International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 07 | July 2023 www.irjet.net p-ISSN: 2395-0072

STRUCTURAL BEHAVIOUR OF SQUARE AND ELLIPTICAL CROSS SECTIONS OF STEEL TUBULAR COLUMNS WITH DECONSTRUCTABLE SPLICE JOINT

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Abstract - *A steel tubular column is a vertical structural member used in construction to provide essential support. Splice joint is a method of joining two members end to end. When the material being joined cannot be obtained in the desired length, the splice joint is used. For high rise buildings the continuity of columns may break, hence splice connections are provided and columns are installed. Splice joints are deconstructable type joints as the failed parts can be repaired, reassembled or can be even removed. Deconstructable steel structure system possesses good construction efficiency and quality. This paper focuses on developing models of square and elliptical cross sections of steel tubular columns with deconstructable splice joint using a finite element modeling software ANSYS and study their structural behavior. This paper includes a parametric study on the effect of axial loading by varying splice length and thickness, bolt diameter and pattern of square and elliptical cross sections of steel tubular columns with deconstructable splice joints. Load v/s deflection curves are obtained which gives the maximum strength and ductility cases. Cyclic load testing is done on square and elliptical cross sections to obtain bending moment rotation curves.*

Key Words: Local buckling, Splice joint, ANSYS, Deconstructable joints, High strength Bolt

1.INTRODUCTION

In addition to the benefits of high construction efficiency, good construction quality, and sustainable development associated with prefabricated steel structures, deconstructable steel structure systems enables quick disassembly and reuse of structural members following the completion of the structure. Deconstructable steel systems therefore have greater promise in the engineering field [4]. Splicing joint is made of lower square steel tubular column, upper column, four numbers of splice plates and number of high strength bolts. Usage of high strength bolt gives higher strength than regular bolts. High strength bolts are made of some alloy steel. These bolts ensures that structure remains safe even under harsh weathers. The splice plates are designed as four numbers of independent plates in order to make sure that the splice plates well fit into the four other component plates of the column. Steel tubular constructions with distinct advantages are being employed more frequently as long span skyscrapers and high-rise buildings continue to emerge [12]. Deconstructable structural design also refers to the use of reusable materials in the design stage to create structural components that are simple to assemble and disassemble [11]. At present the research on deconstructable steel structure system is very limited. While closed section column-to-column splicing joints frequently use fully welded connections, which can't satisfy the requirements of convenient disassembly, the majority of the column-to-column joints use fully bolted connections [4].The current study proposes square and elliptical cross sections of steel tubular column with conventional high-strength bolts in order to realize deconstructable connection of closed section steel column splicing joints. 3-D finite element model was built using Ansys Workbench 2022 R2 software and further validated against the experiments, which may serve as an important reference for its use in real-world engineering applications. Non-linear analysis is being conducted .In cyclic loading tests, the bending moment rotation curves were obtained. Axial loadings were given to square and elliptical column sections and corresponding ultimate load and deflection curves were plotted.

2. VALIDATION

Cyclic loading is being tested for validation. The material properties and dimension for validation is taken from work by [4] as shown in Table 2 and Table 2. Specimen chose for validation were splice connection in square steel tubular column with splice plates being exactly placed at middle position. The square steel tubular column of size 2245mmx220mmx10mm is taken for validation. High strength type of bolt is chosen with nominal diameter M24, 10.9 grade bolt and the total number of bolts is 64. The splice plate of size 785mmx168mmx14mm is used. For cyclic testing bottom is fixed. At the top degrees of freedom in the vertical direction and rotation direction in the bending plane are released. Element type used is SOLID 186(steel plates).Adaptive meshing is used for modeling. Connector elements BEAM 188(Bolt) is used for modeling bolts[11]. Hence bolts are modeled as 1D beam element. Element size is 12mm.Element shape of meshing is HEXAHERDON with higher order element of 20 nodes. Total deformation, equivalent plastic strain and directional deformation is obtained after analysis using ANSYS workbench 2022 R2.

Table -1: Material properties of 14mm steel plate

Properties	Value	Unit
Young's modulus	219000	MPa
Poisson's ratio	0.3	
Friction coefficient	0.4	
Yield strength	385.2	MPa

Table -2: Material properties of 10mm steel column

Properties	Value	Unit
Young's modulus	210000	MPa
Poisson's ratio	0.3	
Yield strength	405.2	MPa

2.1 Cyclic loading

Loading is applied as per FEMA protocol enlisted in Table 3. As per this protocol 0.375% of drift is given first. Above 2-4% if a structure withstands the load without fail, then the structure is said to be seismically best suited. Hence there is no need to test above 4%. Loading Height = 6.9 / 0.00375 = 1840 mm.

Table-3: Cyclic loading scheme

Load step	Loading displacement(mm)	Cycle number	Storey drift angle(rad)
1	6.9	6	0.00375
2	9.2	6	0.005
3	13.6	6	0.0075
4	18.5	4	0.01
5	27.7	2	0.015
6	36.9	2	0.02
7	55.4	2	0.03
8	73.8	2	0.04

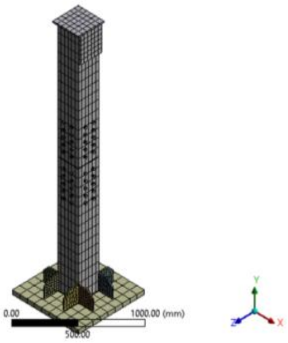

Fig -1: Meshing

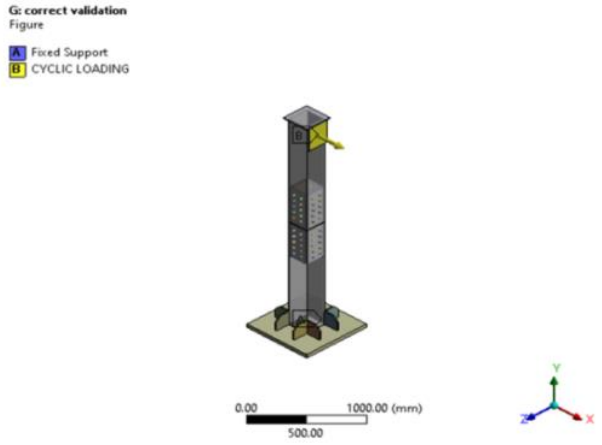

Fig -2: Boundary conditions for cyclic testing

2.2 Analysis

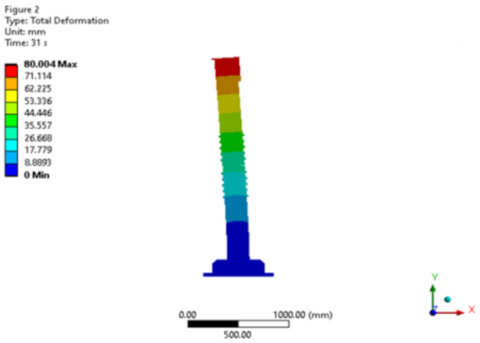

Fig -3: Total deformation

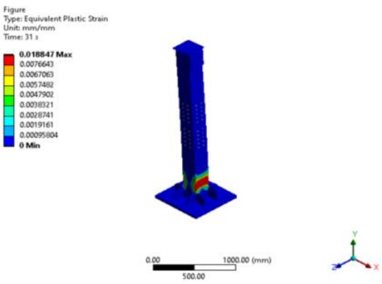

Fig -4: Equivalent plastic strain

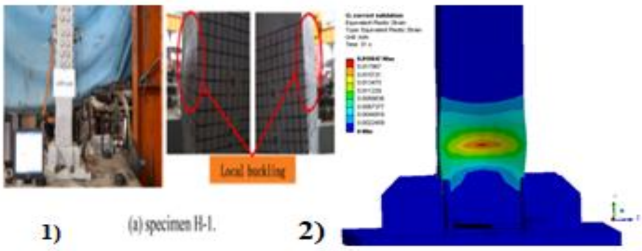

Fig -5: Failure pattern of local buckling from experiment and validation result.

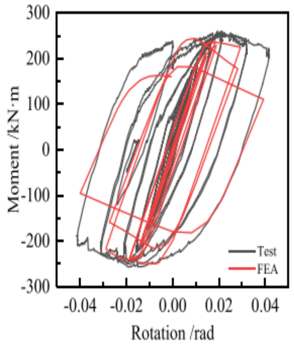

Fig -6: Hyseresis curve obtained from experiment

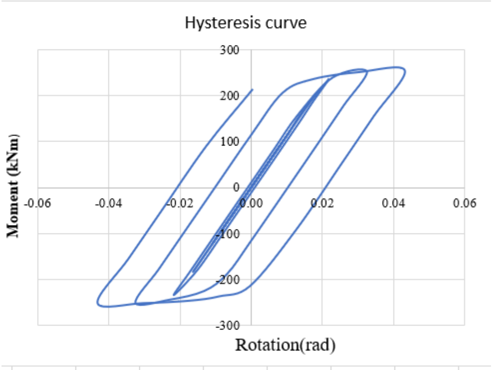

Fig -7: Hyseresis curve obtained from ANSYS software

Table- 4: Validation results after cyclic loading test

	Moment(KNm)	Storey drift(% rad)
Experimental	253.9	4
FEA	251.77	4.1
% error	0.85	2.44

3. Effect of axial loading on square steel tubular column with deconstructable splice joint.

The square steel tubular column with deconstructable splice joint modeled for validation is chosen and tested for axial loading by considering four parameters namely splice thickness, splice length, bolt diameter and bolt pattern. Boundary condition adopted is at top axial load applied and bottom is hinged. Under each parametric study load v/s deflection curve is obtained and studied their failure pattern.

3.1 Effect of axial loading by varying splice thickness

Splice plate of thickness 14mm,12mm, 10mm, 8mm and 6mm are varied and tested.

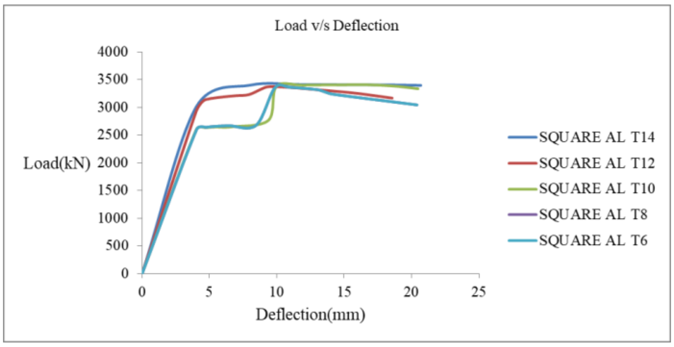

Chart-1: Load v/s Deflection curve by varying splice thickness

Table-5: Ultimate load and ultimate deflection

Splice Thickness	Ultimate Deflection(mm)	Ultimate Load(kN)	%
SQUARE AL T14	12.057	3412	-
SQUARE AL T12	9.82	3374.1	1.11
SQUARE AL T10	15.55	3407.2	0.14
SQUARE AL T8	10.97	3361.9	1.47
SQUARE AL T6	10.97	3361.9	1.47

3.2 Effect of axial loading by varying splice length

Splice plate of length 785mm, 685mm and 585 mm are tested under axial loading.

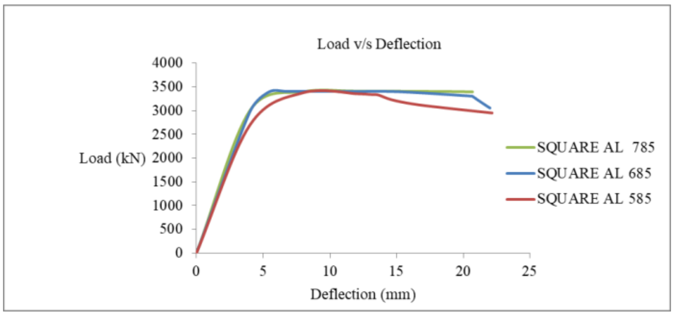

Chart-2: Load v/s Deflection curve by varying splice length

Table-6: Ultimate load and ultimate deflection

Splice Length	Deflection(mm)	Load(kN)	%
SQUARE AL 785	12.057	3412	-
SQUARE AL 685	9.2039	3407.70	0.13
SQUARE AL 585	8.0245	3380	0.94

3.3 Effect of axial loading by varying bolt diameter

Bolt diameters are varied from 24mm, 22mm, 20mm, 18mm and 16mm.

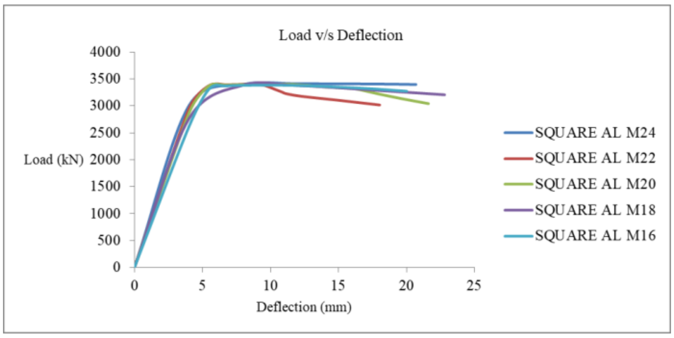

Chart-3: Load v/s Deflection curve by varying bolt diameter

Table-7: Ultimate load and ultimate deflection

Bolt Diameter	Deflection(mm)	Load(kN)	%
SQUARE AL M24	12.057	3412	-
SQUARE AL M 22	8.2853	3401.7	0.30
SQUARE AL M 20	11.125	3403.4	0.25
SQUARE AL M18	8.0181	3384.6	0.80
SQUARE AL M16	8.908	3382	0.88

3.4 Effect of axial loading by varying bolt pattern

Bolt pattern is varied with 64, 48 and 32 numbers of bolt.

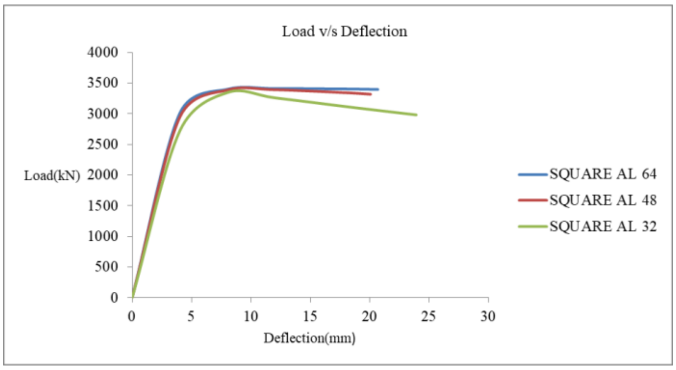

Chart-4: Load v/s Deflection curve by varying bolt pattern

Table-8: Ultimate load and ultimate deflection

Bolt pattern	Deflection(mm)	Load(kN)	%
SQUARE AL 64	12.057	3412	-
SQUARE AL 48	12.035	3392	0.59
SQUARE AL 32	8.038	3347.1	1.90

4. Modelling of elliptical steel tubular column with deconstructable joint

Elliptical steel tubular column with deconstructable splice joint is modeled using square steel tubular as base model. Area of steel is 8424mm^2.Hence the major axis of elliptical column is 340mm and minor axis is 200mm. Material properties of elliptical column and splice plate are similar to square steel tubular column. Modelling is done using ANSYS Design Modeler.

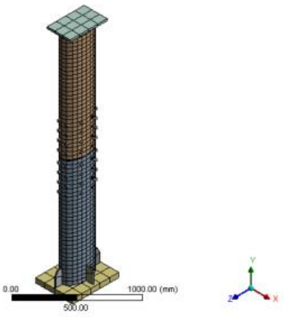

Fig -8: Finite element meshing

4.1 Cyclic testing

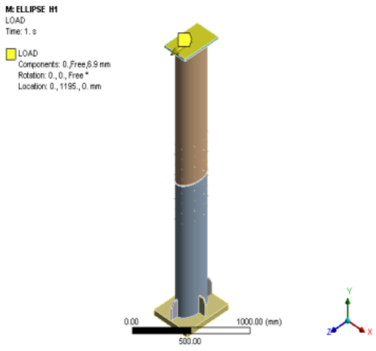

Fig -8: Top loading applied

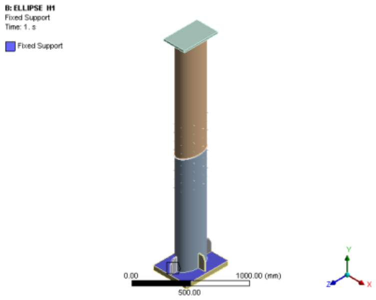

Fig -9: Bottom fixed

4.2 Analysis

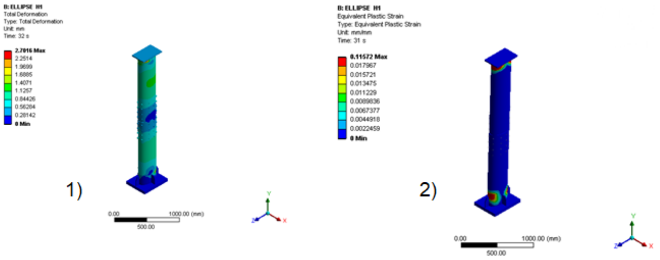

Fig-10: 1)Total deformation 2) equivalent plastic strain

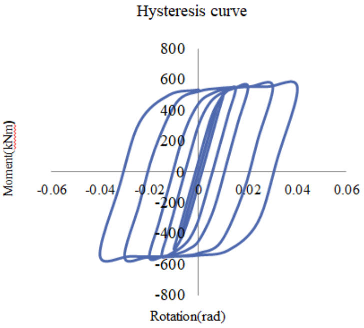

Fig-11: Hysteresis curve obtained after cyclic loading test

5. Effect of axial loading on elliptical steel tubular column with deconstructable splice joint.

Similar to square steel tubular column with deconstructable splice joint, axial testing is done for elliptical cross section considering the four parameters namely splice thickness, splice length, bolt diameter and bolt pattern.

5.1 Effect of axial loading by varying splice thickness

Splice plate of thickness 14mm,12mm, 10mm, 8mm and 6mm are varied and tested.

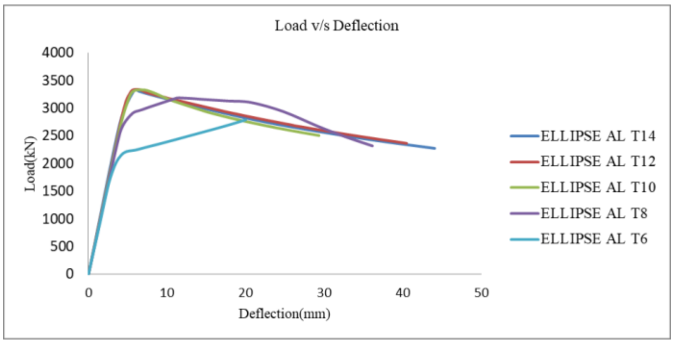

Chart-5: Load v/s Deflection curve by varying splice thickness

Table-9: Ultimate load and ultimate deflection

Splice thickness	Deflection(mm)	Load(kN)	%
ELLIPSE AL T14	5.8008	3321.3	-
ELLIPSE AL T12	6.1365	3341.9	0.62
ELLIPSE AL T10	6.8031	3332	0.32
ELLIPSE AL T8	11.668	3186.6	4.06
ELLIPSE AL T6	20.004	2789.4	16.01

5.2 Effect of axial loading by varying splice length

Splice plate of length 785mm, 685mm and 585 mm are tested under axial loading.

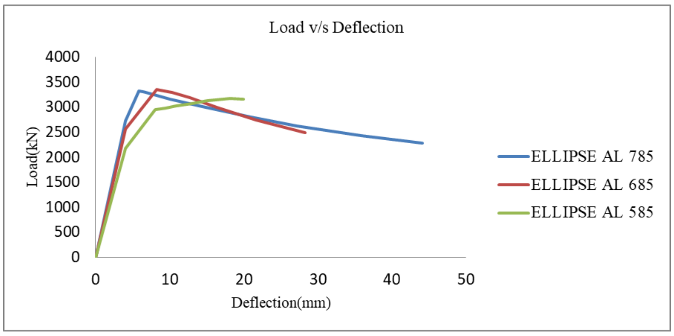

Chart-6: Load v/s Deflection curve by varying splice length

Table-10: Ultimate load and ultimate deflection

Splice length	Deflection(mm)	Load(kN)	%
ELLIPSE AL 785	5.8008	3321.3	-
ELLIPSE AL 685	8.2029	3350.9	0.89
ELLIPSE AL 585	18.16	3179.3	4.28

5.3 Effect of axial loading by varying bolt diameter

Bolt diameters are varied from 24mm, 22mm, 20mm, 18mm and 16mm

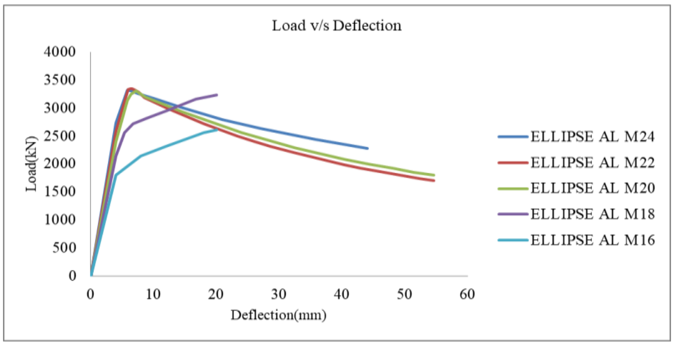

Chart-7: Load v/s Deflection curve by varying bolt diameter

Table-11: Ultimate load and ultimate deflection

Bolt diameter	Deflection(mm)	Load(kN)	%
ELLIPSE AL M24	5.8008	3321.3	-
ELLIPSE AL M 22	6.3236	3342.9	0.65
ELLIPSE AL M20	7.2158	3299.4	0.66
ELLIPSE AL M18	20.004	3237.5	2.52
ELLIPSE AL M16	20.003	2613.2	21.32

5.4 Effect of axial loading by varying bolt pattern

Bolt pattern is varied with 64, 48 and 32 numbers of bolt.

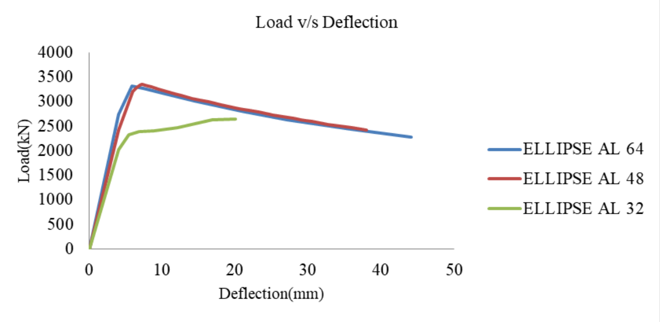

Chart-8: Load v/s Deflection curve by varying bolt pattern

Table-12: Ultimate load and ultimate deflection

Bolt pattern	Deflection(mm)	Load(kN)	%
ELLIPSE AL 64	5.8008	3321.3	-
ELLIPSE AL 48	7.3108	3341.3	0.60
ELLIPSE AL 32	20	2636.7	20.61

6. Interpretation of results

Table-13: Under axial loading

Cross section	Maximum deflection(mm)	Maximum load carrying capacity(kN)	Cases
SQUARE	12.057	3412	14X785XM24 X64
ELLIPTICAL	8.2029	3350.9	14x685XM24 x64

Table-14: Under cyclic testing

Cross section	Bending Moment(kNm)	Storey drift(% rad)
SQUARE	251.77kNm	4.1
ELLIPTICAL	557.58	3

7. Conclusions

Research has been not been done so far by changing the splice and bolt parameters on square and elliptical cross sections of steel tubular columns with deconstructable splice joint. Square cross section shows maximum load carrying capacity of 3412kN under axial loading compared to elliptical section. The structure can withstand up to 12.057mm deflection compared to elliptical section which can withstand only 8.2029mm.Hence more ductility is shown by square section. The steel tubular columns with deconstructable splice connection with maximum load give greater strength. Square sections have a larger moment of inertia than tubular sections. This means that a square section can offer better bending and torsion resistance for a given cross sectional area, making it structurally efficient. When compared to tubular sections, square sections frequently have simpler connection details. The simplicity of linking and connecting square pieces to other structural parts is made possible by their straight edges, which also help to simplify design and construction. For square column cyclic loading test almost gave same results obtained from experiment with 0.8% error and storey drift of 2.44. Maximum bending moment of 251.77kNm and storey drift of 4.1 was obtained from ANSYS software.3-D finite element models were developed and tested for cyclic loading for elliptical cross section which showed maximum moment of 557.58kNm with 3% drift. As per FEMA protocol the structure is seismically stable if it takes about 2-4% of drift. Hence square and elliptical cross sections can withstand seismic action. From the parametric study conducted on square cross section we can conclude that since it is a symmetric section, higher strength case is always shown by the structure with maximum thickness, length, diameter and number of bolts. Overall structural performance is shown by column. When these parameters are reduced load carrying capacity is also reduced. For elliptical cross section(being an unsymmetrical section)maximum strength case is shown with higher thickness, diameter and number of bolts. Splice length of 685 shows more load carrying capacity than 785mm.Under cyclic stresses, steel columns may suffer progressive deformation including local buckling and stiffness loss.

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