

# Numerical Investigation on Aluminium Alloy Stub Columns with Openings

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**ABSTRACT:** This study primarily focuses on the numerical investigation of aluminum alloy square hollow section (SHS) stub columns. The total service life of steel stub columns as an impact of corrosion is limited to 10 years particularly for the buildings in the marine and industrial environments. The 6061T6 aluminium alloy columns are studied so as to suggest as an alternative for steel stub columns. The column strengths obtained from the numerical investigation of both Aluminium alloy and Steel hollow stub columns are compared. The effect of opening size on the structural behaviour of perforated aluminum alloy stub columns were evaluated. The effect of thickness of columns are analysed numerically using ANSYS 15. The shape and position of openings on columns are also studied. The 6061T6 aluminium alloy stub columns are found to offer better structural behaviour and hence can be suggested as an alternative for steel stub columns.

**KEYWORDS:** Stub column, Square hollow sections, Aluminium alloy, Effect of openings, Axial loading.

## I. INTRODUCTION

Aluminum alloy structural members are increasingly used in space structures, curtain walls, bridges, and many other structural applications owing to their high strength-to-weight ratio, excellent corrosion resistance, attractive appearance, and ease of extrusion, transportation, and assembly. Generally, aluminium is attractive in many applications, because of a favourable life-cycle cost, which is given by the sum of the initial cost of the finished product, the cost of operating or maintaining the product over its life and the cost of disposing of or recycling it after its useful life. In addition, aluminium has sustained and increased its use in many fields, partly because the price for aluminium relative to that for steel and its lightness. The specific weight is  $\rho = 2700 \text{ kg/m}^3$ , equal to one-third that of steel. Corrosion resistance. The exposed surface of aluminium combines with oxygen to form a thin inert aluminium oxide film which blocks further oxidation. Contrary, steel must be always corrosion protected in any kind of environment. From the point of view of mechanical resistance, aluminium alloys series form a big family of materials, where the elastic limit widely varies from 30 N/mm<sup>2</sup> (pure aluminium) to 500 N/mm<sup>2</sup> and the ultimate elongation in many cases, but not always, lies in a suitable or for structural applications.

Currently, openings are commonly introduced in structural members to facilitate building services and inspection, such as piping, electric wiring, heating conduits, plumbing, repair, and maintenance work of buildings. These openings are typically prepunched perforations, which result in a redistribution of membrane stresses within the members that may alter the elastic stiffness and ultimate strength of a structural member. The shape, size, location, and number of openings greatly influence the behavior of structural members with perforations. To facilitate the use of aluminum alloy structural members, design guidelines should be prepared for perforated aluminum alloy stub columns. This study primarily focuses on the experimental investigation of aluminum alloy square hollow section (SHS) stub columns containing different openings at mid height of the columns [1].

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## II. RELATED WORK

Ran Feng<sup>1</sup> and Ben Young conducted test program on a wide range of aluminum alloy square hollow section stub columns containing central circular openings and it showed that most of the current design rules for perforated carbon steel structural members are inappropriate for the design of perforated aluminum alloy stub columns[1]. H.X. Yuan, Y.Q.Wang, T.Chang, X.X.Du, Y.D.Bu, Y.J.Shi carried out an experimental programme to investigate the local buckling and post buckling strengths of aluminium alloy I-section stub columns and was revealed that the predicted compressive strengths from the four design standards were generally conservative [2]. A test program was performed on aluminum alloy columns of square and rectangular hollow sections that were compressed between fixed ends by Ji-Hua Zhu and Ben Young and was found that the design strengths predicted by the American and Australian/New Zealand specifications are generally conservative, whereas the design strengths predicted by the European Code are relatively quite conservative[3]. An experimental investigation was performed on aluminum alloy circular hollow sections in combined axial compression and bending by Ji-Hua Zhu and Ben Young and Axial load versus moment interaction curves were plotted for each test series. It was shown that the bending capacities and beam-column design strengths predicted by the three specifications are generally conservative[4]. H.X. Yuan a,n, Y.Q.Wang a, Y.J.Shi a, L.Gardner on testing twenty eight stub columns of two stainless steel alloys in pure axial compression it was demonstrated that the predicted strengths from EN 1993-1-4 provisions were generally conservative, while both the CSM and the DSM predicted values were closer to the test strengths[5]. L. Gardner and D. A. Nethercot through their study describes numerical modeling of the structural response of stainless steel hollow sections, ultimate load was predicted to within 3% and with a low standard deviation; deformation at ultimate load was within 6%, but exhibited a higher standard deviation; and the general form of the load deformation response and the failure modes were similar[6]. These tests were carried out by James A. Swanson and Roberto T. Leon as part of a SAC Phase II project in order to provide insight into the behaviour, failure modes, and ductility of these components. The main variables tested include the size of the T-stub, the gauges of the bolts, and the type and diameter of the bolts. The results indicate that current design equations provide conservative estimates of the ultimate strength of the Stubs but that they are not necessarily good predictors of the governing failure modes[7]. Yi Zheng, Tsutomu Usami and Hanbin Ge focused on the ductility capacity of thin-walled steel box stub-columns with or without longitudinal stiffeners. Combined compression and bending loads are applied to the stub-columns to simulate the loading condition under horizontal earthquake actions[8].

Demaio Yang and Gregory J. Hancock through their study describes a series of compression tests performed on stub columns fabricated from cold-formed high strength steel plates with nominal yield stress of 550 MPa. The tests include lipped-square and hexagonal sections, including 94 box-shaped fix-ended stub columns. The purpose of these tests was to determine the influence of low strain hardening of G550 steel on the compressive section capacities of the column members and as expected, the greatest effect of low strain hardening was for the stockier sections where material properties play an important role[9]. K. J. R. Rasmussen and G. J. Hancock presented compression tests on square and circular stainless steel tubes, including stub column and long column tests and the It is demonstrated that the proposed design procedure provides column strengths that are much closer to the test strengths than design strengths based on the annealed material properties[10]. Hasan Abdulhadi Ajel , Abdunnasser M. Abbas considered the effect of concrete compressive strength, thickness of steel tube, stiffeners and longitudinal reinforcement through their study and was shown that the results obtained from finite element solution convergence between analytical and experimental failure load varied from 2 to 15 % [11]. 49 stub columns fabricated from 35XF sheet steel and 48 stub columns fabricated from 50XF sheet steel are studied experimentally and analytically under different strain rates by M. Kassar, C. L. Pan and W. W. Yu and was found that It is found that better agreement can be achieved between the predicted and tested stub column strengths when using the dynamic yield stresses and considering the effect of cold work[12].

## III. RESEARCH SIGNIFICANCE

Stub columns offers better resistance to buckling. Steel stub columns are found to provide less service life and also prove to be uneconomical as an impact of corrosion on steel structures. This study aims to highlight the importance of

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hollow stub columns and also suggests Aluminium alloy hollow stub columns as an alternative for steel hollow stub columns. Structural properties of hollow Steel stub columns and 6061 T6 Aluminium alloy stub columns are compared. The effect of shape, size and position of openings are also studied.

## IV. NUMERICAL INVESTIGATION

### Model

The numerical study involves modeling, analysis and comparison of SHS of both 6061T6 aluminium alloy stub columns and Mild steel stub columns of cross section 150×150 mm with a height of 450 mm. The thickness being a critical parameter considered in the study, a range of thickness were initially provided and an optimum thickness was obtained using ANSYS 15. The specimen with the optimum thickness were then provided with different openings and were evaluated using ANSYS15.

### Material Properties

Table-1 Properties of materials

Properties	Material	
	6061T6 Aluminium alloy	Mild steel
Tensile strength	340 MPa	250 MPa
Yield strength	310 MPa	248 MPa
Modulus of elasticity	69000 MPa	2×10 <sup>5</sup> MPa
Density	270 g/cc	7.85 g/cc
Poisson's ratio	0.35	0.3

### Thickness Optimization

SHS of both 6061T6 Aluminium alloy and SHS of mild steel were considered for the study. The specimens were of 150×150mm in cross-section with 450mm height. Different thicknesses of 2mm,4mm,6mm,8mm and 10mm were used for the analysis where the properties were assigned as per table-1. Thickness optimization was applied to obtain the optimum thickness by setting thickness and deformation as parameters and by limiting their minimum values as the bound values.

### Specimen Dimension

Table-2 Specimen Dimensions

6061 T6 Aluminium alloy	Steel specimen
AL 150×150×450×2 mm	ST 150×150×450×2 mm
AL 150×150×450×4 mm	ST 150×150×450×4 mm
AL 150×150×450×6 mm	ST 150×150×450×6 mm
AL 150×150×450×8 mm	ST 150×150×450×8 mm
AL 150×150×450×10 mm	ST 150×150×450×10 mm

### Optimization Output

Candidate Points			
	Candidate Point 1	Candidate Point 2	Candidate Point 3
P1 - thickness (mm)	★ 4.468	★ 5.028	— 5.588
P2 - Total Deformation Maximum (mm)	★ 1.5843	★★ 1.4137	★★★ 1.2772

Fig.1. Optimization output for 6061 T6 Aluminium alloy

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Candidate Points			
	Candidate Point 1	Candidate Point 2	Candidate Point 3
P2 - thickness (mm)	★ 4.468	★ 5.028	— 5.588
P1 - Total Deformation Maximum (mm)	★ 0.54317	★★ 0.48463	★★ 0.43774

Fig.2.Thickness optimization output for Mild Steel specimen

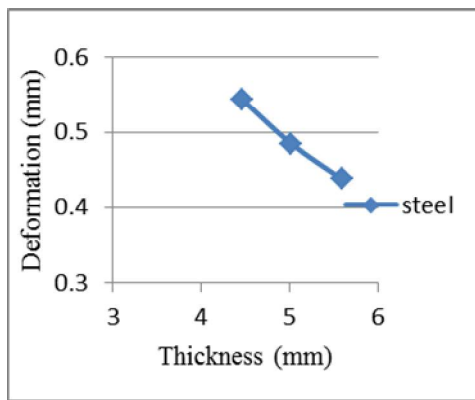


Fig.3.Thickness optimization graph of MS of 6061T6

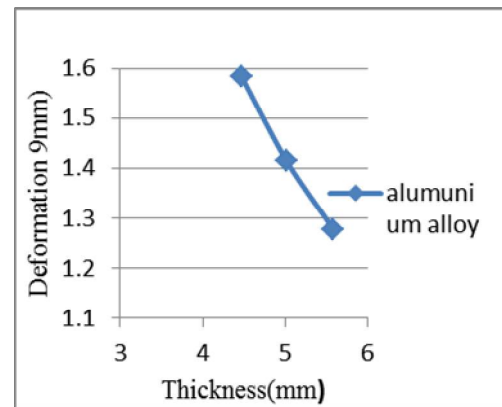


Fig.4.Thickness optimization graph

## Optimization Results

For both the 6061 T6 aluminium alloy specimens and steel specimens, modeled and analysed as per dimensions in table2,the optimized thickness corresponding to lower deflection of 1.2772 mm was obtained at 5.588 mm(fig.1 and fig.4) for aluminium alloy specimens and the steel specimens were also optimized to a thickness of 5.58 mm for a minimum deflection of 0.043774 mm(fig.2 and fig.3). **Hence the specimen adopted is 150× 150 × 450 × 6 mm.**

## Model Analysis

The specimen of dimension 150×150×450 mm with a thickness of 6 mm were analysed and were provided with different openings.

### Analysis of Specimen without openings

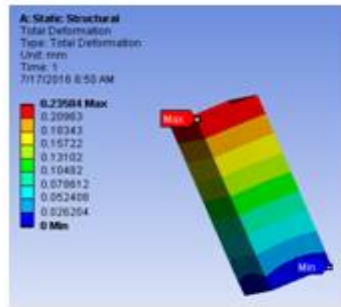


Fig. 5. Deformation of 6061

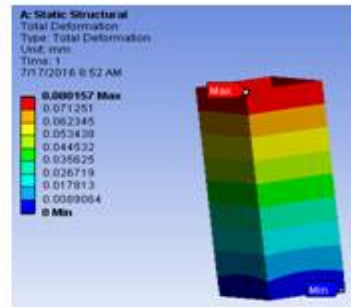


Fig. 6. Deformation of Mild steel specimen

Table-3 Ultimate load obtained from analysis

Thickness(mm)	Ultimate Load (kN)	
	Aluminium alloy	Steel
2 mm	490	462
4 mm	580.48	550.36
6 mm	632	610
8 mm	650.4	635
10 mm	710.32	690.16

From the analysis of both Aluminium alloy specimen and steel specimen (fig.5 and fig.6) of different thicknesses it can be seen that the load carrying capacity (table-3) of 6061T6 aluminium alloy is higher than that of Steel specimens. Hence aluminium alloy specimens are further analysed to study the effect of different openings.

### Openings

Openings are commonly introduced in structural members to facilitate building services and inspection piping, electric wiring, heating conduits, plumbing, repair, and maintenance work of buildings. These openings are typically prepunched perforations, which result membrane stresses that alter elastic stiffness and ultimate strength of a structural member. The shape, size, location, and number of openings greatly influence the behavior of structural members with perforations [1].

Table- 4 Specimen dimensions

Description	Model	Cross Section(Mm)	Height(mm)	Thickness(mm)	Opening Size	
Column without opening	A	150× 150	450	6		
Column with opening	Rectangular	B	150× 150	450	6	Length :55mm Width :35mm
	Square	C	150× 150	450	6	Side : 44mm
	Triangular	D	150× 150	450	6	Base :31mm Height :31mm
	Circular	E	150× 150	450	6	Diameter:50mm
	Hexagonal	F	150× 150	450	6	Side : 27mm

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### Optimization of position for openings to be provided

Candidate Points			
	Candidate Point 1	Candidate Point 2	Candidate Point 3
P1 - Plane4.H13 (mm)	225	207.33	189.48
P2 - Total Deformation Maximum (mm)	★★★ 0.35359	★★★ 0.3553	★★★ 0.35985

Fig.7:Optimisation output for specimen with Circular Opening

Table-5 Optimisation output for specimen with different Openings

Specimen	Optimum height for the openings to be provided
Circular Opening	225
Square Opening	225.02
Triangular Opening	22
Hexagonal Opening	225.01
Rectangular Opening	225

The openings of different shapes were provided as per the dimensions given in table-4. From optimization of position for the openings it can be seen from fig.7 that minimum deformation of 0.353mm is obtained at about the midheight of the column provided with circular opening. Similarly from table-5, for the columns with other openings also minimum deformation is obtained at about the midheight of the columns. Hence the different openings circular, rectangular, square, hexagonal and triangular are provided at a depth of 225mm.

### Analysis of Aluminium alloy specimen with openings

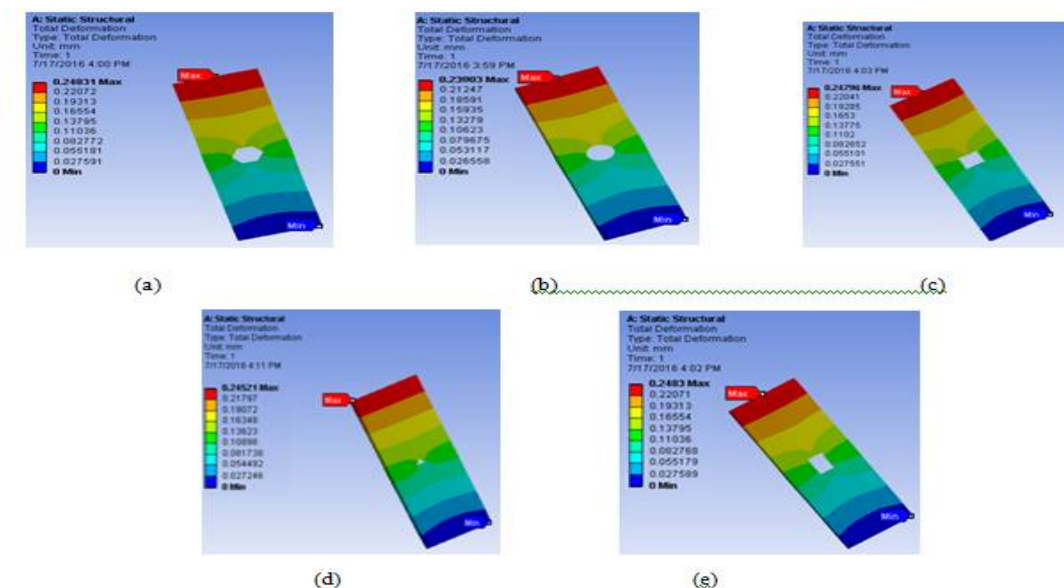


Fig.8. Deformation diagram for Aluminium alloy specimen with (a) Hexagonal,(b)Circular,(c)Square,(d)Triangular and (e) Rectangular Openings



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## V.SIMULATION AND RESULTS

Table-6 Yield load for specimen with different openings

Column designation	Specimen	Yield load (kN)	Ultimate Load(kN)
AH	Without opening	491	632
AHC	Square opening	482	624
AHT	Rectangular opening	473	593
AHS	Triangular opening	468	572
AHR	Hexagonal opening	432	556
AHH	Circular opening	428	544

From numerical analysis using ANSYS15,  $150 \times 150 \times 450 \times 6 \text{ mm}$  is found to be the optimized specimen dimension. The optimum position for providing openings was found at the midheight of the specimen. Ultimate load for aluminium alloy specimen with different openings were compared(table-6) and the specimen with circular opening is obtained as the one with higher ultimate strength and least deformation.

## VI.CONCLUSION

Numerical and experimental investigation on 6061 T6 aluminium alloy stub columns proved to perform better in comparison to the steel sub columns. The study also shows that openings provided at mid height have better load carrying capacity. Out of different openings provided, circular openings are better in its performance with greater ultimate load and least deformations. Whereas specimens hexagonal openings are the poorest.

Corrosion being detrimental to the steel stub columns, the requisite service life of steel buildings in industrial environments have reduced to less than 10 years and also causes economic and environmental losses. From the Numerical studies it can be stated that 6061 T6 aluminium alloy with its higher ultimate strength and other properties can be suggested as an alternative for steel stub columns that overcomes the economic aspect as well. The effects of different openings provided are also evaluated numerically. The specimen with circular openings offers least deformation and greater load carrying capacity.

## REFERENECES

- [1] Ran Feng and Ben Young, "Experimental Investigation of Aluminum Alloy Stub Columns with Circular Openings", American Society of Civil Engineers ISSN 0733-9445/04015031(10),04015031(1-10)2015.
- [2] H.X. Yuan, Y.Q.Wang , T.Chang , "Local buckling and post buckling strength of extruded aluminium alloy stub columns with slender I-sections" ScienceDirect Thin-WalledStructures90,pp.140–149, 2015.
- [3] Ji-Hua Zhu1 and Ben Young, "Tests and Design of Aluminum Alloy Compression Members" Journal of Structural Engineering, Vol. 132, Vol. 132, ISSN 0733-9445/2006/7-1096–1107,2006.
- [4] Ma Ji-Hua Zhu, Ben Young, "Aluminum alloy circular hollow section beam-columns" Thin-Walled Structures 44 (2006) 131–140.
- [5] H.X. Yuan,Y.Q.Wang, Y.J.Shi a, L.Gardner, "Stub column tests on stainless steel built-up sections"; IJRET: International Journal of Research in Engineering and Technology eISSN: 2319-1163 |pISSN: 2321-7308,pp.1-14, 2013.
- [6] L. Gardner1 and D. A. Nethercot, "Numerical Modeling of Stainless Steel Structural Components—A Consistent Approach"; Thin-WalledStructures96(2015)105–119 2009
- [7] By James A. Swanson1 and Roberto T. Leon, "Bolted Steel Connections" Journal of Structural Engineering, Vol. 126,pp.50-56, 2000.
- [8] By Yi Zheng, Tsutomu Usami, and Hanbin GeDemao Yang and Gregory J. Hancock, "Ductility Of Thin-walled Steel Box Stub-columns"; Journal of Structural Engineering, Vol. 129,pp.1304-1311,2000.
- [9] Demao Yang and Gregory J. Hancock, "Compression Tests of Cold-Reduced High Strength SteelSections. I: Stub Columns" Vol.130, ISSN 0733-9445/00/0011-1304–1311,pp.1772-1781,2004.
- [10] K. J. R. Rasmussen and G. J. Hancock J, "Design Of Cold-Formed Stainless Steel Tubular Members. H Columns". Struct. Eng., Vol. 119, ISSN 0733-9445/93/0008,pp.2349-2367,2005.
- [11] Hasan Abdulhadi Ajel, Abdulnasser M. Abbas,"Experimental and Analytical Investigations of Composite Stub Columns"Science Direct ,Thin-Walled Structures 68 Vol. 4, Issue 2,pp.185-200,2013.
- [12] Be By M. Kassar,1 C. L. Pan,2 and W. W. Yu, "Effect Of Strain Rate On Cold-Formed Steel Stub Columns" ASCE ,Vol. 118,ISSN 0733-9445/92/0011,pp.3151-168,2009.