquake Engineering*, Beijing, China, October 12-17, 2008.
[8] CSI (2010), CSI Analysis Reference Manual, Computers and Structures, Inc., Berkeley, California.
[9] ABAQUS, Version 9.11 Documentation, ABAQUS, Inc., Providence, RI.