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Behavior of Bracing in High Seismic Region

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***Abstract*—Industrial plants located in the high seismic zone and subjected to high seismic forces require selection of appropriate bracing model with suitable connection type. The use of steel bracing as lateral load resisting system in steel structures is very common and effective. Bracing system increases the structural stiffness and it resists large displacements. Structures in high seismic zone require special seismic detailing which has significant impact on fabrication and construction costs. In this paper, behavior of different bracing system under seismic condition has been illustrated. Suitable bracing systems and their connection in the area of high seismic zone have been discussed. Seismic detailing provisions, accommodation of brace buckling by allowing end rotation with sufficient ductility (fold line theory concept) and case study have been described.**

***Index Terms*— Industrial Structure, Bracing System, Seismic Detailing, Connection Ductility, Fold Line, Zipper Column.**

I. INTRODUCTION

Lateral Load Resisting Systems are conventionally either braced or unbraced frames. Unbraced frames are so-called Moment Resisting Steel Frames; the study is beyond the scope of the current paper. Steel braced frame is one of the economical structural systems used to resist lateral loads in different types of steel structures. Bracings systems in structure under lateral loading, reduces displacement significantly and provide high stiffness. However, increase in the stiffness due to bracing system generally attracts a larger inertia force in earthquake, and attracts more lateral force but on the other side it decreases the bending moments and shear forces in columns and beams.

II. VARIOUS TYPES OF BRACING SYSTEM

A. *Concentric Bracing System*

Concentric Braced frame are the braced frame in which axes of the members aligning centrically at the joints and forming a truss system to resists lateral loads.
Diagonal Bracing: The diagonal bracing members can be arranged in a variety of forms designed to carry only tension, only compression and alternatively tension & compression depending on brace configurations and load directions.
X Bracing: In the X-brace system, lateral force from one direction induces tension in one member while the other brace is in tension when the force is reversed. Several past analytical studies have shown that the tension acting brace in X-bracing can provide an efficient support at the brace intersecting point for the compression brace, which result in reduced brace slenderness.

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K Bracing: The members in K-bracing create out-of-balance horizontal load to a column. K-braces are generally provided in light structures and not permitted in seismic regions as per code specifications.
Chevron bracing (V & inverted V bracing): Chevron bracings are designed for both tension and compression force.

B. Eccentric Bracing System

Eccentric bracing is used to allow access for doorways and corridors in the braced bays. Lateral stiffness of the system in eccentric bracing pattern, mainly depends upon the flexural stiffness of the beams. In an eccentrically braced frame bracing members connect to separate points on the beam/girder. The beam/girder segment or link (intermediate stiffeners) between the bracing members absorbs energy from seismic activity through plastic deformation, so system has lesser lateral stiffness but better energy dissipation capacity.

III. BEHAVIOUR OF BRACING UNDER HIGH SEISMIC CONDITION

Under Earthquake condition, frames undergo in significant inelastic deformation. Bracing members experience inelastic deformations in cyclic tension beyond yield and compression into the post-buckling range. Specially designed braced frames can sustain plastic deformations and dissipate energy in a stable manner through successive cycles of buckling in compression and yielding in tension. Therefore, plastic deformations only occur in the braces, leaving the columns, beams, and connections undamaged. This system also allows the structure to survive strong earthquake without losing gravity-load resistance.

IV. SEISMIC DESIGN CRITERIA FOR BRACINGS

Seismic design criteria should be developed as per different seismic zones. Ordinary Moment frames and ordinary braced frames can be adopted in lower seismic zones. But in the high seismic areas, structure should be compliant with special seismic provision such as special moment frames (SMF) and special concentrically braced frames (SCBF) which increase inherent ductility and in this case, a large response modification factor (R) value can be used.

A. Ductility of Bracing Member

Traditionally, braces have shown almost no ductility after overall (member) buckling, which produces a plastic hinge at the brace midpoint. At this plastic hinge, local buckling can cause large strains, leading to fracture at low drifts. As per IS specification brace cross section shall be plastic to achieve ductile behaviour.

B. Slendernes Ratio

Slenderness of brace affects the inelastic performance. Braces with smaller Kl/r ratios dissipate significantly more energy through inelastic deformation prior to brace fracture. As per IS specification slenderness limit around 120.

C. Failure Pattern of Brace

Braces in SCBF are required to have gross section tensile yielding as their governing limit state so that they will yield in a ductile manner. So bolting arrangement should be such that, net section rupture should not govern.

V. STRUCTURAL BRACING PREFERENCES

Structural framing with effective bracing system in high seismic zone should be made early in a projects which requires seismic provision. Few type of bracing system are not very desirable in seismic. So, structural layout without workable bracing pattern at early stage of project sometimes cause engineering impact.

A. X-Bracing

In X brace system when compression brace buckles, we still have truss action occurring between the tension braces and the columns, due to remaining triangular configuration. The use of X-Braces increases the lateral stiffness of buildings and decreases the lateral displacements, which also result in lesser P-Delta effects. So, in X braced system, columns are protected against reaching nonlinear state because most of the energy dissipates by braces.

In two story X brace system (“Fig. 2”), when the compression brace buckles at the first floor, the braces at the second floor prevents the brace frame beam from buckling and you don’t have to design the beam for an unbalanced loading.
X-bracing system is considered preferred bracing system in high seismic zone.

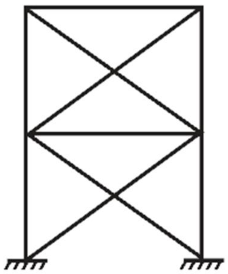

Figure 1. Single story X-bracing

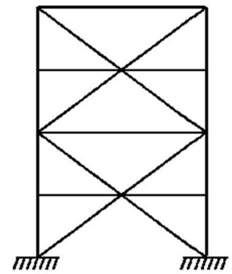

Figure 2. Two story X-bracing

B. Chevron Bracing

When the compression brace buckles, the tension brace force now doubles (before buckling has 50% of lateral force “V” in the tension brace and 50% of “V” in the compression brace). Large unbalanced forces and bending moments on the beam occur because the buckling load is smaller than tensile yield resistance. The vertical force resulting from unequal compression and tension strength of the braces introduces flexure in the beam, and creates a plastic hinge in the beam.
When chevron bracing is used, the beam must be designed for bending moment caused due to unbalanced load when compression brace buckles. This results very heavy beam sections.
So V-bracing is not considered preferred bracing system in high seismic zone.

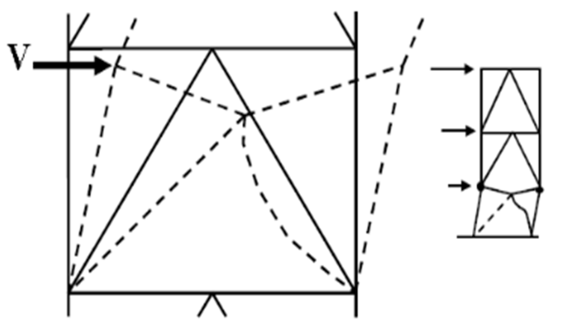

Figure 3. Chevron brace buckling

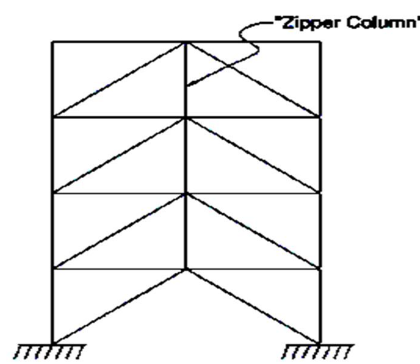

Figure 4. Zipper column with chevron-bracing

Khatib et al (1988) proposed to add zipper columns to link together all brace-to-beam intersecting points with the aim to drive all compression braces to buckle simultaneously and which results in greater energy dissipation capacity of the system. There are no guidelines to determine the number of compression braces which may buckle. AISC has recommended the braced frame in a zipper-bracing configuration as an innovative system able to improve the post-elastic seismic performance of CBF with chevron configuration.
In case V-bracing is followed zipper column must be provided in high seismic zone.

C. K-Bracing

K-braces intersect at mid-height of the column. It has the same unbalanced force problem as noted with chevron bracing. The unequal buckling and tension-yielding strengths of the braces would create an unbalanced horizontal load at the mid-point of the columns and plastic hinge forms, which damages the ability of the column to carry gravity loads.
So, K-brace is not at all preferred bracing system in high seismic zone.

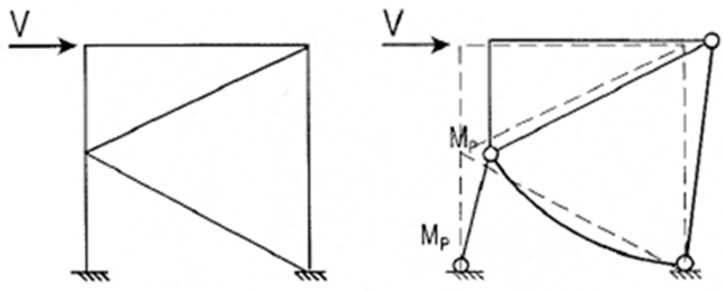

Figure 5. Plastic collapse mechanism of K-braced frame with plastic hinge in column

VI. SEISMIC DETAILING

Braces in SCBF are expected to undergo cyclic buckling under severe ground motions, forming plastic hinges at their centre and at each end. To prevent fracture resulting from brace rotations, bracing connections must either have sufficient strength to confine inelastic rotation to the bracing member and sufficient ductility to accommodate brace end rotations. To have sufficient strength of end connections, it should be designed to resist the expected compressive strength and the expected flexural strength of the brace as it transitions from pure compression to pure flexure (Astaneh-Asl et al., 1986).

A. Connection Ductility-fold line theory

Sufficient ductility to accommodate brace end rotation is typically accomplished by means of a single gusset plate with the brace terminating before the line of restraint. Due to inelastic rotation of brace member, weak axis bending in the gusset plate is induced, which results formation of hinge at gusset plate location and at mid span in brace member. To develop restraint-free plastic rotation in gusset plate, sufficient free length between the end of the brace and the assumed line of restraint for the gusset plate is required. A length of two times the plate thickness is recommended (Astaneh-Asl et al., 1986). Note that this free distance is measured from the end of the brace to a line that is perpendicular to the brace centreline, drawn from the point on the gusset plate nearest to the brace end that is constrained from out-of-plane rotation.
When both connection end condition is flexible, first plastic hinge will be formed in the brace mid span. Test results also indicate that forcing the plastic hinge to occur in the brace rather than the connection plate results in greater energy dissipation.

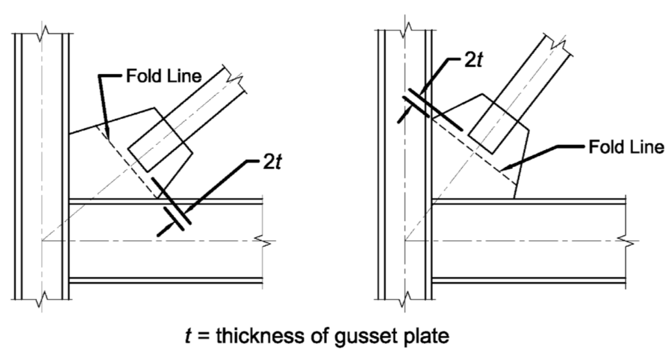

Figure 6. Illustration of fold line theory

B. Connection Ductility-elliptical hinge zone

The 2t linear clearance method needs thicker gusset plates, which provide greater restraint to the end rotation and reduce the inelastic deformation prior to brace fracture. Recently an approach based on the use of thinner gussets and elliptical hinge has been developed, based on work by Roeder et al. (2011). This approach suggests an elliptical hinge zone of eight times gusset thickness (8t) on the gusset and allows the brace to extend nearer to the beam and column members. This approach encourages thinner, more compact gusset plates that facilitate end rotation caused by buckling of the brace.

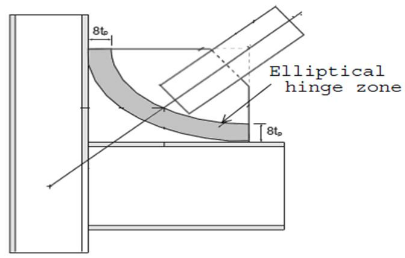

Figure 7. Elliptical hinge zone configured for out of plane buckling

C. Impact for Seismic Detailing

Following are some key points which generally impact in industrial projects in high seismic areas. The capacity design approach need to be followed with special consideration that creates space constraints for other disciplines.

The Connections require larger and thicker gusset plates, continuity plates, doubler plates and more bolts that results increase of material and fabrication cost. It also requires lots of engineering detailing effort.

In general case, weight of connections is 10% of total steel. In the case of ductility design, connection weight goes up to 20% of total steel.

Figure 8a. Special concentric brace frame connection detailing

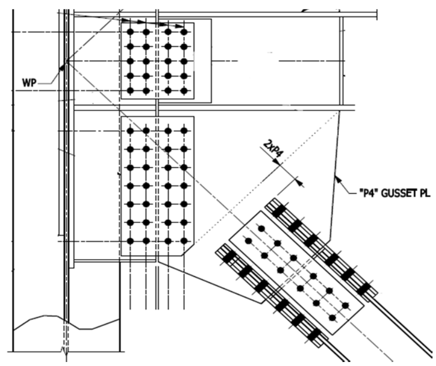

Figure 8b. Special concentric brace frame connection detailing

VII. CASE STUDY

Many times we provide I-sections as bracing members. Sometimes we have to put small length of bracing members. Member sizes and connections are being finalized in design stage as per seismic detailing requirements. I-sections as bracing system requires much bigger connection due to capacity design requirement.

In one case as shown in "fig. 9", fabricator has highlighted the issue that both end connections are clashing with each other. We had to change this section with other seismically required sections like angle section.

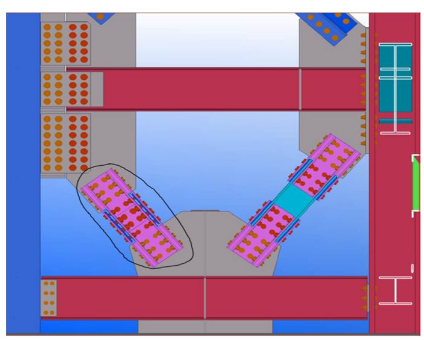

Figure 9. Overlapped end connection due to seismic detailing

VIII. CONCLUSION

Early planning of structural layouts with involvement of experienced structural engineers in seismic design is necessary. Effective bracing system and concept of ductile detailing which require much bigger connection should be kept in mind to mitigate impacts at later stage of engineering.
Concentrically braced frames with proper configuration, member design and detailing can possess ductility to mitigate the stringent effect of high seismic force. Special design and detailing of end connections greatly improve the post buckling behaviour of concentrically braced frames.
Most preferable bracing arrangement shall be X-bracing as the ductility and energy absorption capacity of the system is more compare to the other bracing systems.
Requirement of zipper column, connection ductility (fold line theory) should not be overlooked.

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