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Research on Square and Circular Steel Tubular Columns with Deconstructable Splice Joint Under Cyclic and Axial Testing

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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 when failure occurs. These papers focuses on developing models of square and circular cross sections of steel tubular columns with deconstructable splice joint using a finite element 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 circular cross sections of steel tubular columns with deconstructable splice joints. Bending moment rotation curves were obtained from cyclic load testing for square and circular cross sections.

Keywords: Deconstructable splice joint, local buckling, steel tubular columns

I. 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. 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 circular 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 software and further validated against the experiments, which may serve as an important reference for its use in real-world engineering applications. In cyclic loading tests, the bending moment rotation curves were obtained. Axial loadings were given to square and circular column sections and corresponding ultimate load and deflection curves were plotted.

II. VALIDATION

The material properties and dimension for validation is taken from work by Fan.et.al (2022) [4] as shown in Table 1 and Table 2.Specimen H1 is chose for validation were splice connection is exactly placed at middle position. The square steel tubular column of size 2245mmx220mmx10mm is taken for validation. The type of bolt is M24 10.9 grade bolt and number of bolt is 64.The splice plate of size 785mmx168mmx14mm is used. Boundary condition adopted is bottom fixed and top cyclic load acting. Element type used is SOLID 186(steel plates).Connector elements used is BEAM 188(Bolt).Minimum element size is 12mm.Element shape of meshing is HEXAHERDON. Total deformation, equivalent plastic strain and directional deformation is obtained after analysis using ANSYS workbench 2022 R2.



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| Table 1 | | | |
|--------------------------------------|--------|------|--|
| Material properties of steel column. | | | |
| Properties | Value | Unit | |
| Young's modulus | 219000 | MP | |
| | | а | |
| Poisson's ratio | 0.3 | | |
| Friction | 0.4 | | |
| coefficient | | | |
| Yield strength | 385.2 | MPa | |

| | Table 2 | |
|--------------------------------------|---------|------|
| Material properties of splice plate. | | |
| Properties | Value | Unit |
| Young's modulus | 210000 | MPa |
| Poisson's ratio | 0.3 | |
| Yield strength | 405.2 | MPa |

A. 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 4% if a structure withstand 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 | Cycle | Storey drift |
| | displacement(mm) | number | 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. Mmesh and boundary condition applied









Fig .3. Equivalent plastic strain



(a) specimen H-1.









Fig .6. Hysteresis curve obtained from experiment



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| Table 4 Validation results. | | |
|--------------------------------|-------------|---------------------|
| | Moment(kNm) | Storey drift(% rad) |
| EXPERIMENTAL (Base Journal) | 253.9 | 4 |
| FEA | 251.77 | 4.1 |
| % error | 0.85 | 2.44 |

The ultimate load carrying capacity of the structure from the literature is 3352kN [4] and ultimate load carrying capacity from the validation model is 3561.2kN. The percentage error was found to be 6.34% .hence model is validated.

III. MODELLING AND ANALYSIS OF SQUARE STEEL TUBULAR COLUMN WITH DECONSTRUCTABLE SPLICE JOINT

The square steel tubular column with deconstructable splice joint modeled for validation is taken and tested for axial loading and studied their failure pattern. Bottom hinged and top load is applied.

A. Effect of axial loading by varying thickness of splice plate

| Table 5 Cases for varying thickness. | | |
|---|--|--|
| Thickness of splice plate | Designation | |
| 14mm | SQUARE AL T14 | |
| 12mm | SQUARE AL T12 | |
| 10mm | SQUARE AL T10 | |
| 8mm | SQUARE AL T8 | |
| 6mm | SQUARE AL T6 | |
| E Science AL 114 Tack Sciences Tar 112 (Sciences) Tar 18 8 18 027 18 027 18 027 18 027 18 027 18 027 18 027 18 027 | R. SOMME AL 111 Expanse Mode Danie Trans Europer Marchano Provi 1: 4500000 4500000 4500000 4500000 45000000 45000000000 450000000000 | |



Fig .8. Total deformation and equivalent plastic strain of 14mm splice plate



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Fig. 9. Total deformation and equivalent plastic strain of 12mm splice plate



Fig .10. Total deformation and equivalent plastic strain of 10mm splice plate



Fig .11. Total deformation and equivalent plastic strain of 8mm splice plate



Fig .12. Total deformation and equivalent plastic strain of 6mm splice plate

B. Effect of axial loading by varying length of splice plate

| Cases for varying length. | | |
|---------------------------|---------------|--|
| Length of splice plate | Designation | |
| 785mm | SQUARE AL 785 | |
| 685mm | SQUARE AL 685 | |
| 585mm | SQUARE AL 585 | |

| Table 6 | | |
|---------------------------|-------------|--|
| Cases for varying length. | | |
| Length of splice plate | Designation | |
| 785mm | SQUARE AL 7 | |
| <0.5 | | |



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Fig .13. Total deformation and equivalent plastic strain of splice plate of length 785mm



Fig .14. Total deformation and equivalent plastic strain of splice plate of length 685mm



Fig 15:Total deformation and equivalent plastic strain of splice plate of length 585mm

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C. Effect of axial loading by varying diameter of Bolt

| Table / | | |
|----------------------------------|---------------|--|
| Cases for varying bolt diameter. | | |
| Diameter of bolt | Designation | |
| M24 | SQUARE AL M24 | |
| M22 | SQUARE AL M22 | |
| M20 | SQUARE AL M20 | |
| M18 | SQUARE AL M18 | |
| M16 | SQUARE AL M16 | |



Fig .16. Total deformation and equivalent plastic strain of bolt diameter M24



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Fig .17. Total deformation and equivalent plastic strain of bolt diameter M22



Fig .16.Total deformation and equivalent plastic strain of bolt diameter M20



Fig .17. Total deformation and equivalent plastic strain of bolt diameter M18



Fig. 18. Total deformation and equivalent plastic strain of bolt diameter M16

D. Effect of Axial Loading by Varying bolt Pattern

| Table 8 | | |
|---------------------------------|--------------|--|
| Cases for varying bolt pattern. | | |
| Bolt pattern | Designation | |
| 64 bolts | SQUARE AL 64 | |
| 48 bolts | SQUARE AL 48 | |
| 32 bolts | SQUARE AL 32 | |



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Fig .19. Total deformation and equivalent plastic strain of 64 number of bolts



Fig .20. Total deformation and equivalent plastic strain of 48 number of bolts



Fig .21. Total deformation and equivalent plastic strain of 32 number of bolts

IV. MODELING AND ANALYSIS OF ELLIPTICAL STEEL TUBULAR COLUMN WITH DECONSTRUCTABLE SPLICE JOINT

Circular steel tubular column with deconstructable splice joint is modeled using square steel tubular as base model. Area of steel is 8424mm².Diameter is 103.56mm. Material properties of column and splice plate are similar to square steel tubular column. For axial testing bottom hinged and top load applied.



Fig .22. Boundary condition for axial testing





Fig 23:Finite element meshing

A. Cyclic loading

Boundary condition is bottom fixed and top cyclic load applied. Similar to square cross section cyclic loading is applied as per FEMA protocol.



Fig .24. Bottom fixed support



Fig .25. Top cyclic load applied





Fig .28. Hysteresis curve obtained after cyclic testing

B. Effect of axial loading by varying thickness of splice plate

| Table 9 | | |
|------------------------------|-----------------|--|
| Cases for varying thickness. | | |
| Thickness of splice plate | Designation | |
| 14mm | CIRCULAR AL T14 | |
| 12mm | CIRCULAR AL T12 | |
| 10mm | CIRCULAR AL T10 | |
| 8mm | CIRCULAR AL T8 | |
| 6mm | CIRCULAR AL T6 | |





Fig .29. Total deformation and equivalent plastic strain of 14mm splice plate



Fig .30. Total deformation and equivalent plastic strain of 12mm splice plate



Fig .31. Total deformation and equivalent plastic strain of 10mm splice plate



Fig .32. Total deformation and equivalent plastic strain of 8mm splice plate



Fig .33.Total deformation and equivalent plastic strain of 6mm splice plate



C. Effect of Axial Loading by varying length of splice plate

| Table 10 | | |
|---------------------------|-----------------|--|
| Cases for varying length. | | |
| Length of splice plate | Designation | |
| 785mm | CIRCULAR AL 785 | |
| 685mm | CIRCULAR AL 685 | |
| 585mm | CIRCULAR AL 585 | |



Fig .34. Total deformation and equivalent plastic strain of splice plate of length 785mm



Fig .35. Total deformation and equivalent plastic strain of splice plate of length 685mm



Fig. 36. Total deformation and equivalent plastic strain of splice plate of length 585mm

D. Effect of Axial Loading by Varying Diameter of Bolt

| Table 11 | | |
|----------------------------------|-----------------|--|
| Cases for varying bolt diameter. | | |
| Diameter of bolt | Designation | |
| M24 | CIRCULAR AL M24 | |
| M22 | CIRCULAR AL M22 | |
| M20 | CIRCULAR AL M20 | |
| M18 | CIRCULAR AL M18 | |
| M16 | CIRCULAR AL M16 | |





Fig .37. Total deformation and equivalent plastic strain of bolt diameter M24



Fig. 38. Total deformation and equivalent plastic strain of bolt diameter M22



Fig .39. Total deformation and equivalent plastic strain of bolt diameter M20



Fig .40. Total deformation and equivalent plastic strain of bolt diameter M18



Fig .41. Total deformation and equivalent plastic strain of bolt diameter M16



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E. Effect of Axial Loading by Varying bolt Pattern

| Table 12 | | |
|---------------------------------|----------------|--|
| Cases for varying bolt pattern. | | |
| Bolt pattern | Designation | |
| 64 bolts | CIRCULAR AL 64 | |
| 48 bolts | CIRCULAR AL 48 | |
| 32 bolts | CIRCULAR AL 32 | |



Fig .42. Total deformation and equivalent plastic strain of 64 number of bolts



Fig .43. Total deformation and equivalent plastic strain of 48 number of bolts



Fig .44. Total and equivalent deformation plastic strain of 32 number of bolts

V. RESULTS

From the analysis carried out using ANSYS WORKBENCH 2022 R2 ultimate load and corresponding deformations were plotted.

A. For Square Cross section



Fig .45. Load v/s Deflection curve for varying splice thickness

3361.9

3361.9



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1.47

1.47

| ltim | ate load and ultimate | e deflection for var | rying thick | ness of splice | pl |
|------|-----------------------|----------------------|-------------|----------------|----|
| | Splice thickness | Deflection(m | Load(k | % | |
| | | m) | N) | | |
| | SQUARE AL | | | | |
| | T14 | 12.06 | 3412 | - | |
| | SQUARE AL | | | | |
| | T12 | 9.82 | 3374.1 | 1.11 | |
| | SQUARE AL | | | | |
| | T10 | 15.55 | 3407.2 | 0.14 | |

10.97

10.97

SQUARE AL T8

SQUARE AL T6

Table 13 U ate.



Fig .46.Load v/s Deflection curve for varying splice length

Table 14

Ultimate load and ultimate deflection for varying length of splice plate. Deflection(mm) Splice Length Load(kN) % **SQUARE** AL785 12.057 3412 _ SQUARE AL 9.2039 685 3407.70 0.13 SQUARE AL

0.94 585 8.0245 3380



Fig .47. Load v/s Deflection curve for varying bolt diameter



| Ultimate load and ultimate deflection for varying diameter of bolt. | | | |
|---|----------------|----------|------|
| 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 |





Fig .48. Load v/s Deflection curve for varying bolt pattern

| Table 16 | | | |
|---|----------------|----------|------|
| Ultimate load and ultimate deflection for varying bolt pattern. | | | |
| 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 |

B. For Circular Cross Section



Fig . 49. oad v/s Deflection curve for varying splice thickness

| Table 17 | |
|---|-----|
| Ultimate load and ultimate deflection for varying thickness of splice pla | ite |

| erunnae roue and arannare denoeden for varying anomioss of spree prace | | | |
|--|----------------|----------|-------|
| Splice thickness | Deflection(mm) | Load(kN) | % |
| CIRCULAR AL T14 | 8.0574 | 2503.5 | - |
| CIRCULAR AL T12 | 6.6893 | 2423.4 | 3.20 |
| CIRCULAR AL T10 | 6.6123 | 2357.8 | 5.82 |
| CIRCULAR AL T8 | 6.2034 | 1991.8 | 20.44 |
| CIRCULAR AL T6 | 20.426 | 2048.2 | 18.19 |





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Table 18

Ultimate load and ultimate deflection for varying length of splice plate.Splice LengthDeflection(mm)Load(kN)%CIRCULAR4.17858.05742503.5-CIRCULAR AL68512.8732520.40.68

1575.8

37.06

CIRCULAR AL 585



20.034

Fig .51. Load v/s Deflection curve for varying bolt diameter

 Table 19

 Ultimate load and ultimate deflection for varying diameter of bolt.

| Bolt Diameter | Deflection(mm) | Load(kN) | % |
|------------------|----------------|----------|-------|
| CIRCULAR AL M24 | 8.0574 | 2503.5 | - |
| CIRCULAR AL M 22 | 18.13 | 2438.8 | 2.58 |
| CIRCULAR AL M 20 | 20.03 | 1976.6 | 21.05 |
| CIRCULAR AL M18 | 20.03 | 1532.9 | 38.77 |
| CIRCULAR AL M16 | 20.02 | 1170.8 | 53.23 |



Fig .48.Load v/s Deflection curve for varying bolt pattern



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| Bolt pattern | Deflection(mm) | Load(kN) | % |
|----------------|----------------|----------|-------|
| CIRCULAR AL 64 | 8.0574 | 2503.5 | - |
| CIRCULAR AL 48 | 8.5809 | 2455.8 | 1.91 |
| CIRCULA AL 32 | 20.031 | 1997.1 | 20.23 |

Table 20. Ultimate load and ultimate deflection for varying bolt pattern.

VI. **INTERPRETATION OF RESULTS**

| Table 21. Maximum strength case under axial loading | | | |
|---|-------------------|---------------|--|
| Cross section | Maximum load | Cases | |
| | carrying capacity | | |
| SQUARE | 3412kN | 14x785XM24x64 | |
| CIRCULAR | 2520.4kN | 14x685XM24x64 | |

VII. CONCLUSION

- 1) Finite element analysis is an effective method to study the behavior of the connections.
- 2) The tubular columns with deconstructable splice connection with maximum load give greater strength. The section with maximum deflection gives greater ductility.
- 3) 3-D finite element models were developed and tested for cyclic loading for circular cross section which showed maximum moment of 277.67kNm with 3% drift.
- For square column cyclic loading test almost gave same results obtained from experiment using Specimen H1 with 0.8% error 4) in moment and storey drift of 2.44. Maximum bending moment of 251.77kNm and storey drift of 4.1 was obtained from software.
- 5) Studied the axial behavior of square and circular steel tubular columns with deconstructable splice joint. Columns showed local buckling in most cases. Square section has maximum load carrying capacity of 3412kN.
- 6) From the parametric study conducted on square and circular cross section of steel tubular column with deconstructable splice joint, we can conclude that variation of splice and bolt parameters affect the strength, stiffness and ductile characteristics of column section. Going beyond materials ultimate strength can result in failure, such as buckling or excessive deformation.

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