Seismic Retrofitting by using Friction damper in Horizontally Irregular Infilled Structures

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Abstract
Steel frames with masonry infill walls are common systems in the ordinary residential structures. High stiffness value of the infill walls has significant effect on the behavior of structure, torsional problem is the one them. A friction damper device can be used to minimize torsional effects in the structure. Nonlinear analysis and modeling of the infill walls and the damper is done by “Opensees” [1]. Results show that the presence of infill walls can lead to severe torsion increase through the frame which can be solved by using friction damper device. This technique can benefit the complete capacity of structure with minimum intervention in the structure and architecture.

Keywords: masonry infill walls, torsion, nonlinear analysis, friction damper device.

1. Introduction

An ideal form of structure is considered normally in order to analyze the structure, which undoubtedly has differences with its actual model. The actual model has also some differences with the computational model such as defects in the existence of infill walls, which will be neglected from their effects on the structure analysis and design. Distribution of these elements and their effects on stiffness and lateral strength of the constructions have generally overlooked during the design process. Seismic retrofitting of the structures needs detailed evaluation of these elements in reaction of structures to the applied loading. Although existence of the infill walls basically provides higher stiffness and strength for the frames, but their detrimental effects on the structure performance is ignored due to lack of adequate information about the behavior of frames and infill walls. Meanwhile, recent studies has shown that different arrangements of stiffness, mass and strength towards each other can have significant effect on structure behavior and their response parameters[2].Upon changing the arrangement of infill walls, the centers of stiffness and strength through the structure will be changed which can cause torsion to be appeared. Finally, low strength and ductility, high weight and severe decrease in strength under seismic loads can be among the main reasons of failure in structures with brick walls. Reconnaissance of recent earthquakes indicates that to implement a system-based capacity assessment method, these critical (weak) points are appropriate to choose proper technique to adequate strengthening of them.

The principal function of a structure is to transfer the effective loads, significant part of which has dynamic nature (seismic, harmonic and impactive), to the foundation as well as the soil beneath it. Safe and effective transmission of these loads as well as providing the necessary silence for serviceability requires that vibrations and their relevant forces be decreased and limited through the structural and nonstructural components. Therefore, in recent years some significant efforts have been implemented on researching the structure control devices particularly during earthquakes, which has led to prevalent advancements in using these instruments during two recent decades. Generally, structure control systems are used to decrease the responses of structure (movement, speed and acceleration) and utilizing these systems seems to be an appropriate strategy for seismic energy dissipation and protection of structure against earthquake loads.
2. Model Description

As shown in figure 1, 2 in this paper 3 story, Steel building with intermediate moment resisting frame designed based on Iranian Codes for lateral and gravity loads have been investigated. All structures have same 3 by 3 bays plan with 5.5 m length and the type of soil considered as II, based on 2800 building codes [3]. The Initial accidental eccentricity of the building as the accidental torsion is 5% of the building dimensions vertical to earthquake in two contrary directions. Model analysis is done through equivalent static method while its design is laid out based on Steel Regulations (section10) [5].

3. Structural Elements

3.1. Steel Frame

3.1.1. Materials Used in Frame

Beams and columns are selected are from same materials. Stress-strain relation for these materials is elastic for linear analysis and elasto-plastic for nonlinear analysis. Thus, the latter needs to define the materials yielding stress first and the slope of curve after yield then. The secondary elastic modulus is considered to be one percent of the primary elastic modulus.

<table>
<thead>
<tr>
<th>Yield stress $kg/cm^2$</th>
<th>Primary elastic modulus $kg/cm^2$</th>
<th>Secondary elastic modulus $kg/cm^2$</th>
<th>Poisson coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>2400</td>
<td>2.1e6</td>
<td>2.06e6</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The connections between beams and columns are supposed to be rigid, while the connections of the base plate to the ground are also supposed to be rigid.
Table 2: Characteristics of analytical sample (all dimensions in meters)

<table>
<thead>
<tr>
<th>Story</th>
<th>Column</th>
<th>Exterior Beam</th>
<th>Interior Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dimention</td>
<td>Thikness</td>
<td>Web</td>
</tr>
<tr>
<td>1</td>
<td>25×25</td>
<td>1</td>
<td>30×1</td>
</tr>
<tr>
<td>2</td>
<td>20×20</td>
<td>1</td>
<td>30×1</td>
</tr>
<tr>
<td>3</td>
<td>20×20</td>
<td>1</td>
<td>30×1</td>
</tr>
</tbody>
</table>

3.2. Infilled Walls

In-filled walls are normally treated as non-structural elements. However, unlike most non-structural components, they can develop a strong interaction with the bounding frames when subject to earthquake loads, therefore, contribute significantly to the lateral stiffness and load resistance of the structure. In-filled frames exhibit a complex composite behavior, which is affected by numerous factors, such as material properties, relative dimensions, type of loading, etc. In spite of the research efforts that have spanned several decades, the performance of these structures in a severe earthquake remains a major controversy among structural engineers and researchers today. Despite the difficulties and uncertainties in studying the performance of infilled frames, it is still a beneficial task to understand more about this type of structure.

3.2.1. Modeling the Infill Walls

Common approach for modeling the infill walls includes considering the equivalent diagonal member. The idea of using equivalent element instead of infill walls was introduced in 1967 by Poliakev for the first time [6]. Figure 3 shows the equivalent diagonal strut for modeling the infill walls.

![Figure 3. Using the equivalent diagonal strut for modeling the infill walls](image)

This study has adopted to use diagonal strut method based on Tabeshpour’s handbook 18 [7], in which the width of diagonal strut is obtained in centimeters from the following equation.

\[
a = 0.25 \left( \frac{\lambda h_{col}}{r_{inf}} \right)^{-0.4} r_{inf}
\]

Where:

\[
\lambda = \left( \frac{10E_{nec}^2 h_{inf} \sin 2\theta}{E_{fc} I_{col} h_{inf}} \right)^{0.25}
\]

And

- \( h_{col} \) = Column height between centerlines of beams, cm
- \( h_{inf} \) = Height of infill panel, cm

\[ (1) \]

\[ (2) \]
$E_{fe}$ = Expected modulus of elasticity of frame material, kg/cm
$E_{me}$ = Expected modulus of elasticity of infill material, kg/cm
$I_{col}$ = Moment of inertia of column, cm
$L_{inf}$ = Length of infill panel, cm.
$r_{inf}$ = Diagonal length of infill panel, cm.
$t_{inf}$ = Thickness of infill panel and equivalent strut, cm
$\theta$ = Angle whose tangent is the infill height-to-length aspect ratio, radians
$\lambda$ = Coefficient used to determine equivalent width of infill strut

For modeling nonlinear behavior and acceptance criteria of diagonal strut, values presented in handbook 18, masonry infill walls in structural frames will be used [8]. Noteworthy here is that the equivalent thickness of diagonal strut in this technique is selected same as the thickness of infill walls.

### 3.2.2. Calculating the Stiffness of Wall

$$K_{inf} = 0.175 \left[ \frac{\sin 2\theta}{4E_{fe}I_{col}\tan \theta} \right]^{0.1} h_{inf}^{0.8} (t_{inf}E_{me})^{0.9} \cos \theta$$

$$K_{inf} = 19117.57(kg/cm^2)$$

### 3.2.3. Calculating the Weight of Wall

<table>
<thead>
<tr>
<th>Weight per meter length</th>
<th>Net weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>850 $\times$ 0.2</td>
<td>Bricks with cement and mortar</td>
</tr>
<tr>
<td>1600 $\times$ 0.02</td>
<td>Chalk and soil</td>
</tr>
<tr>
<td>1300 $\times$ 0.005</td>
<td>Chalk overlay</td>
</tr>
<tr>
<td>2100 $\times$ 0.002</td>
<td>Cement mortar</td>
</tr>
<tr>
<td>250 (kg/m$^2$)</td>
<td>Net weight</td>
</tr>
<tr>
<td>(3.2-0.2)$\times$250=750 (kg/m)</td>
<td>Weight per meter length</td>
</tr>
</tbody>
</table>

Calculating the weight of walls:

750 (kg/m) $\times$ 5.5(m) =4125(kg)
4125(kg)/2=2062.5(kg)

### 3.3. Friction Damper Device:

#### 3.3.1. Components of Friction Damper Device

As shown in figure 5, the main components of Mualla damper are one central vertical plate, two lateral horizontal plates and two circular frictional pads, which have placed between steel plates [9]. The vertical plate hinged to the center of girder to be able to move freely. The two horizontal plates have also hinged from their end to the inverted-V brace. The bracing bars are pin-connected at both ends to the damper and to the column bases. Combination of the two lateral plates and the central one can increase the friction surface area. For connecting three damper plates to each other, hardened steel nuts and bolts have been used. They were adjustable bolts, which provided the possibility to set the compression stress between steel plates and friction discs. In order to maintain a constant clamping force, several discs spring washers are used. To avoid damages from washers to plains, hardened steel washers have been selected. Figure 6 shows the performance of damper device during the stimulation phase. When the lateral loading, beam stimulates the frame has
displaced horizontally; in this situation the bracing system has activated and a frictional force has created between the contacting surfaces and the damper resists against motion.

3.3.2. Parameters of Friction Damper Device

The friction damper device used in this study is consisted of two main parts, bars and friction tools, which work together serially. Friction damper device acts in two phases, adhesion phase and slip phase. In adhesion phase, the stiffness of friction tools is supposed to be infinite so the total stiffness would be a result of bars stiffness. Here, the stiffness value can be calculated from equation (4).

$$K_{hd} = \frac{2EA_b}{l} \cos^2(\nu)$$

(4)

In which, E is elastic modulus of the bars, $A_b$ is area of the bar, $\nu$ is angle between the bar and horizon and $l$ is length of the bar. If the slip moment of friction hinge reaches $M_f$, then limit force of the bars can be calculated from equation (5).

$$F_a = \frac{M_f}{\sigma_y h_a \cos \nu}$$

(5)

Where the length of central plate is $h_a$, and $\sigma_y$ is the yield stress of the bar material.

4. Torsion

According to the section 1-8-1 of 2800 standard building code, building having an eccentricity between the static center of mass and the static center of resistance in excess of 20 percent of the building dimension perpendicular to the direction of the seismic force should be classified as irregular. Based on this section, brief calculations have been offered bellow.
5. Pushover Results

In order to compare the behavior of the initial structures and final structures, the pushover curves of three cases show below.

![Figure 9. Pushover curves](image_url)

As shown in the pushover curves with considering infill walls, stiffness and strength of buildings increased compared to a building without considering infill walls. It is a valuable phenomenon and has engineering advantages. Because of torsional problem structure torsion and plastic hinges appears. Changing the slope in pushover curves shows this phenomenon. However, in the pushover curves with considering friction damper, stiffness and strength of buildings in the elastic part of analysis are constant compared to a building with considering infill walls. But when the behavior of the structure changes to the plastic behavior this slope changes and increase so the maximum strength will increase. Since infill walls are brittle material and have a high stiffness, in the distribution of forces between elements, these walls attract a large amount of lateral load till they fail. After failure of infill walls, we have a drop of stiffness (slope) and strength in curves. As it can be seen in the figure after failure of the infill walls, the slope of the curve will be the same as model No. 0 (bare frame).

![Figure 10. Rotation curves for center of mass](image_url)
As shown in figure 10, the center of mass in the bare frame didn’t have any rotation but by adding infill walls lead to hard the system and the torsional problems are accrues therefore the structural torsion will be increase and it can be destroyed and change the seismic response of it. By using friction damper center of mass rotation can be controlled and it will be in the safe amplitude as section 1-8-1 of 2800 standard building code are allow

6. Conclusions

In this paper 3 story, Steel building with intermediate moment resisting frame designed based on Iranian Codes for lateral and gravity loads have been investigated. All structures have same 3 by 3 bays plan with 5.5 m length. One arrangement of infill walls has been used. The Main objective of this paper was investigating the torsional failure mechanism in three stories of these buildings. According to patterns of infill walls distribution in a plan and determining friction damper to avoid torsional failure. The Iranian code considers shear walls and braces irregularity only but the obtained results consider irregularity of masonry infill walls. To determine this solution nonlinear push over analysis were applied by choosing each case and analyzing it. Finally all data of this problem for 3 story building and patterns were illustrated in one diagram and by eliminating the effects of torsional problem by using friction damper in these results a curve was obtained for determining the structures with infill walls and without any torsional problem at design phase.

7. REFERENCES

6. Tabeshpour, M. R., (1384), Handbook 18, masonry infill walls in structural frames. s.l. : Fadak Isatis,  