On the connection behavior of gate bracing system

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In this paper, the connection behavior of a particular configuration of a brace system, which is used in seismic areas, is investigated. This system which is called Gate Brace SYSTEM (GBS) consists of six members that are symmetrical and the diagonal member is not straight; it is connected to the corner of the frame by the third member. This system improves the energy dissipation due to earthquakes as well as its eccentricity allowing more openings for the architects. In this paper, some common types of this brace system which has been used in many parts of Iran is investigated, also, a comparison between the behavior of different common construction types of this system is done and some recommendations for improving the behavior of these systems are proposed. In order to examine this system behavior, ANSYS, which is a well known finite element software is used. The investigation results indicate that by increasing the rigidity of mid connection of brace elements, the stiffness of the system dramatically increases. Moreover, for increasing this rigidity some methods are proposed.

Key words: Brace, buckling, seismic, earthquake.

INTRODUCTION

In regions subjected to seismic activities, the occurrence of severe earthquakes can cause serious damage to properties and loss of lives if buildings are not provided with seismic resistance capability, the need to have buildings suitably designed against earthquakes is even more necessary in highly urbanized areas with many tall buildings where economical and human loss is of major concern to the community. It is now generally recognized that seismic design of buildings should satisfy at least two fundamental requirements (UBC 97). First, the structure must behave elastically and protect relatively brittle non-structural components against minor earthquake ground shaking. Therefore, a structure should have sufficient strength and elastic stiffness to limit structural displacements, such as interstory drift. Secondly, the structure must not collapse in a major earthquake. For this case, significant damage of the structure and non-structural components is acceptable (Davaran and Hoveidae 2009; Asgarian et al., 2010). In order to prevent the structure to collapse and minimize the loss of life, it must have a large energy dissipation capacity during large inelastic deformations. In general, structural systems which exhibit stable hysteretic loops perform well under the large inelastic cyclic loadings characteristics of major earthquakes. Such stable hysteric characteristics of a structure can be obtained provided that the structural members and joints are designed to have sufficient ductility (Khatib et al., 1988; Asgarian et al., 2010).

For high and medium rise buildings, structural steel has been used extensively due to its excellent strength and ductility properties. In seismic design of such steel frames with consideration of aforementioned subjects there are some common conventional seismic resistant approaches that will be explained later but between these conventional methods, brace frames are among the most common steel structures for resisting lateral loads. In general, they are divided into two groups: concentric and eccentric (Ghobarah and Abou, 2001; Kim and Choi 2005; Moghadam et al., 2005). Concentric braced systems are more desirable because of a relative good stiffness, along with their easy construction and economy aspects; hence these important criteria make this group more common than eccentrically braced frames (Yang et al., 2008; Davaran and Hoveidae, 2009).

Eccentric braces need more construction accuracy thereby resulting in a decrease of construction speed and
higher cost in spite of better stiffness performance and higher energy dissipation (Özhendekci and Özhendekci, 2008; Bosco and Rossi, 2009). Significant problems in openings especially in the northern and southern faces of the buildings in this country make designers occasionally use some alternative expedient of braces to solve these problems, regardless of the benefits of the two braced groups. In this paper, one of the invented braces called Gate Brace System which is capable of providing a certain amount of seismic isolation to the structure will be investigated. This system as illustrated in Figure 1 consists of three braced elements, where the diagonal members are not straight and also introduces an eccentricity to the system. This system allows the architects to have more openings in panel areas (Moghaddam and Estekanchi, 1995, 1999). Moreover, because of the cyclic nature of seismic loads, these brace elements are designed symmetrically.

**Characteristics of GBS**

One of the most important and special characteristics of this brace is the role of brace elements in bearing the lateral load. Because of the imposing lateral load three brace elements, which are connected to one connection point get in tension and the three other brace elements, which are connected to the other point get in compression as shown in Figure 2. The three compressive elements which are connected to the mid connection can make the system unstable by the buckling of any of the brace elements and the buckling of the mid connection to the out of frame plane (Saffari and Yazdi, 2010). To clarify the out of plane buckling of this connection point by imposing lateral load, a frame is modeled by the SAP2000 software.

As shown in Figure 3, with higher scale, all three compressive brace elements conduct the plate of mid connection to the out of frame plane. With this buckling, this system gets unstable. Consequently, because of the cyclic nature of seismic loads in the next cycle, this condition gets vice versa. Thereby the out of plane buckled members will not be able to bear the tension loads in this cycle which makes this system to collapse or results in damages during severe earthquakes.

**GBS's Stiffness**

To investigate the stiffness of this system, two parameters nominated as $m$ and $n$ are introduced to indicate the location of the mid connection point from the top corner of the frame. These parameters represent the coefficients of height and span width of the frame in which horizontal distance of the brace element connection from the frame corner is $mL/2$ and its vertical distance is $nH$, where $L$ and $H$ are span width and height of frame panel, respectively (Figure 4).

By using SAP2000 and modeling this frame (Manual 2009), the stiffness of different connection locations in the panel area is studied. In order to do this investigation, for different values of $m$ and $n$, stiffness of the system based on Hook's law and the frame displacement due to the lateral load is calculated and the results for a frame with $H/L=3/4$ meter are shown in Figure 5, where coefficients of $E$ and $A$ are module of elasticity and the cross section area of brace elements, respectively (Hibbeler, 2005; Mosalman and Ramli, 2009).
For the purpose of this modeling, a brace frame with real dimensions and real cross sectional areas are considered. Thereby, a frame with height to span of $H/L=3/4$ meter and the cross-section of columns, beam and brace elements taken as, IPB200, IPE200 and 2IPE140 respectively is considered. The specifications of these cross sections are shown in Table 1.

Table 1. Cross-section specifications of frame members.

<table>
<thead>
<tr>
<th>Specification</th>
<th>IPB 200</th>
<th>IPE 140</th>
<th>IPE 200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area ($cm^2$)</td>
<td>78.1</td>
<td>16.4</td>
<td>28.5</td>
</tr>
<tr>
<td>$I_x$ ($cm^4$)</td>
<td>5700</td>
<td>541</td>
<td>1940</td>
</tr>
<tr>
<td>$I_y$ ($cm^4$)</td>
<td>2000</td>
<td>44.9</td>
<td>142</td>
</tr>
</tbody>
</table>

$$K = \frac{F}{\Delta}$$

Where, $K$, $F$ and $\Delta$ are stiffness, lateral force and lateral displacement of system, respectively.

For this investigation, the connection of brace elements to the frame corners are considered as pinned connection. For the mid connection there are various types of construction, that in this paper are modeled and an assessment is done for their lateral load capacity. As illustrated in Figure 5, as much as the eccentricity of the connection point gets increased, the stiffness decreases and thus it is better for designers to select the connection point near the diagonal of the frame to have higher stiffness.

MODELING EXPLANATIONS

For studying the behavior of this system, inspecting its defaults and effective parameters, the ANSYS software is used and a typical model is shown in Figure 6. This software is one of the best softwares that has many characteristics making it the best for the finite element modeling. However, with regards to the material characteristics of this system and using one type of steel, which is more regular for constructing buildings, the input data are introduced. Afterwards, noticing the finite elements that are used in this field element, the SHELL181 is used for modeling the brace members (Manual, 2004; Moaveni, 2007). In this study the researchers tried to compare the different kinds of Gate Brace system which are commonly used in seismic areas. Also the different proposed methods for modifying these system behaviors are studied and some suggestions for improving this system are proposed.

For the purpose of this modeling, a brace frame with real dimensions and real cross sectional areas are considered. Thereby, a frame with height to span of $H/L=3/4$ meter and the cross-section of columns, beam and brace elements taken as, IPB200, IPE200 and 2IPE140 respectively is considered. The specifications of these cross sections are shown in Table 1.

RESULTS AND DISCUSSION

In this part, the various parameters which affect the stiffness of this system are studied.

Plate dimensions in the connection point of brace elements

For inspecting the dimensions' effect of the connection
plate on the system behavior, a frame with the aforementioned characteristics is modeled and the plates with different dimensions are studied. The dimensions for square plates are taken as 30, 40, 50 cm. The analysis results as shown in Figure 7 which indicate the lateral displacements get decreased by increasing the plate dimensions. Furthermore, it prepares more sufficient length for welding the brace elements which makes the connection to be more rigid (Figure 7).

**Figure 7.** Effect of plate dimensions on GB system.

**Method of installing internal connection plate**

In this section the method of erecting the connection plate as shown in Figure 8 is studied. The analysis results as indicated in Figure 9 which shows that two plates at the connection point are more useful and this method can decrease the lateral displacement in comparison with one plate with the same size which is located in the middle of brace elements. Hence, erecting the connection plate at both sides of this point has a significant role in increasing the capacity of lateral buckling load of this system.

**Figure 8.** GBS with two connection plates.

**Figure 9.** The analysis' results of plates in the connection.

**Effect of brace elements’ moment of inertia**

Moment of inertia of brace elements has a significant effect on the stiffness of the GB system. Therefore, as depicted in Figure 10, the major and minor axial are changed about the axis of the frame plane. According to the results that are shown in Figure 11 it is better for the
Comparison between some construction methods

In this section a comparison between some methods that are occasionally constructed in some projects, as shown in Figure 12, and the above methods is carried out. As indicated in Figure 13, by making a comparison between methods explained before and this new method, the best reaction of this system is related to the case where the two plates support the brace element connection point. Therefore, with this proposed method very good results are achieved while having reduced costs. It is necessary to emphasize on the construction of the connection which leads to better behavior of the system that makes the connection more rigid as shown in Figure 14.

Conclusions

Gate Brace systems used in seismic areas are very useful because they have the ability to dissipate seismic load and also it allows the architectures to have more openings. With the consideration of some technical points it is possible to increase their abilities to bear the lateral load. This study, by using ANSYS program for finite element modeling, proposes some method to achieve better behavior with this system. Hence, by increasing the dimension of internal connection plate, installing two plates at the both sides of the connection point and erecting the brace member as the major local axle in the frame, the behavior of system can be improved and stiffness can be increased. Also, as the connection gets closer to the corner, stiffness gets decreased and moreover the best method while considering the economic aspects, is to construct the mid connection with two plates at both sides of it.

REFERENCES


