

# Study of Eccentrically Braced Outrigger Frame under Seismic Excitation

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**Abstract** ----Outrigger braced structures has efficient structural form consist of a central core, comprising braced frames with horizontal cantilever "outrigger" trusses or girders connecting the core to the outer column. When the structure is loaded horizontally, vertical plane rotation of the core is restrained by the outriggers through tension in windward column and compression in leeward column. The effective structural depth of the building is greatly increased, thus augmenting the lateral stiffness of the building and reducing the lateral deflections and moments in core. In effect, the outriggers join the columns to the core to make the structure behave as a partly composite cantilever. By providing eccentrically braced system in outrigger frame by varying the size of links and analyzing it. Push over analysis is carried out by varying the link size using computer programs, Sap 2007 to understand their seismic performance. The ductile behavior of eccentrically braced frame is highly desirable for structures subjected to strong ground motion. Maximum stiffness, strength, ductility and energy dissipation capacity are provided by eccentrically braced frame. Studies were conducted on the use of outrigger frame for the high steel building subjected to earthquake load. Braces are designed not to buckle, regardless of the severity of lateral loading on the frame. Thus eccentrically braced frame ensures safety against collapse.

**Index term**-- Ductile, Outrigger, Eccentrically braced system, Seismic performance, link etc...

## 1. INTRODUCTION

Seismic resistant eccentrically braced frame are a lateral resisting system for steel building that are capable of combining high stiffness in the elastic range with good ductility and energy dissipation capacity in the elastic range. In this system the segment of beam placed between the braces absorbs the earthquake energy by large inelastic deformations and other members essentially remain elastic. Eccentrically braced frame stand out by their effectiveness. They provide an exceptional ductility through inelastic deformation of links. Links are modeled as inelastic element with concentrated end flexural and shear hinges. A design procedure generally assumes that the dissipation of energy is exclusively to links and aim to achieve the elastic response of all other frame members, while maintaining link deformation below the acceptable limits.

Outrigger braced structures is a efficient structural form consist of a central core, comprising braced frames with horizontal cantilever outrigger trusses or girders connecting the core to the outer column. When the structure is loaded horizontally, vertical plane rotation of the core is restrained by the outriggers through tension in windward column and compression in leeward column. The effective structural depth of the building is greatly increased, thus augmenting the lateral stiffness of the building and reducing the lateral deflections and moments in core. In effect, the outriggers join the columns to the core to make the structure behave as a partly composite cantilever. Perimeter column other than those connected directly to the ends of the outrigger, can also be made to participate in the outriggers action by joining all the perimeter

column with a horizontal truss or girder around the face of the building at the outrigger level.

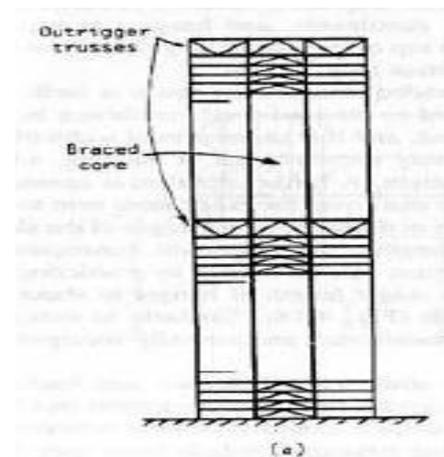


Fig -1: Outrigger Braced Frame

## 2. AIM OF STUDY

The aim of the study is to evaluate the outrigger frame with eccentrically braced system by varying the eccentricity.

### 2.1 Objectives of the study

The objective of this project is to evaluate the forces induced in outrigger frame with respect to seismic motion. To study the behavior of steel frame with different bracing

configuration with varying eccentricities under seismic load and to find optimum eccentricity

**2.2 Scope of study**

The scope of this project work involves to analyze outrigger using SAP 2000. The study is restricted to three dimensional steel frame and the soil structure interaction is not included. Design recommendation for links and connections in eccentrically braced frame.

**3. LITERATURE REVIEW**

An introduction and characteristics of EBF like-stiffener and strength, forces in links, Energy dissipation, mechanism. Tests were done on three storeys EBF. They are tests on links with equal end moment, test on links with unequal end moment and tests on composite link. From the experiment they are giving optimum link length, stiffener spacing and link rotation. With the above details the design of eccentrically braced frame has been considering the design philosophy with optimum link and connection details. This paper has provided an overview of seismic resistant eccentrically braced frames, with particular emphasis on the behavior and design of shear links. Inelastic dynamic analysis of EBFs subjected to real earthquake records is providing additional useful rules for improving upon the basic code based design procedure.( Egor P.Popov and Michael D.Engel Hardt, 1988)

Frames were analyzed with different, eccentric braces(inverted V, V, Diagonal) for three different storey height (4,8,12 storey).Then the frames were assessed by nonlinear static (push over) analysis based on FEMA 440(2005)[Federal Emergency Management Agency].The main objective of this paper is to do a quantitative comparison of ductility levels of different bracing systems. Sap 2000 is adopted for performing nonlinear analysis. Inelastic Time history analysis is carried out to study the structural response to seismic forces. This allows tracking of order of yielding and failure on the members. This has been designed according to AISC LRFD. National provision of Iran and 2800 code are used as loading codes From analysis conducted on all nine frames it is concluded that eccentric diagonal bracing has more stiffener than the other two types(Inverted V and V).( Seyed Mehrdad Nourbaksh 2011)

Theoretical and experimental research of the most ductile element of the eccentrically braced steel frames called seismic links. Four types of short seismic links were chosen with same length but with different number of stiffeners. Nonlinear numerical modeling was conducted with result theoretical analysis should be done. The seismic link should be designed. So that it may bear great inelastic deformation without losing resistance and most of seismic energy is dissipated within it. This paper has summarized the Design of seismic links, Analysis of specimen, Experimental analysis, Comparison of analytical and Experimental. Calculating the reliability for all cases as a operative value of the probability of collapse was conducted through VAP will give the optimum value. The detailing of seismic links has been done according to the Euro code. (M. Causevic, M. Bulic, B. Androic, 2008)

The use of replaceable link in Eccentric braced frame (EBF) as a seismic structural system has been defined. This

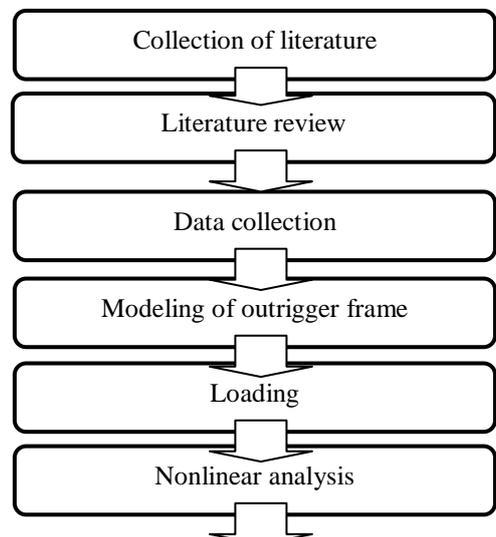
study mainly focuses on damage avoidance and repair impact minimization and it is achieved by introducing new shear links. Convention EBF has generally performed better than expected. Full scale testing and finite element work was undertaken on six frames with removable links. This research showed the performance of the removable link exhibiting good ductile behavior, developing stable repeatable yielding. The testing has been done by providing different link rotations and drift for six frames. Specifically two D-braced and K-braced frame in longitudinal and transverse direction is adopted. (J. J. G. Ramsay, A. Fussell and R. G. Wilkinson, 2013)

includes both analytical and experimental studies such as to determine the most appropriate analytical models to represent the seismic behavior of all frame members and to verify if the current design procedure achieves desired frame response and also evaluate the impact of the element behavior non anticipated in design on global frame performance. Two dimensional nonlinear Time history analysis was conducted for three storey structure.( **J.Rozon, S.Koboevic and R.Tremblay,2011**)

**4. METHODOLOGY**

The work involves detailed analytical investigation by making use of structural analysis software with following components in

- Literature review for different bracing steel frame is to be collected.
- Modeling of steel frame with different eccentricity for different storey should be done.
- Push over analysis is to be carried out for different storey frames.
- From the result the load transfer of outrigger frame should be analyzed..
- Based on the knowledge gained on the literature study the project is carried out with the following flow chart.



Results and discussion

Fig. 2. Methodology

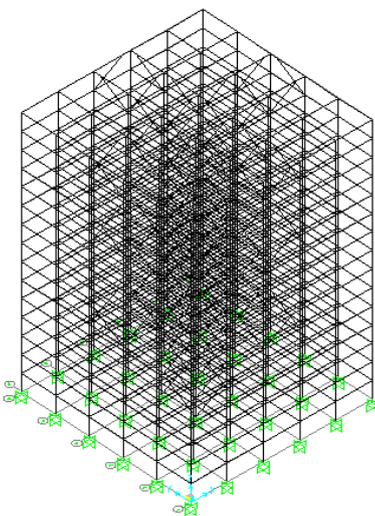
**5. MODELING**

**5.1. Modeling of Outrigger Frame**

Literature review for different bracing steel frame is to be collected. Modeling of steel frame with different eccentricity for different storey should be done. From the result the optimum eccentricity is to be taken. Analyzing and comparisons of the outrigger frame by providing different bracing configuration with different eccentricity. The more reliable dimension of the link to the seismic load for different stories provided. From the result, the optimum eccentricity can be found and thus it will be more resistance for seismic load.

Accurate modeling of the nonlinear properties of various structural elements is very important in nonlinear analysis of any structure and since the present study is based on the nonlinear analysis of structural models of regular multi-storied buildings. This chapter presents the summary of various parameters defining the computational models and the building geometry considered for this study. And also presents the properties of plastic hinges and the procedure to generate these hinge properties.

In the present study the structural models of the 2-D frames used are modeled, designed and analyzed using the finite element software Structural Analysis Program SAP-2000 version 14. The analytical software SAP (Structural Analysis Program) is a computational tool for modeling and analyzing structures. The 3D model is analyzed on two different seismic approaches. The modeling of the frames involves assemblage of various structural and non-structural elements. It also includes defining material properties, sectional properties, load cases and non-linear hinge properties. The frame was designed for zone III with PGA=0.16g and structural parameters for 16 different ground motions are obtained.



**3-D Model**

**Fig-3:**

**5.2 Building Geometry**

In the present study regular 3-D frames with storey height 3.5m and bay width 7.3m are used. Frames with Fifteen stories are studied. The design of all the frames was according to the Indian standards IS 800(2000), seismic code IS 1893(2002). A series of iteration were carried out for the assigned section to get the apt section for the structure. Section properties of beam and column has been chosen by trial and error method with the help of SAP2000. The material property for all the members in frames as follows

- Young Modulus of steel : 22360000 Mpa
- Poisson's Ratio ( $\mu$ ) of steel : 0.3
- Type of bracing – single diagonal bracing with eccentricity.
- Eccentricity  $e < 1.6 M_p / V_p$
- Plastic moment  $M_p = Z_f y$
- Shear capacity of section  $V_p = 0.55 f_y d_w t_w$
- Eccentricity should be within 2m

**5.3 Loading**

All the beams and columns are modeled as frame elements. The beam-column joints are modeled by giving end-offsets to the frame elements and assumed to be rigid. The column end at foundation was considered as fixed for all the models in this study. All the frame elements are modeled with nonlinear properties at the possible yield locations. The structural effect of slabs due to their in-plane stiffness is taken into account by assigning 'diaphragm' action at each floor level. The load contribution of slab is modeled separately on the supporting beams. The frames used for the study as mentioned earlier was designed using Indian standards IS 1893-2002(Part-1), IS 800 2000, IS875 1987(part 2), IS875 1987(part 3). The frames were designed for the following load combination of (IS 1893):

- 1.7(DL+IL)
- 1.3(DL+IL+EL)
- 1.3(DL+IL-EL)
- 1.7(DL+EL)
- 1.7(DL-EL)

**6. NONLINEAR ANALYSIS**

The essential requirements for the development of framework as to be identified to create a schematic representation this framework is developed based on the TQM model. With the help of the questionnaires received from the organizations the quality assurance the most notable negligence factor has been identified and rectified accordingly.

The factors which affect the most are inadequate supervision and verification on site, use of superseded drawing and specifications, poor workmanship during construction, quality assurance sampling and testing, which increases the workload, cost overrun on projects and inadequate commitment to service quality by contractors has been rectified using Total Quality Management system with four different processes which are quality management program, improvement

suggestions in organizations, top management support, self-motivation towards continuous improvement.

**6.1 Modeling Of Hinges**

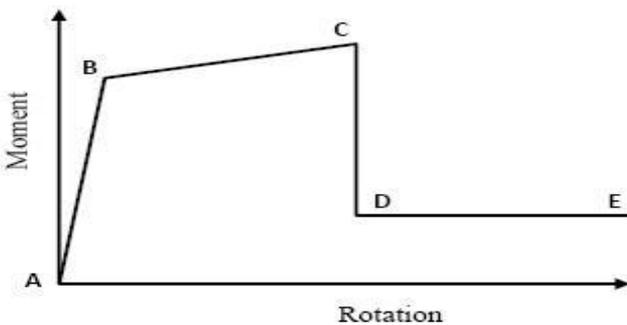
During the inelastic failure of the structure, plasticity is assumed to be concentrated at critical locations called failure points or hinges. There are two approaches for specifying the hinge properties:

- Distributed plasticity model
- Lumped plasticity model

In the distributed plasticity model, the zone of yielding is assumed to be spread over a certain length whereas in the lumped plasticity model, the zone of yielding is assumed to be concentrated at critical points in the element. The modeling approach used in this study is based on the lumped plasticity model, as implemented in SAP2000. This approach is favored in FEMA356, which directly refers to plastic hinge rotations rather than local strains or curvatures. Plasticization of the section is assumed to occur suddenly and not gradually. However the lumped plasticity model may be less accurate than the distributed plasticity model in representing the actual nonlinear behavior of the element. There are three types of hinges namely moment hinges, axial hinges and shear hinges.

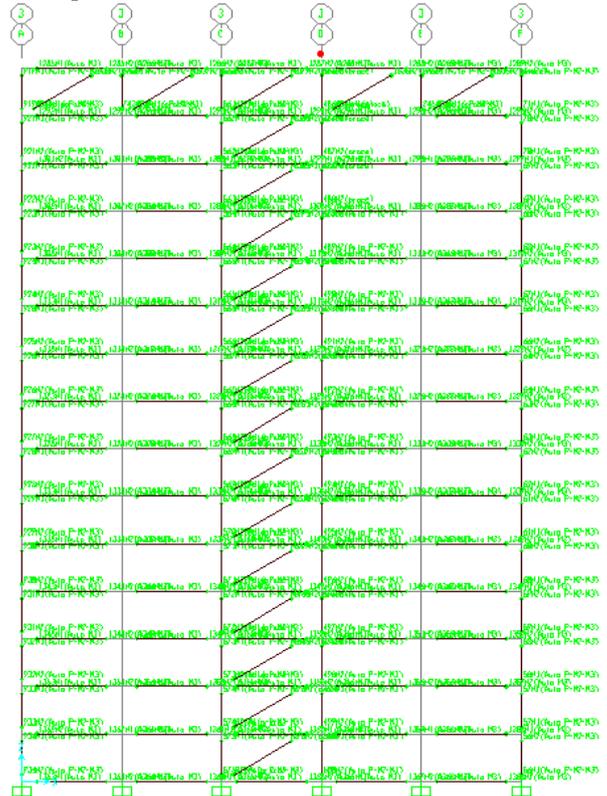
The flexural hinges in beams are modeled with uncoupled moment (M3) hinges whereas for column elements the flexural hinges are modeled with coupled P-M2-M3 properties that include the interaction of axial force and bi-axial bending moments at the hinge location. Each plastic hinge is modeled as a discrete point hinge. Therefore, the plastic hinge length is considered while generating the hinge characteristics. Plastic hinge length (considering the ultimate flexural strength developing at the support) is the distance from the support over which the applied moment exceeds the yield moment. The established practice has been to take  $L_p = 0.5D$ .

Nonlinearity is assumed to be distributed along the length of the plastic hinge. This provides a more accurate representation of the actual nonlinear behavior of the element. There are three types of hinge properties in SAP2000. They are default hinge properties, user-defined hinge properties and generated hinge properties. Only default hinge properties and user-defined hinge properties can be assigned to frame elements. When these hinge properties are assigned to a frame element, the program automatically creates a different generated hinge property for each and every hinges. Default hinge properties cannot be modified. They also cannot be viewed because the default properties are section dependent for a particular hinge point. Fig 3.3 shows the hinge properties recommended by FEMA 356.

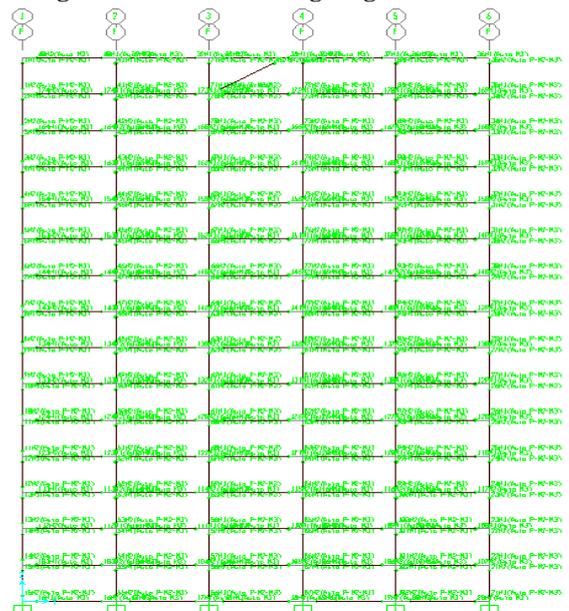


**Fig -4: Typical format recommended by FEMA 356 for hinge properties**

Point A is the origin, B is yield point no deformation occurs in the hinge up to B, regardless of the deformation at point B. The displacement at point B will be subtracted from the deformation at points C, D, E. Only plastic deformation beyond point B will be exhibited by the hinge. C is the ultimate capacity and points D and E are a measure of residual strength and rotation/moment capacity. Typical values of roof drifts for the three performance levels are as follows (FEMA 356).



**Fig-5: SAP model showing hinges X-Z PLANE**



**Fig-6: SAP model showing hinges y-z PLANE**

6. RESULTS AND DISCUSSION

Push over analysis is performed in two different models by varying the eccentricity at a distance of 0.8m and 1.5m of outrigger frame. For the performance of nonlinear analysis the suitable eccentricity length for fifteen storey building has been found out.

- By providing 0.8m link is proved to be not sufficient for fifteen storey outrigger frame structure. Since the distance is very small the frame is not considering it as link and the failure in the core wall starts from the bracing.

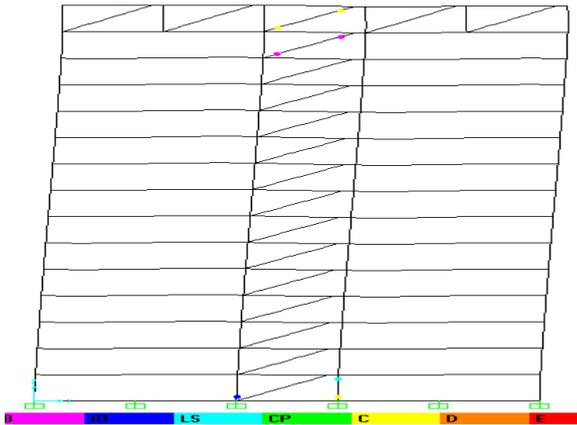


Fig-7: SAP result(e=0.8m)

- By providing 1.5m link is proved to be sufficient for fifteen storey outrigger frame structure. Thus the failure in the core wall starts from the link while performing the nonlinear analysis with the help of software SAP2000.

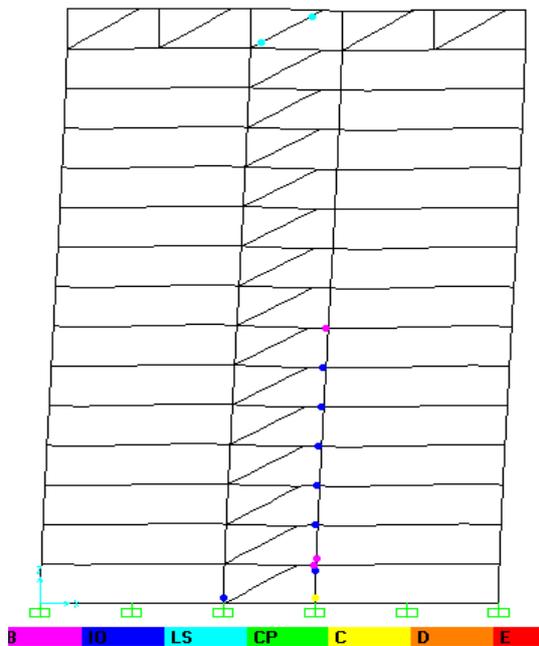


Fig-8: SAP result(e=1.5m)

7. END SECTIONS

7.1 Acknowledgements

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(R.SNEHANEELA)

7.2 References

[1] Popov and Engelhardt ‘Seismic eccentrically braced frame’, University of California, 1988.

[2] Seyed mehrdad noubaksh ‘Inelastic behavior of eccentric braces in steel structure’, Eastern Mediterranean University, 2011.

[3] Causevic, Bulic, Androic, (2008) ‘Reliability of short seismic links in eccentrically braced steel Frames’, 14th World conference on Earthquake Engineering.

[4] Ramsay, A. Fussell and Wilkinson, Design (2013), ‘Replaceable link eccentric braced frames in post earthquake’.

[5] Rozon, Koboevic and Tremblay (2011) ‘Study of global behavior of eccentrically braced frames in response to seismic loads’.

[6] Yau, and Chan ‘Inelastic and Stability analysis of flexibility connected steel frame by spring –in –series model’. Journal of structural engineering. American society of civil engineers, Vol.120, pp. 2803-2819, 1994.

[7] Bureau of Indian Standards IS 800, General Construction in Steel – Code of Practice, 2007.

[8] Bureau of Indian Standards IS 808, Dimensions for Hot Rolled Steel Beam, Column, Channel and Angle Sections, 1989.

[9] IS 1893(Part1), ‘Indian Standard Code of Practice for Criteria for Earthquake Resistant Design of Structures’, Bureau of Indian Standard, (New Delhi), 2002.

[10] IS 875(Part 2 ‘Indian Standard code of Practice for design Loads For Buildings and structures’ Bureau of Indian Standard, (New Delhi), 1987.

[11] IS 875(Part 3) ‘Indian Standard code of Practice for design Loads for Buildings and structures’ Bureau of Indian Standard, (New Delhi), 1987.

[12] IS 12778, ‘Indian Standard code Hot Rolled Parallel Flange Steel Sections for Beams, Columns and Bearing Piles, Dimensions and Section Properties’ Bureau of Indian Standard, (New Delhi), 2004?

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