

Original Research Paper

# Evolutionary Structural Optimization of Wind Bracing Connection Plates in Steel Structures

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**Abstract:** Evolutionary Structural Optimization (ESO) is one of the rules in structural engineering which has received much attention by the researchers. Today, the reduction of construction cost and weight is an important issue in the structure design. The optimization phenomenon is pursuing to fulfill this objective. Thus, presenting a design which could be both safe and economic is of special significance. Despite the valuable researches which have been conducted on optimization of steel structures, the gap of research on ESO of wind bracing connection plates and other metal connections is sensible. The purpose of the present paper is to make an optimal design of these types of connections in the frames with convergent bracing. In this study, the software of Finite Element Method (FEM) of abaqus has been used to design the concentrically (convergent) wind bracing of connection plates based on optimization principles. The Von-Mises stress distribution contour has been presented for two statuses in different angles. In the designed bracing frame, dimensions and thickness of connection plate have been defined as the design variables and the design of optimization is compared with the design of ordinary status and the past works as well. This shows a noticeable reduction in the weight of the optimal designed plate in comparison with the ordinary design.

**Keywords:** Evolutionary Optimization, Steel Structures, Convergent Bracing, Von-Mises Stress Distribution

## Introduction

Convergent bracing frames are among the most prevailing types of steel structures in Iran and reduction of construction cost and weight has always been one of the important issues in the design and implementation of this type of structures (Thomopoulos and Koltsakis, 2003). As the optimal shape of the structure under loading is achieved gradually and through design circles, so this technique is called evolutionary optimization (Kameshki and Saka, 2001).

The standards of optimization consider the minimization of possible fracture. The advantage of Evolutionary Structural Optimization (ESO) is that it is not planned based on optimization algorithms of complex mathematics and employs a modern method (Michael and Sungmoon, 2012). Also, the method of placing the wind bracing and its angles in two statuses of 30 and 56 degrees is compared in which the stress distribution in connections

and concentration of stress is observable around the nuts and connection areas (Kurata *et al.*, 2012).

After general modeling, the connection of wind bracing and its assembly, the mechanical properties of different parts of structure and also existing contacts are specified. Later on, elementation for model components is made and static, buckling analysis and free vibrations are conducted respectively (Maraveas and Tsavdaridis, 2019).

For the design of the connections, the software of Finite Element Method (FEM) of Abaqus has been used. This software has been initially designed for the application in nuclear energy and drilling engineering, because engineers of this branch were in need of an instrument for the study of complex and non-linear problems (Kavoura *et al.*, 2015).

In the design of wind bracing connections, the following four controls should be investigated. (1) Control of connection plate, (2) Connection of the member of bracing to the connection plate (3) Connection of the

connection plate to column and beam and (4) Connection of beam to the column (Cyrille *et al.*, 2018).

In this study, the structure of the optimal shape, weight reduction, cost-effectiveness and light structure is attempted and the location of the maximum stresses is determined (Xian *et al.*, 2015). What are the critical points. Through the convergence diagram, the meshes examined the number of meshes on a surface by finite element method.

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For meshing in the Procedure of finite element, choosing the concerned segment, the fineness and commonness of components is defined depending on the convergence graphic of mesh, a graphic which is determined depending on the amount of pressure (tension) and the number of components, then determining the sort of resolution, the issue will be ready to be examined and it determines the meshing size is correct. They checked the mesh size.

This article determines sections of the consequences of an investigation allocated to the resolution of bolted steel connections by means of finite elements. at first, the article examines the calibration of finite elements of the code ABAQUS on experiment information software package. These links were suggested as the final limit state (Gilson *et al.*, 2005). Then, a collection of three-dimensional beam finite elements is suggested to model the bolt treatment in a clarified fashion. Finally, a three-dimensional finite element model is defined with the ABAQUS code till assuming the hardness and stability treatment of expanded end-plate steel links. The analogy between calculated and measured amounts in each stage points out the benefit and degree of precision of the suggested finite element models (Faisal and Piotr, 2016). It determines and considers the consequences of parametric resolutions plate links applying Finite Element (FE) modeling imtrumentations. Brace slightness proportion, width to thickness proportion and to a minor limit, the end link were identified as the key components in the Experiments (Sohail *et al.*, 2012). The stability and treatment of linear against through plate connections are henceforth defined and a united limit states design method for these related connections propose (Book, 2003).

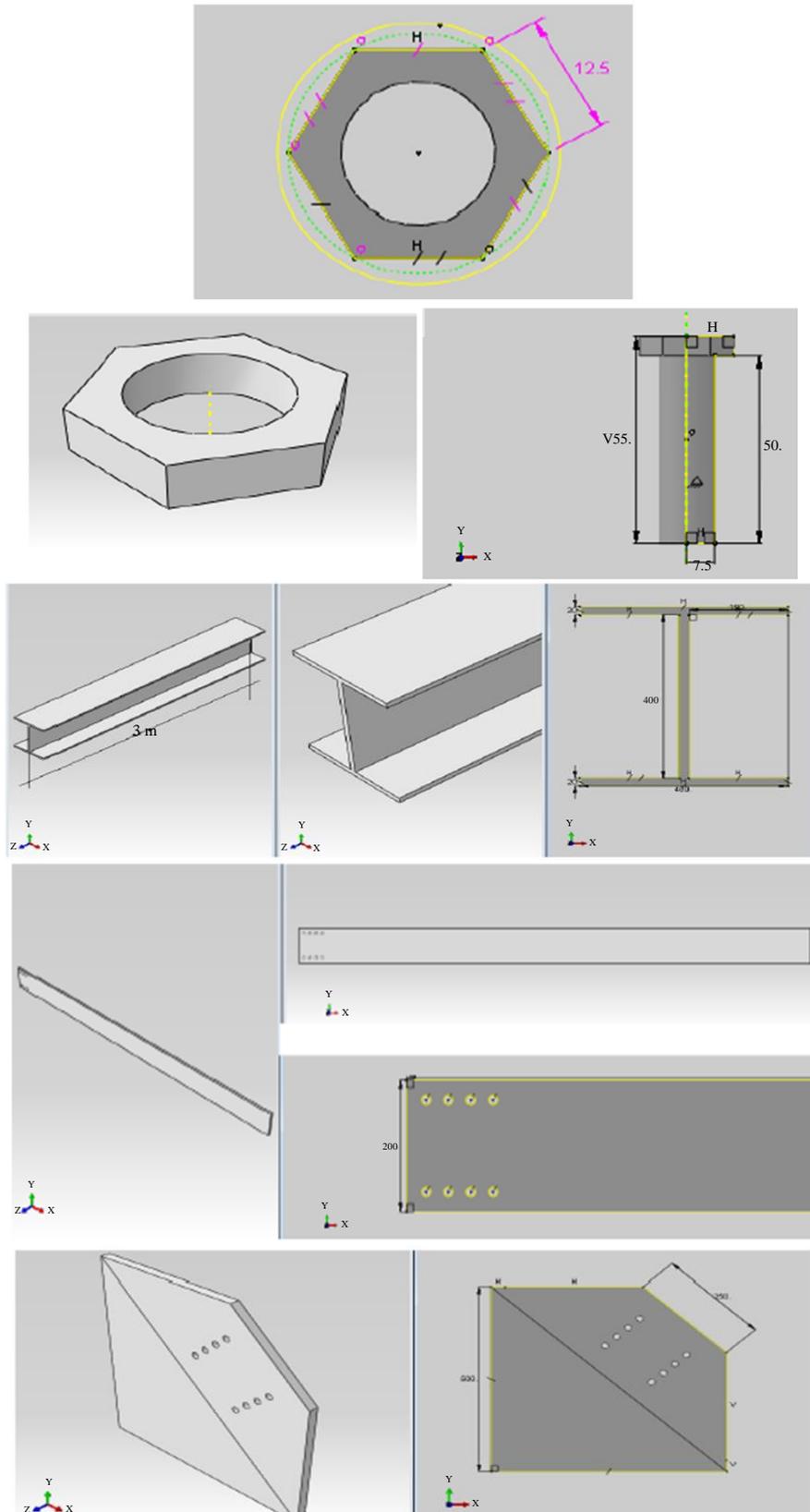
The plan of constructions is often associated with a number of presumption made by engineers in checking on the constancy of the construction. Not rarely, these presumptions are rather unclear (Thomopoulos and Koltzakis, 2003). In the available article, the results of the hardness of various members on the bracing hardness of steel constructions is considered (Feng, 2018). The discovery form this job would help engineers in sketching the lateral load withstanding process for homes (Yujie and Zhihua, 2018). The accredited finite element pattern was then applied for parametric

investigations to define the results of different elements of the frame, containing column base link hardness and correction to the brace link plan, on the frame position and treatment. The construction treatment of beam-column hinges acts as a serious part in the seismic answer of frame constructions (Laura *et al.*, 2011). The vulnerability of steel-framed constructions in many new incidents has incited construction engineers to comprehend their efficiency under such risk. Numerical finite element patterns depend upon definitely to assess the treatment of steel constructions. This vision is a construction hinge having a bias brace, beam and column constantly associated with regard to each other by parallel plates inclined of in a face-to-face relationship on contrary sides of the brace, beam and column and developing from the column along with the directions of the beam and the brace (Jiazhen *et al.*, 2011). The other end of the bias brace may be associated to another construction hinge of beam and column, or to another beam only, or to another column only, by constantly attaching with regard each other, as the occasion may be, the parallel plates encountered in face-to-face connection on contrary sides of the brace, beam and column. Construction frame that concludes a column, a beam, a bracing beam combined with an angle to the column and the beam and a plate to link the brace beam with the column and the beam (Jorge *et al.*, 2019). The frame also concludes a shear plate with horizontally slipped gaps to couple to the column to the beam. The construction frame may also conclude double structure angles or a bent plate combined to the plate and to the beam through spacer plates to prepare for a semi-rigid link (Jiho *et al.*, 2008). A construction steel structure frame concluding interrelated vertical and horizontal columns and beams are appointed with bracing versus wind and seismic strengths. A renovation method that employs a thin steel plate as an auxiliary shear wall system for small, low-rise steel constructions is defined (Albermani *et al.*, 2004).

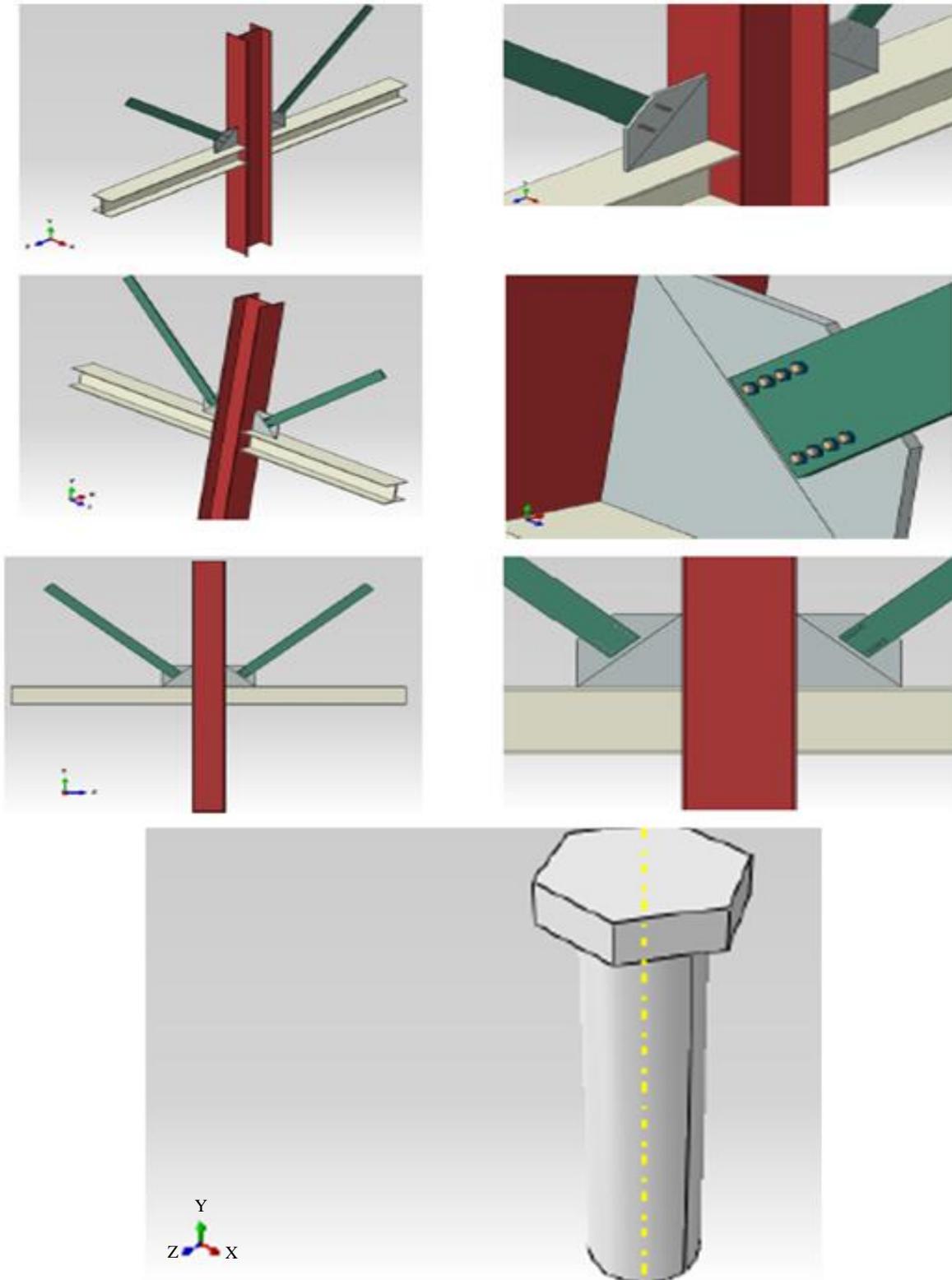
## Model Development

### *Method and Stages of Design; Using the Software of Finite Element Method (FEM) of ABAQUS*

First, using the module Part, clicking on Create Part icon, selecting the name of the beam, column, connection plate and connection screws, type of 3D model, selecting the three-dimension member (solid) and inserting the necessary size, the geometry of the sections is modeled (Jiazhen *et al.*, 2011). It is worth noting that the dimensions of the section surface have abilities to be edited and changed so that they can reach to the best target geometry and aiming to minimize the stress and weight of the structure, they can also reach to an ideal design based on evolutionary optimization principles (Chiara and Claudio, 2014).



**Fig. 1:** Design of members of steel bracing frame in Abaqus software by showing the section specifications



**Fig. 2:** Display of bracing full frame after performing the assembly of the designed model

As it was mentioned earlier, the angle of wind bracing connection with beam and column should have an ability to change, so that if necessary, it could be possible to have a new analysis based on the new geometry (Jing *et al.*, 2018).

Figure 1 shows plan of parts of steel bracing frame in Abaqus software by the exhibition the section characteristics. Figure 2 shows the exhibition of bracing full frame after carrying out the gathering of the plan pattern (Sivaganesh and Mahendrakumar, 2019). Figure 4 shows Using border condition and loading for static resolution. Figure 5 shows Two angles under the condition for education the procedure of setting of wind bracing into the column (Alberto *et al.*, 2019a).

### Definition of Existing Contacts in the Model

When two environments are in contact with each other, in order to introduce the type of contact in ABAQUS software, we should take assistance from the module of the type of interaction, otherwise, the software will not be able to detect the type of contact and analysis is not made (Burdzik and Skorpen, 2014).

In general, there are different contacts such as general contact, self-contact, surface to surface contact, pressure penetrating, model change, elastic foundation, tie, rigid body and other. In the present work, for the link of connection, the tie method has been used

(Sivaganesh and Mahendrakumar, 2019). For connecting two surfaces to each other, even if the elements have dissimilar elements, this type of contact can be used (Anders and Roberto, 2019).

### Elementation of Different Parts of the Model

For the analysis of finite parts, the structure should be divided into smaller parts namely elements. This job in the terminology of the limited element is called Mesh generation. To the extent that these parts are more regular and coordinated, to the same extent, the answers are more precise and the results will enjoy great reliability. In ABAQUS, two types of sweep and structured meshes are of the most precise elements. As it is observed in the following Fig. 3, most the areas are of the type of sweep and a part of the area of connection plate is of the structure type (Alberto *et al.*, 2019b).

For meshing in the method of limited element, selecting the concerned piece, the thinness and coarseness of elements is determined based on the convergence diagram of mesh, a diagram which is defined based on the quantities of stress (tension) and the number of elements, then defining the type of analysis, the problem will be ready to be analyzed (Formisano *et al.*, 2016).

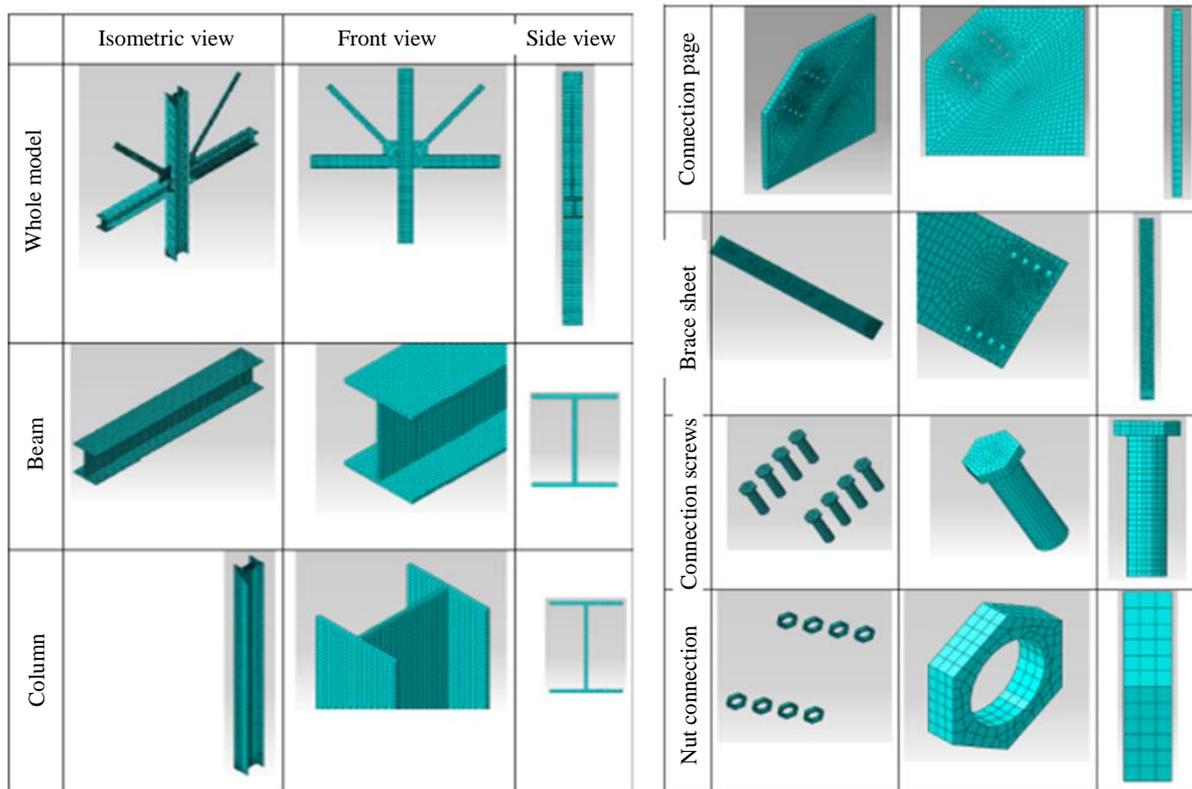
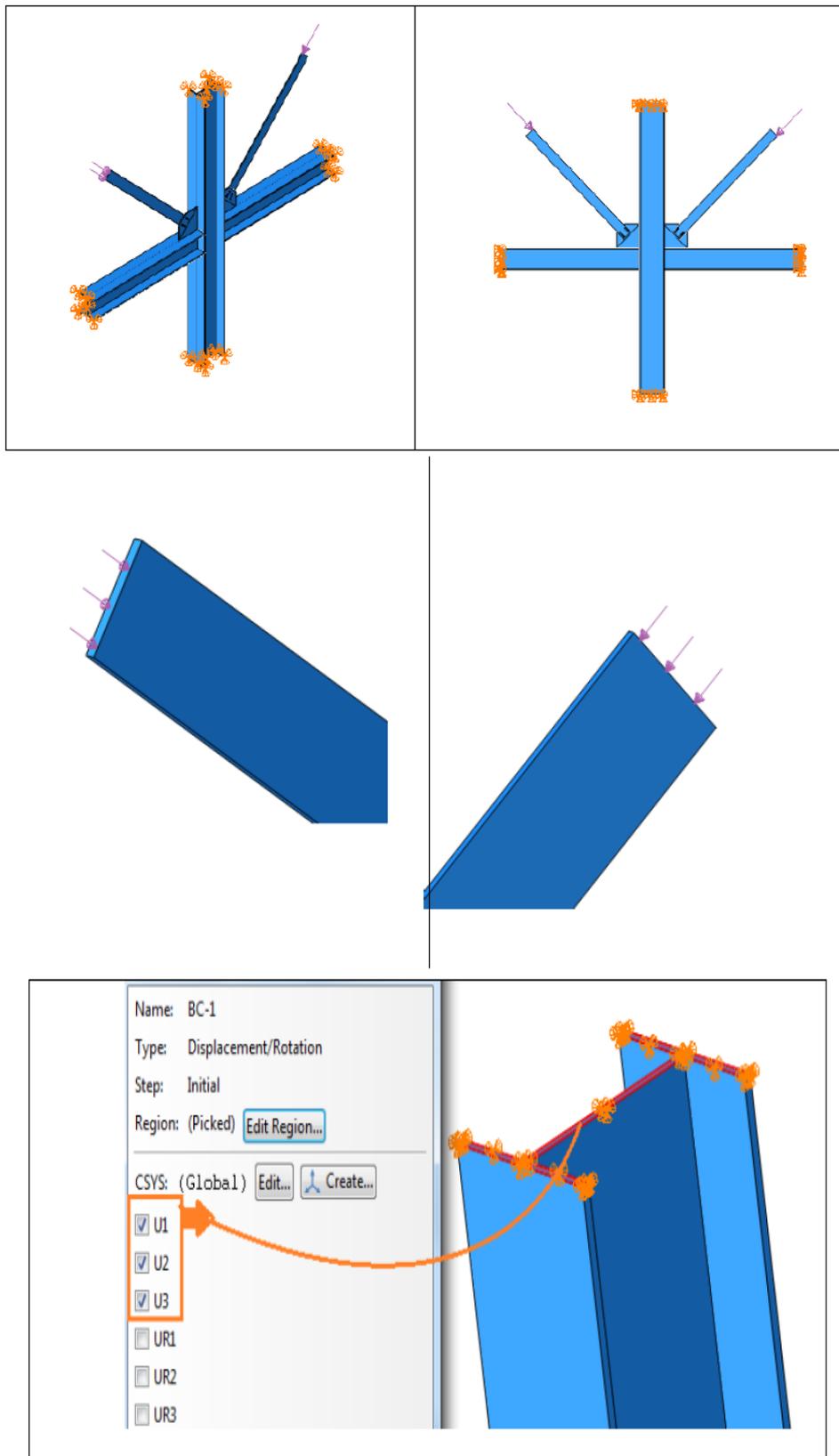
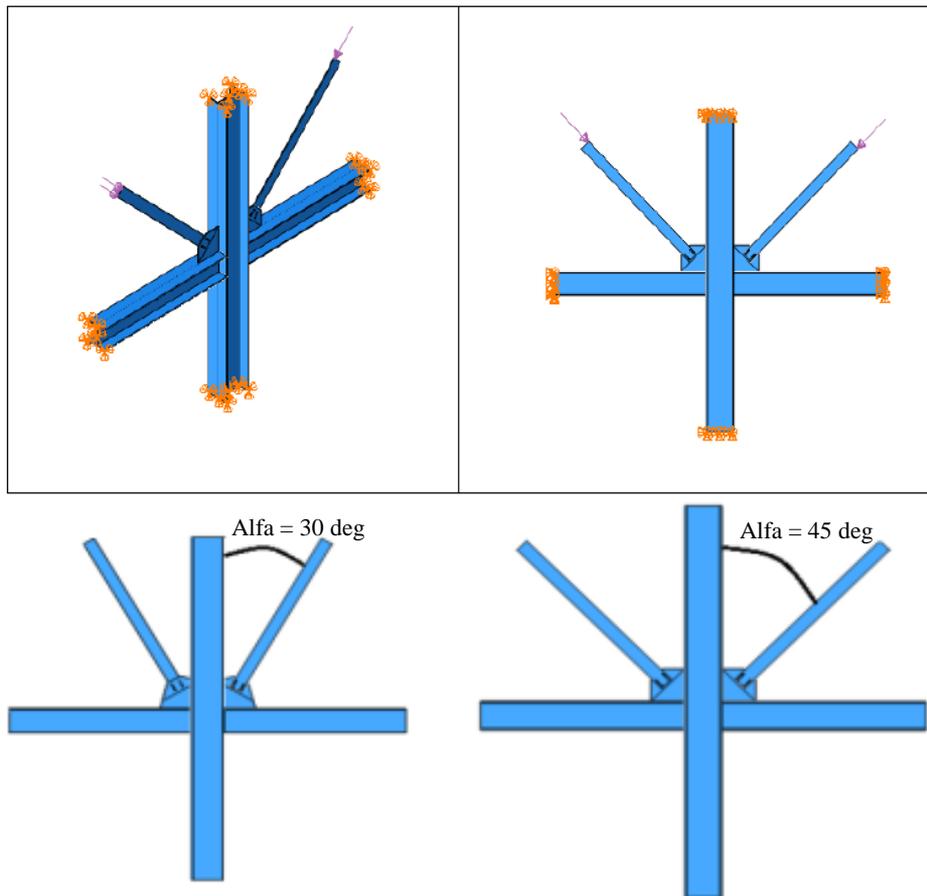


Fig. 3: Different profiles of frame Mesh generation and shaping components of steel bracing frame in ABAQUS



**Fig. 4:** Applying border condition and loading for static analysis



**Fig. 5:** Two angles under consideration for learning the method of placing of wind bracing towards the column

In continuation of our discussion, different static, buckling and free vibrations analyses for the existing structure will be made (Loh *et al.*, 2006). Also, the method of placing the wind bracing connection will be analyzed to find out a proper position from the viewpoint of the angel with a column (Boscato *et al.*, 2018).

As it is observed from the above results, with the existing assumptions in this problem, if the angle of installation of connection to be 45 degrees, the structure is more appropriate from the viewpoint of design in comparison with the position in which this angle is 30 degrees (Charles *et al.*, 2011).

With regard to the outputs, as it is inferred from comparing the results, the Von Mises stresses at 45-degree position have a better reliability margin as compared with the 30-degree position. Of course, in many standards and industry reports, the strains and displacements are compared. In the present work, in addition to the counter output of the above stress, the strain counter outputs have also been taken and some results proportional and similar with the above results were obtained (Jiazhen *et al.*, 2011). Figure 6 shows the Von-Mises pressure dispensation counter for setting the wind bracing in the

45-degree situation towards the vertical orientation. Figure 7 shows Von-Mises pressure dispensation counter for setting wind bracing at 30 degrees towards vertical orientation. It is obvious to determine the various situations such as close view, isometric view, colour division table (Egorov *et al.*, 2018).

### Buckling Analysis

In buckling analysis, the goal is to obtain the critical load for the destruction and reversal of the structure due to this phenomenon. In solving the limited element, after determining the solution whose method is displayed in the following Fig. 8, the software shows the possible mood along with the quantity of the feature. Consequently, it is possible to obtain the rate of critical load for buckling analysis. The size of the critical load is obtained from the Eigen value product:

$$F_{Critical} = Eigen_{value} \times F_{Inerance} \quad (1)$$

The specific values related to 10 moods of steel bracing frame resulting from buckling analysis are displayed in the Table 1.

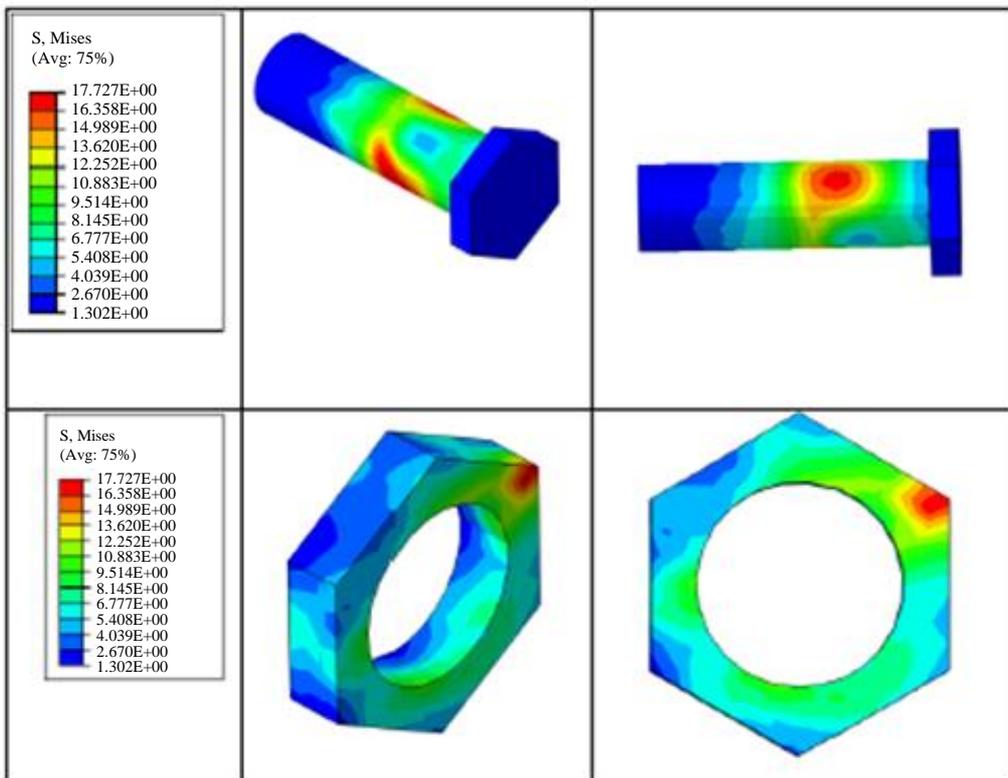
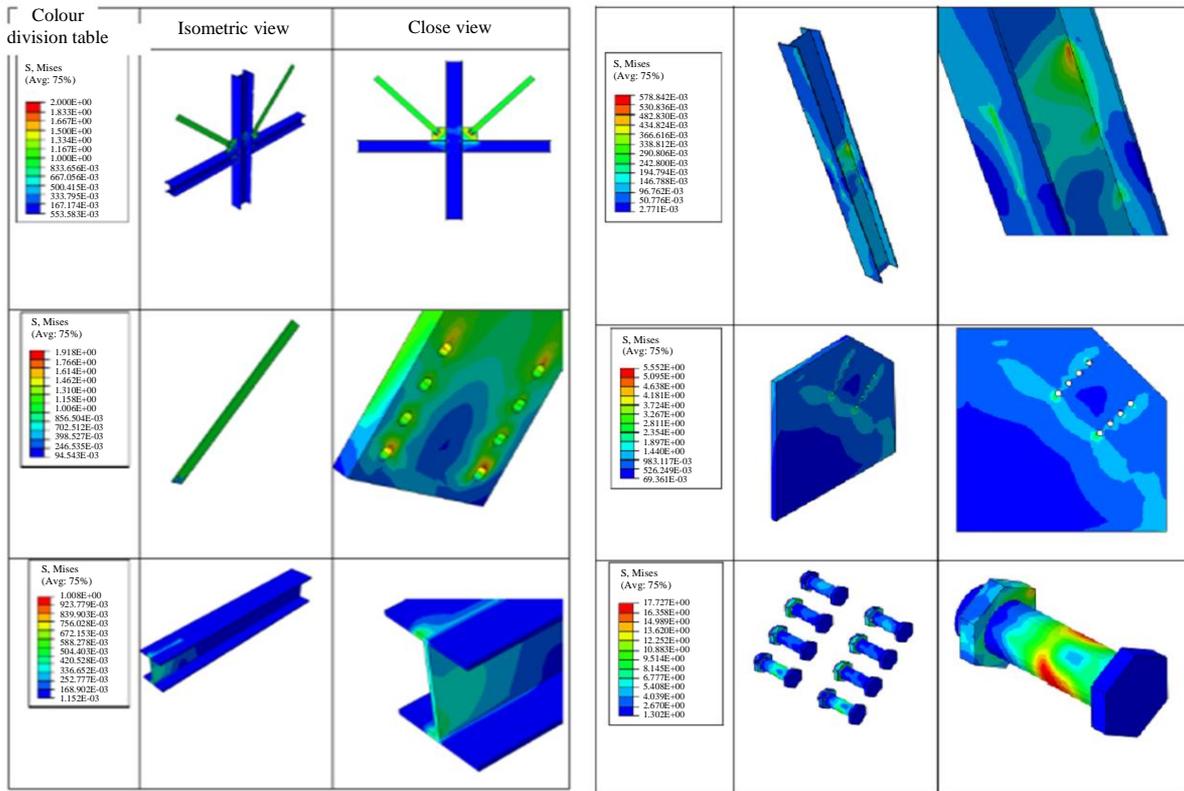


Fig. 6: Von-Mises stress distribution counter for placing the wind bracing in the 45-degree position towards the perpendicular

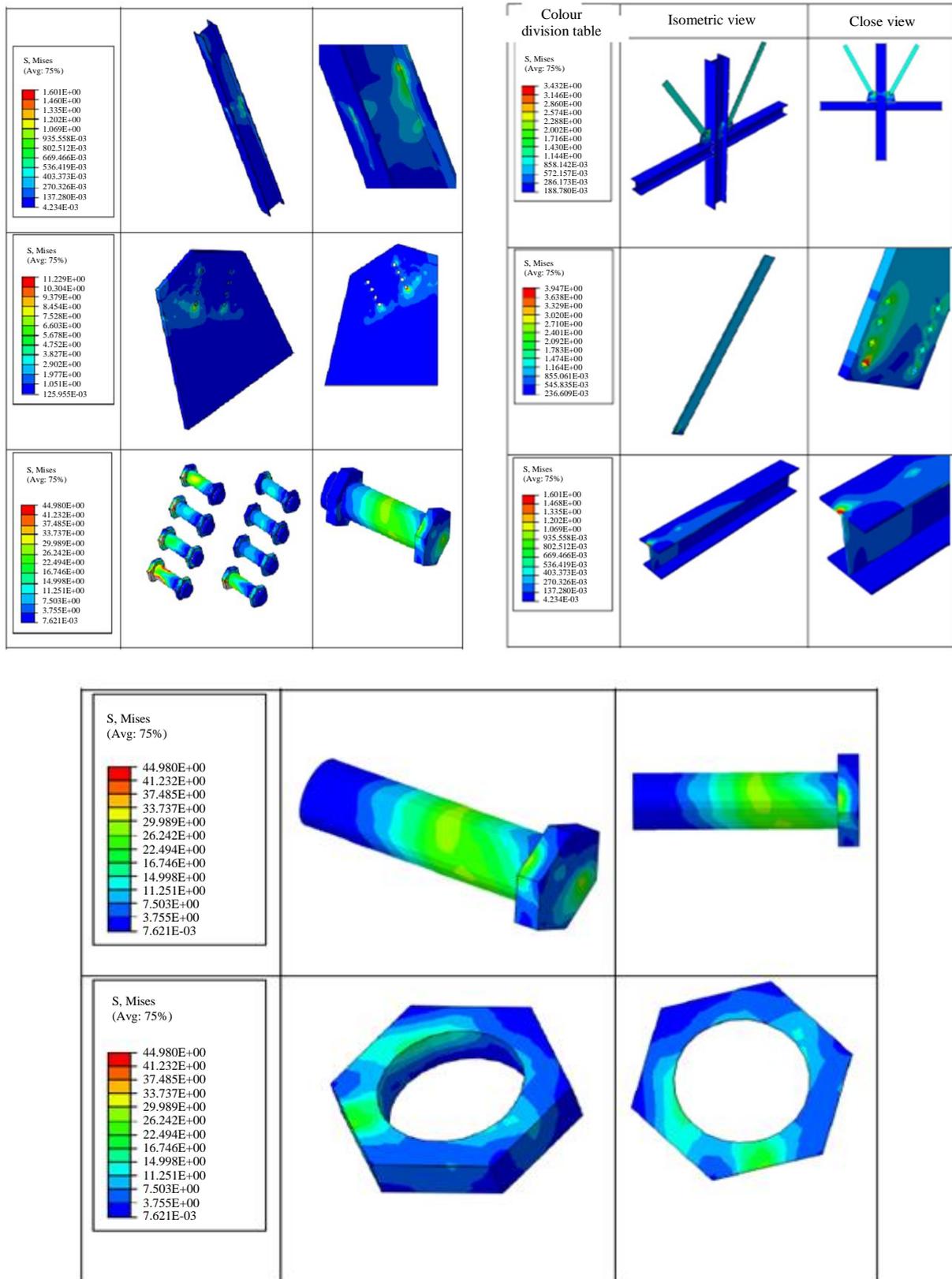
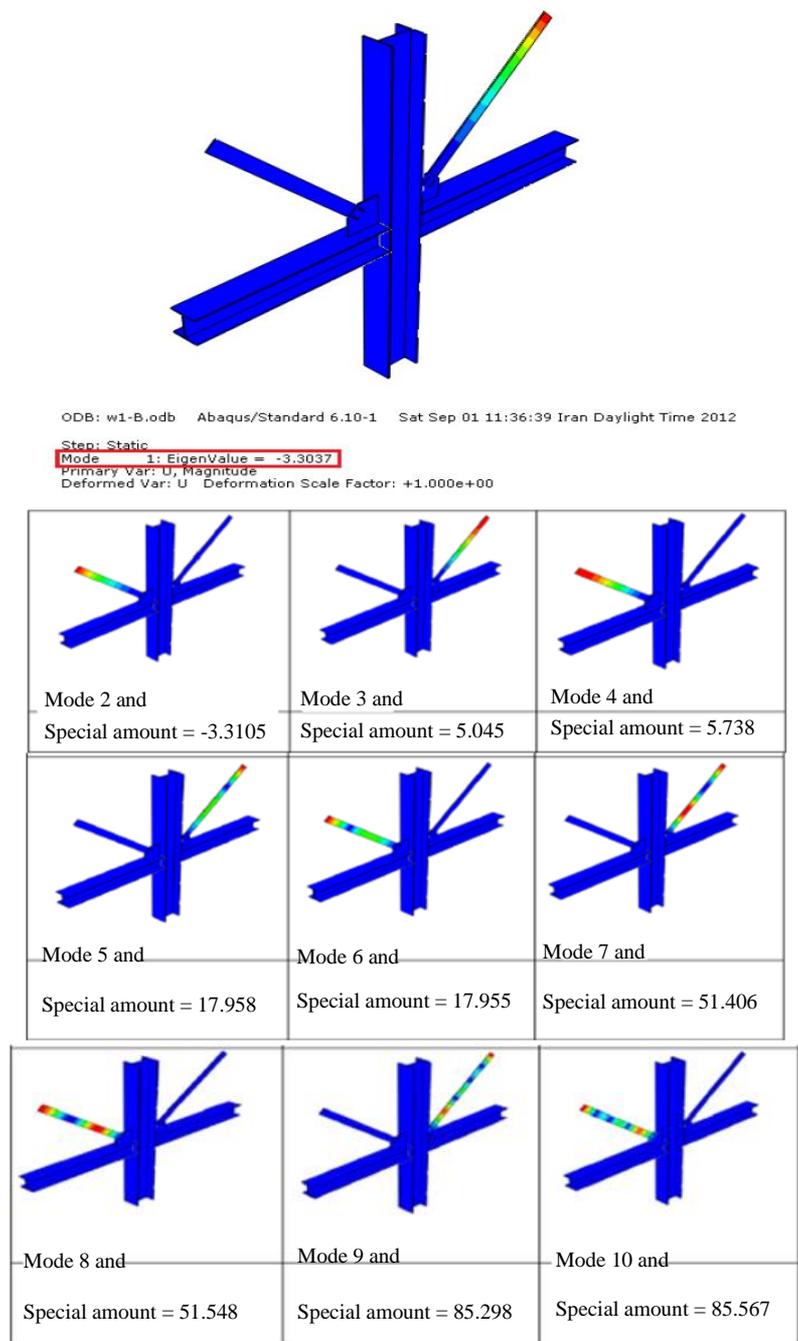


Fig. 7: Von-Mises stress distribution counter for placing wind bracing at 30 degree towards perpendicular direction



**Fig. 8:** Shapes related to buckling analysis of different moods and specific (Eigen) values for steel bracing frame

**Table 1:** Comparing the Von Mises stress for two different positions of wind bracing member towards the perpendicular direction

Stresses difference (MPa)	Maximum stress of 30-degree position (MPa)	Maximum stress of 45-degree position (MPa)	The concerned piece in the bracing frame
1.203	1.601	0.578	Beam
0.595	1.603	1.998	Column
2.029	3.947	1.918	Wind bracing
5.677	11.229	5.552	Connection plate
27.27	44.98	17.71	Screw (Nut)
27.27	44.98	17.71	Bolt

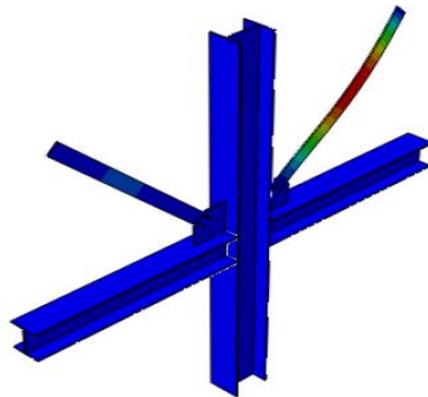
The quantity, i.e., the critical load is equal to 3.3 MPa which of course should be in the opposite direction of the applied force (due to negative sign), thus in this specific position, the concerned mood is impossible (Nima *et al.*, 2019).

*Free Vibration Analysis*

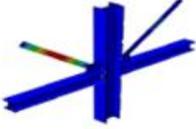
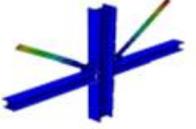
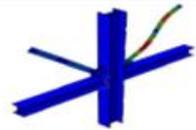
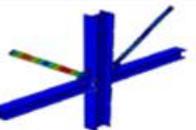
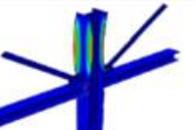
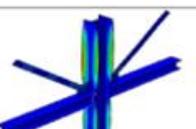
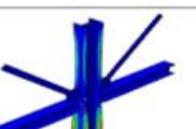
As one of the most basic objectives of embedding the wind bracing connections is to reinforce the structure against the earthquake, so the natural frequency of the structure should be obtained. For this important goal, in this part, the designed structure modal will be dealt with.

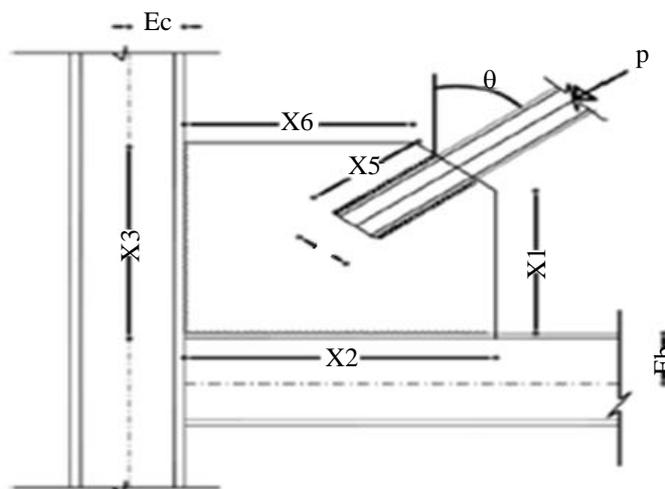
If the structure is stimulated with the mood of the shape displayed with this frequency, it will arrive into a dangerous limit and to be destructed. The results of this analysis should have a distance from the environmental stimulating vibrations including earthquake and movements; otherwise, the structure is not placed in a safe area from the vibration viewpoint (Piseth *et al.*, 2017).

Table 2 shows the Plan Procedures which has an usual plan with various points and weights, Objective Function has a different result rather than Optimal design or plan. The result of them shows various answers for different situations.



ODB: w1-M.odb Abaqus/Standard 6.10-1 Sat Sep 01 11:03:38 Iran Daylight Time 2012  
 Step: Static  
 Mode 1: Value = 1.9392 Freq = 0.22163 (cycles/time)  
 Primary Var: U, Magnitude  
 Deformed Var: U Deformation Scale Factor: +1.000e+02

 Mode 3 and Natural frequency = 0.22224	 Mode 3 and Natural frequency = 0.58123	 Mode 4 and Natural frequency = 0.5836
 Mode 5 and Natural frequency = 0.6986	 Mode 6 and Natural frequency = 0.7014	 Mode 7 and Natural frequency = 1.1657
 Mode 8 and Natural frequency = 1.1749	 Mode 9 and Natural frequency = 1.1919	 Mode 10 and Natural frequency = 1.2190



**Fig. 9:** Shapes related to the free vibration analysis of different moods and natural frequency of wind bracing structure

**Table 2:** Design methods

Design method	X1 (CM)	X2 (CM)	X3 (CM)	X4 (CM)	X5 (CM)	X6 (CM)	Weight (Kg)	Objective Function(Rial)
Design in ordinary method	25.0	81	28.0	1.9	41	73	36.86	1012432
Optimal design	19.9	63	41.6	1.8	42	10	29.18	423686
Design in ordinary method	25.0	81	28.0	1.9	41	73	36.86	
Optimal design 1	32.0	50	50.0	2.0	41	32	36.70	
Optimal design 2	32.0	50	50.0	1.9	41	32	34.87	
Optimal design 3	25.0	50	50.0	2.0	41	25	34.34	
Optimal design 4	20.0	50	50.0	2.0	41	20	32.18	
Optimal design 5	20.0	50	50.0	1.9	41	20	30.57	
Optimal design 6	20.0	50	50.0	1.8	41	20	28.97	

Figure 9 shows the images linked to the free vibration resolution of various conditions and normal modulation of wind bracing structure

### Static Analysis

In this part, applying a weight equal to 5 tons to the end of two wind bracing, the impact of the method of their placing is observed. Two ends of beam and column have also been considered in a fixed form.

For different positions of wind bracing towards the column, numerous positions can be compared with each other. In the present work, two positions of 45 and 30 degrees have been studied to determine both the method of job and the response of these two positions with each other.

### Results

Evolutionary Constructional Optimization is one of the statutes in Constructional technology which has obtained much consideration by the scholars. Today, the decrease of building price and weight is an essential case in the construction plan. The optimization occurrence is

following to perform this objective. Therefore, exhibiting a plan which could be both secure and economic is of particular importance. But the useful scholars which have been directed on optimization of steel constructions, the split of investigation on Evolutionary Construction Optimization of wind bracing junction planes and other metal links is reasonable.

### Conclusion

The goal of the available article is to build the optimal plan of these sorts of links in the cases with coming loser together bracing. In this article, the computer software of the finite element procedure of Abaqus has been applied to plan the wind bracing of connection panels depend on optimization fundamentals. The Von-Mises pressure dispensation outlines have been reported for two situations in various angles.

In the plan bracing frame, sizes and width of the link plane have been determined as the plan factors and the plan of optimization is contrasted with the plan of the usual situation and the late tasks as nice. This displays a significant decrease in the weight of the optimally planed plane in contrast with the usual plan.

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## Author's Contributions

All authors contributed to design the study, write and revise the manuscript.

## Ethics

The present Study and ethical aspect were approved by the Isfahan University of the Technology. The present study was approved by the Isfahan University of Technology.

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