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Behavior of concrete-filled stub columns confined with cold formed steel under axial compression: A comparative review

Pranoy Roy [a], Amiya Kumar Samanta [b]

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Abstract

Concrete-filled steel tubes (CFST) as composite has been appreciated around the globe due to higher bearing capacity, slender sections, enlarged energy retention, smooth erection and easy construction. The composite action between the hollow tube and the concrete core enhances the compressive strength and ductility. Steel tube local buckling is limited by the infilled concrete. However, these effects are influenced by some of the factors like the column cross-section, section slenderness ratio, class of concrete and thickness of the confining material.

Hence it is attempted to study the behavior of concrete packed stub columns with cold formed confinement under axial compression. Relevant high quality journals were collected and reviewed and the data of around 300samples were suitably analyzed during this study. An extensive parametric lookout is carried out to estimate the key-factors including slenderness ratio, shape and thickness of confining material on the axially compressed samples. Moreover the prediction of various available codes are also considered to find their relevance in regards to the peak loading of the specimen. The study concludes good agreement of the prediction by Eurocode-4 as compared to other codes. However in a certain range the prediction of other codes are quite satisfactory.

Introduction

Columns transfer the loads to foundation. Concrete widens laterally under compression, creating vertical cracks leads to failure in concrete due to crushing or buckling of columns. Also, in concrete structure exposed to marine environments fails due to deterioration of concrete.

Strengthening of RC structures by confining the concrete loads to restrictions in concrete side movement exerting ductile failure of concrete. Materials like steel tube, PVC tube, fibre tubes are commonly used as a confining material.

Hence the behavior of concrete-packed stub columns with cold formed confined steel under axial compression is studied. An extensive parametric study including slenderness ratio, shape and thickness of confining material on the peak load of the axially compressed specimen is carried out. Moreover the prediction of various available codes including ANSI/AISC 360-10 (USA), BS5400 (UK), Eurocode 4, DBJ-2010 (China), Australian code AS5100, Japanese Code AIJ-2008, proposed provision of Z. Vrcelj and B. Uy (PVrcelj) and design characteristics by Liu et al. are also considered. IS456 can estimate the axial load of short and long columns, whereas there is no provision for the ultimate load carrying capacity of long and short columns with exterior confinement. Hence the use of foreign codes is incorporated in this study.

Section snippets

Use of square and rectangular cold formed sections as confinement to concrete

Y. Ouyang and A.K.H. Kwan (2018) [1] studied the expansion and triaxial characteristics of constricted concrete and concrete-steel interface characteristics on square concrete filled steel tubed (CFST) specimens with various concrete mix, steel yield strength and depth-to-thickness ratio of tube. The confined specimens had increased axial load capacity than the capacities of concrete section and the steel independently.

A. Zhu et al. (2017) [2] investigated concrete packed cold formed steel stub …

Methodology

Parameters for study of selected samples from journal papers:

The samples are categorized based on their shape, thickness of confining steel and grade of concrete.…

Relationship *between thickness of confining material (Steel) and the Ultimate loading Capacity*

The relationship between thickness of confining steel and the ultimate loading capacity of the specimens is shown for square, rectangular, circular, elliptical and oval columns. Based on the grade of infill concrete where medium strength concrete is for concrete below 50Mpa whereas concrete above 50Mpa is considered as high strength concrete. The relationship between the thickness of confining steel and the ultimate load carrying capacity is showcased in Fig. 1.…

Relationship within slenderness ratio and the Ultimate loading Ratio

The relationship within the…

Conclusion

The following interpretations are drawn from this study:

- Confinement of concrete stub columns improves the load carrying capacity of the column and prevents bond failure.…
- Buckling is the primary mode of failure of the confined specimens.…
- Finite element software can accurately predict the failure mode and failure load of confined specimens.…
- Circular columns have more load carrying scope as compared to oval or elliptical columns, square and rectangular columns being the least.…
- The projection of axial…

…

CRediT authorship contribution statement

Pranoy Roy: Conceptualization, Methodology, Investigation, Writing – original draft. **Amiya Kumar Samanta:** Supervision, Writing – review & editing.…

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

Acknowledgements

This study is conducted with the help of laboratory and internet services of NIT Durgapur.…

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finite element analysis of square concrete-filled steel tube (CFST) columns under axial compressive load
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behavior of square tubed steel reinforced-concrete (SRC) columns under eccentric compression
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M.V. Chitawadagi *et al.*
axial capacity of rectangular concrete-filled steel tube columns - DOE approach
Constr. Build. Mater. (2010)

Y. Wang *et al.*
behaviour of concrete-filled corrugated steel tubes under axial compression
Eng. Struct. (2019)

L. He *et al.*
experimental study on axially compressed circular CFST columns with improved confinement effect
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J. Liu *et al.*
axial stress-strain behavior of high-strength concrete confined by circular thin-walled steel tubes
Constr. Build. Mater. (2018)

F. Zhou *et al.*
experimental investigation of concrete-filled single-skin and double-skin steel oval hollow section stub columns
Thin-Walled Struct. (2019)

H. Yang *et al.*
behaviours of concrete-filled cold-formed elliptical hollow section beam-columns with varying aspect ratios
Thin-Walled Struct. (2017)

Z. Vrcelj *et al.*
strength of slender concrete-filled steel box columns incorporating local buckling
Constr. Steel Res. (2002)

Construction and Building Materials, Volume 177, 2018, pp. 366-377

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Research article

Cyclic behavior and ultimate bearing capacity of circular concrete-filled double skin steel tube members subjected to combined compression and torsion

Thin-Walled Structures, Volume 186, 2023, Article 110707

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Research article

A decision making framework for selection of coarse aggregate for achieving sustainable concrete

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Contents lists available at ScienceDirect

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Behavior of concrete-filled stub columns confined with cold formed steel under axial compression: A comparative review

Pranoy Roy [a, *], Amiya Kumar Samanta [b]

[a] Research Scholar at NIT Durgapur and Assistant Professor at Dr. B C Roy Engineering College, Durgapur.
[b] Professor, Department of Civil Engineering, NIT Durgapur, Pin 713209, India

ARTICLE INFO

Keywords:
Review article
Axial compression
Parametric analysis
Confined column
Slenderness
Shape factor

ABSTRACT

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Hence it is attempted to study the behavior of concrete packed stub columns with cold formed confinement under axial compression. Relevant high quality journals were collected and reviewed and the data of around 300samples were suitably analyzed during this study. An extensive parametric lookout is carried out to estimate the key-factors including slenderness ratio, shape and thickness of confining material on the axially compressed samples. Moreover the prediction of various available codes are also considered to find their relevance in regards to the peak loading of the specimen. The study concludes good agreement of the prediction by Eurocode-4 as compared to other codes. However in a certain range the prediction of other codes are quite satisfactory.

1. Introduction

Columns transfer the loads to foundation. Concrete widens laterally under compression, creating vertical cracks leads to failure in concrete due to crushing or buckling of columns. Also, in concrete structure exposed to marine environments fails due to deterioration of concrete.

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2. Literature review

2.1. *Use of square and rectangular cold formed sections as confinement to concrete*

Y. Ouyang and A.K.H. Kwan (2018) [1] studied the expansion and triaxial characteristics of constricted concrete and concrete-steel interface characteristics on square concrete filled steel tubed (CFST) specimens with various concrete mix, steel yield strength and depth-to-thickness ratio of tube. The confined specimens had increased axial load capacity than the capacities of concrete section and the steel independently.

A. Zhu et al. (2017) [2] investigated concrete packed cold formed steel stub specimens with stiffeners examining the rigidity, ductility and failure mode. The prediction of codes AISC and EC4 were found conservative, whereas the method of DBJ code predicted the capacity of the specimens more accurately.

X. Zhou et al. (2015) [3] studied the properties of confined square reinforced-concrete specimens under eccentric condition, studying parameters including tube width-thickness ratio (B/t) and addition of shear connector studs in specimens. The results concluded that the steel tube prevented the columns from bond failure, confirming bonding between confinement and concrete infill.

* pranoyroy.dgp@gmail.com

https://doi.org/10.1016/j.matpr.2023.04.507
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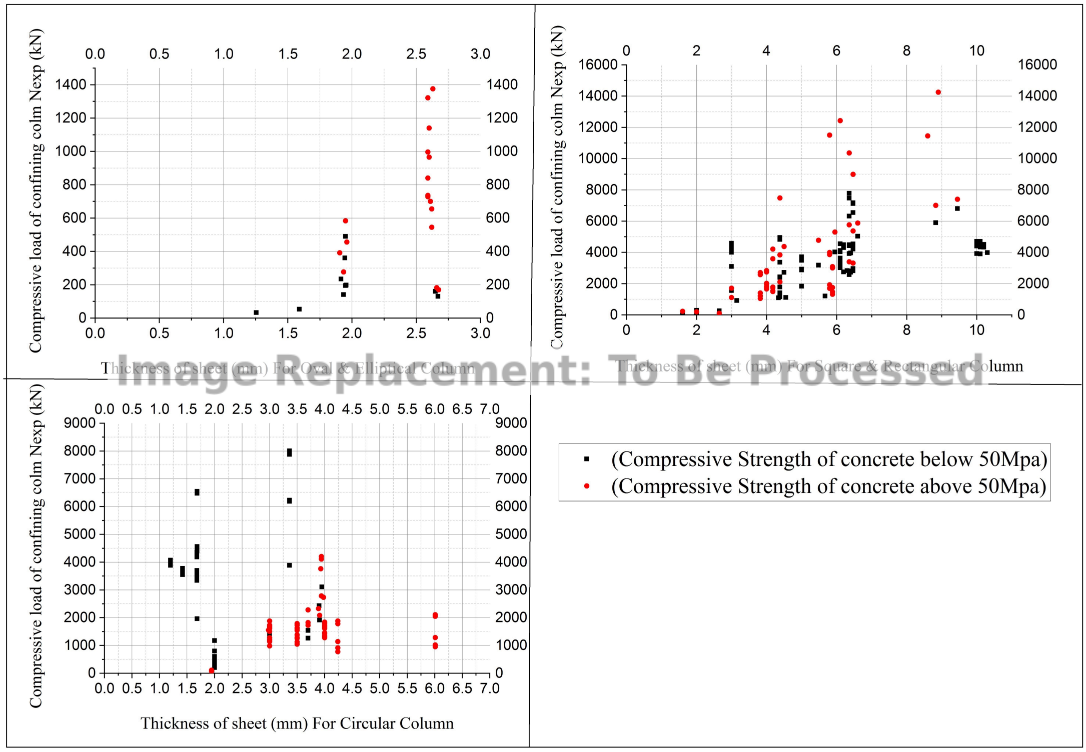

Fig. 1. (a) Compressive Strength Vs Thickness of Confining Material for Oval and Elliptical column; (b) Compressive Strength Vs Thickness of Confining Material for Square and Rectangular Column; (c) Compressive Strength Vs Thickness of Confining Material for Circular Column.

M.V. Chitawadagi et al. (2010) [4] studied the influence of thickness of cold formed tube confinement, concrete grade and effect of surface area including axial shortening with three grades of concrete. The area of steel tube mostly affects both the maximum capacity and axial shrinkage of the CFT.

2.2. Use of circular cold formed sections as confinement to concrete

R. Zhang et al. (2020) [5] investigated concrete of high performance grade jammed in steel tube as columns under non-concentric axial loading. The study showcased local buckling with fracture at the middle of the steel tubed column specimen. Concrete core failed by crushing with multiple transverse cracks. The results obtained showed good agreement with Euro Code 4 and American Code.

M. Usman et al. (2020) [6] studied the combined use of fibers with confinement on 39 concrete cylinders with proportions of steel fibres. Test results signified that steel fibre had minimal change in peak strength, whereas improved in post peak behaviour of concrete was observed.

G.M. Al-Mekhlafi (2020) [7] studied stub columns with carbon fiber reinforced polymer wrapping externally with eccentric compression loading. Twelve stub columns with variable carbon wrap and eccentric load was tested which forcasted that wrapping helps to achieve higher loading bearing capacity.

M. Su et al. (2020) [8] tested the effect of exterior diameter by thickness (D/t) of steel tubes with different grade of concrete. The results was tallied with different available codal provisions. The Euro-code (EC4) proved accurate and consistent compared to American (AISC and ACI), and Japanese (AIJ) codal provisions.

Y.G. Guo (2020) [9] studied polyethylene terephthalate FRP confined -concrete-steel solid columns under compressive load. Results highlighted delayed local buckling in inner steel tube of specimens, mainly due to the interaction of the components.

M. Guan et al. (2020) [10] studied the compressive behaviour of round confined short members with manufactured sand concrete by testing sixty three specimens to study the content of sand, stone powder and steel tube d/t ratio. For short column, the capacity increased with decrease in the d/t ratio of steel tube.

Y Wang et al. (2019) [11] conducted reliability analysis of corrugated steel tube as confinement to concrete, by testing twenty-one items under axial compression. Results indicated superior behaviour of specimens with corrugated steel confinement.

L. He et al. (2018) [12] carried out experimental investigation on columns with varying concrete strength, bonding in steel tube confinement with concrete. Corrugations in the steel tube weakened it vertically. The concrete confining effect was higher with reduced axial loading in the steel tube. Also the corrugations enhances the overall confinement effect.

J. Liu et al. (2018) [13] conducted study on 18 column specimens with varying concrete grade and d/t ratio of steel tube under cyclic axial compression. Key parameters like load-axial displacement curves, concrete steel interaction of confined specimens were studied. Results concluded that the predicted strength showed proportional results to experimental results.

2.3. Use of oval and elliptical cold formed sections as confinement to concrete

F. Zhou and B. Young (2019) [14] investigated oval hollow section as coating to three infilled concrete grade. The load-axial shrinkage followed by failure modes of the column samples were analysed. The compared results showed over estimation of American and European Codes as compared to experimental results.

Y. Cai et al. (2019) [15] studied hot-finished (HF) and cold-formed (CF) elliptical tubular columns with three grades of concrete tested under axial compressive loading. Failure by crushing of infilled concrete

Table 1
Details of Specimens including shape, slenderness ratio and ultimate load carrying ratio.

Shape of Specimen	Type	No of Specimens	Slenderness Ratio (l/d)	Thickness of sheet (mm)	Grade of Concrete MPA	Nexp/ Nfem	Nexp/ NAISC	Nexp/ N EC4	Nexp/N Liu et al.	Nexp/N AIJ 2008	Nexp/P Vrcelj	Nexp/GB 50,936 Nc
Square and Rectangular Column	Short Column	22	2.86 to 11.90	2.00 to 5.88	20.00 to 145.9							
					Mean	–	1.02	1.03	–	1.10	0.95	0.87
					Median	–	1.02	1.03	–	1.10	0.94	0.87
					Mode	–	1.02	1.02	–	1.10	0.87	–
					SD	–	0.00	0.04	–	0.00	0.06	0.06
Square and Rectangular Column	Long Column	86	12 to 40	1.6 to 5.88	30.00 to 145.9							
					Mean	–	0.92	0.96	–	0.94	–	0.92
					Median	–	0.88	0.98	–	0.94	–	0.91
					Mode	–	–	–	–	–	–	–
					SD	–	0.16	0.15	–	0.06	–	0.07
Circular Column	Short Column	22	2.86 to 11.90	2.00 to 5.88	20.00 to 145.9							
					Mean	1.01	0.71	1.38	0.84	1.34	–	–
					Median	1.00	0.69	1.40	0.82	1.37	–	–
					Mode	1.00	0.69	1.35	0.79	1.42	–	–
					SD	0.05	0.05	0.09	0.07	0.10	–	–
Circular Column	Long Column	6	4.24 to 6.01	2.00 to 5.88	145.9							
					Mean	0.81	0.99	0.98	–	0.94	–	0.90
					Median	0.96	0.99	0.97	–	0.94	–	0.91
					Mode	–	–	–	–	–	–	0.91
					SD	0.39	0.03	0.05	–	0.05	–	0.06
Elliptical and Oval Column	Short Column	4	1.6 to 2.6	57.3								
					Mean	–	1.05	0.99	–	–	–	–
					Median	–	1.06	0.99	–	–	–	–
					Mode	–	1.09	–	–	–	–	–
					SD	–	0.04	–	–	–	–	–
Elliptical and Oval Column	Long Column	23	1.26 to 2.68	57.3	40 to 100							
					Mean	–	1.10	0.90	–	–	–	–
					Median	–	1.09	0.94	–	–	–	–
					Mode	–	1.09	0.82	–	–	–	–
	Total	163			**SD**	–	0.15	0.15	–	–	–	–

and buckling of steel tube outwards was observed. EuroCode-4 were less conservative than AISC and ACI specifications.

H. Yang (2017) [16] investigated elliptical hollow section as concrete confinement. Results concluded global buckling, with visualizations of local buckling at the steel tube of the samples. Chinese code GB50936 [20] agreed with experimental outcomes whereas the prediction of Euro Code[4] was restricted to certain aspect ratio.

3. Methodology

Parameters for study of selected samples from journal papers:

The samples are categorized based on their shape, thickness of confining steel and grade of concrete.

3.1. Shape

- Square and Rectangular
- Circular
- Oval and Elliptical

3.2. Thickness of confining steel

- 1.2 to 3 mm
- 3 mm to 10.2 mm

3.3. Grade of concrete

- Medium Strength Concrete (upto 50mpa)
- High strength concrete (above 50mpa)

3.4. Calculation of axial strength of confined Column.

The prediction of axial strength of confined column is conducted using the methods as summerised below.

- Experimental Results.
- FEM Analysis using different software.
- Different Codal Provisions:

IS456 can estimate the axial load of short and long columns, whereas there is no provision for the ultimate load carrying capacity of long and short columns with exterior confinement. Also no other Indian code specifies on composite confinement of column. Hence the use of foreign codes is incorporated in this study.

- ANSI/AISC 360 [17].

The sectional strength can be calculated as.

$N_{AISC} = f_y A_s + 0.85 f_c' A_c$, where A_s and A_c are sectional area of steel concrete, respectively; f_y and f_c' are the yield stress of steel and the compressive strength of concrete, respectively.

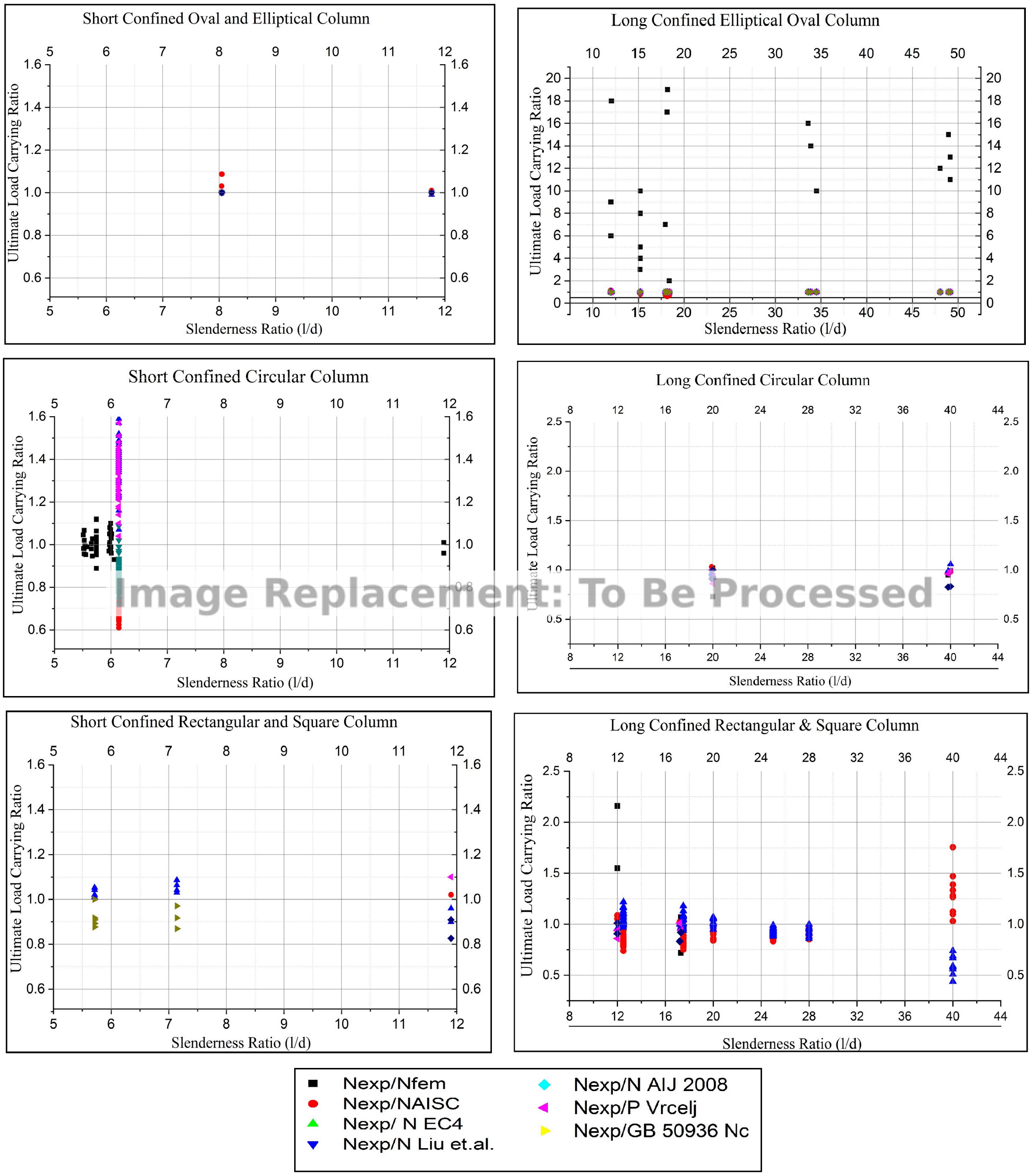

Fig. 2. (A) Ultimate Short carrying ratio of Short Confined Oval and Elliptical Column; (B) Ultimate Load carrying ratio of Long Confined Elliptical and Oval Column; (C) Ultimate Load carrying ratio of Short Confined Circular Column; (D) Ultimate Load carrying ratio of Long Confined Circular Column; (E) Ultimate Load carrying ratio of Short Rectangular and Square Confined Elliptical and Oval Column; (F) Ultimate Load carrying ratio of Long Confined Rectangular and Square Column.

- Eurocode-4 [18].

The plastic resistance to compression $N_{pl.Rd}$ of a composite is calculated by:

$N_{pl.Rd} = A_a f_y / \gamma_{Ma} + Ac(0.85 f_{ck} / \gamma_c) + A_s f_{sk} / \gamma_s$,where A_a, A_c and A_s are the areas of structural steel, concrete and reinforcement respectively.

f_y, f_{ck} and f_{sk} are respectively the yield stress of steel cross-section, concrete grade strength and the yield stress of steel reinforcement.

γ_{Ma}, γ_c and γ_s are partial safety factors at the ultimate limit states.

- Architectural Institute of Japan (AIJ) 2008 [19].

The nominal strength (PAIJ) is.

$P_{AIJ} = 1.27 f_{0.2} A_s + 0.85 f_{ck} A_c$.

Where,

$f_{0.2}$ = Nominal 0.2% proof stress.

f_{ck} = Compressive strength of concrete.

A_c = Area of Concrete.

- Vrcelj and Uy method [20].

Proposed relationship by Vrcelj and Uy: $N_{clb} = \alpha_{1b} N_c$.

where N_{clb} is the buckling load for slender members, N_c is the column buckling load and α_{1b} is the interaction coefficient for local buckling and is in the range $0 \le \alpha_{1b} \le 1.0$.

α_{1b} is calculated as: $\alpha_{1b} = (100 - p_r)/100$, where, ρ_r is the percentage reduction.

$\rho_r = [(N_c - N_{clb})/N_c] \times 100$.

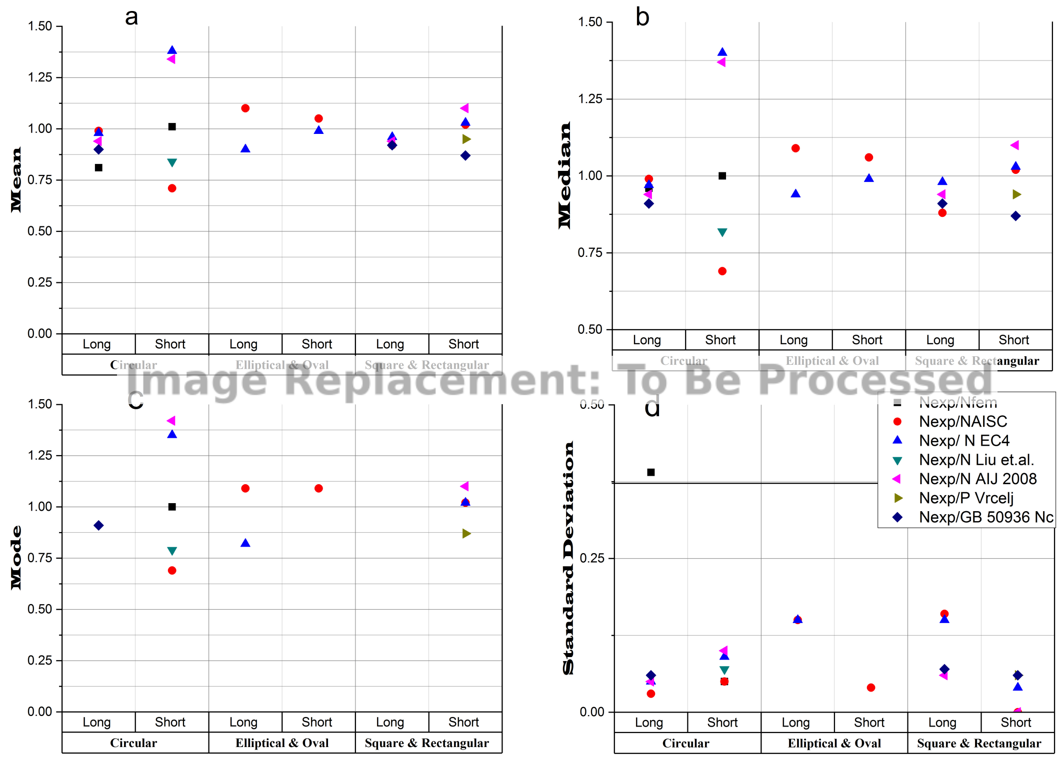

Fig. 3. (A) Mean values of Ultimate Load carrying ratio; (B) Median values of Ultimate Load carrying ratio; (C) Mode values of Ultimate Load carrying ratio; (D) Standard Deviation (S.D.) of Ultimate Load carrying ratio.

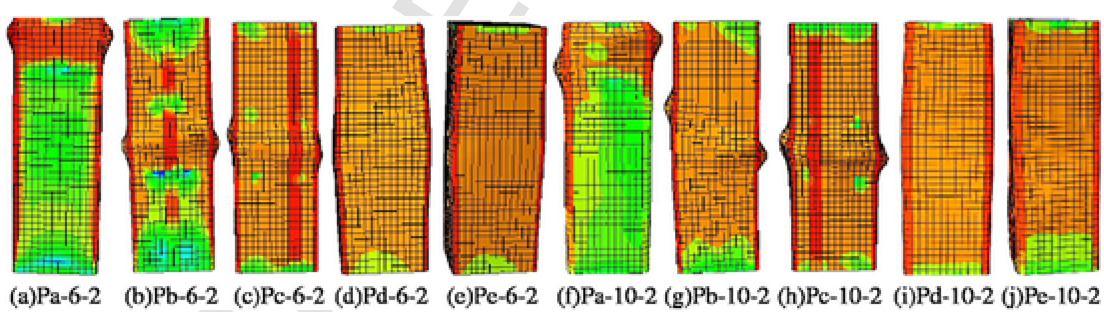

Fig. 4. Typical Failure Modes of Specimens under FEM Analysis A. Zhu et al. (2017) [2].

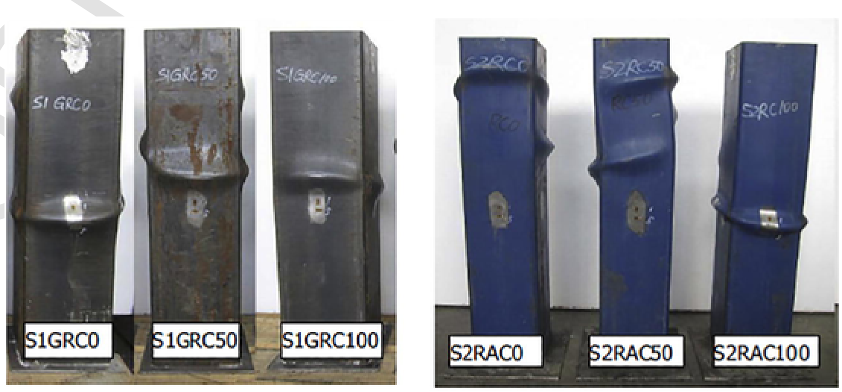

Fig. 5. Typical Failure Modes of Specimens under Axial Compression. X.S. Shi et al. (2015) [22].

- GB 50,936 (2014) [21].

The calculation method in GB 50936 specification is as follows: $f_{sc} = (1.212 + C\xi + D\,\xi^2)f_{c,m}$.

In which, 'C' and 'D' are influence coefficients of cross section. Axial compressive bearing capacity, $F_{uc} = Af_{sc}$.

4. Results and discussions

4.1. Relationship between thickness of confining material (Steel) and the Ultimate loading Capacity

The relationship between thickness of confining steel and the ultimate loading capacity of the specimens is shown for square, rectangular, circular, elliptical and oval columns. Based on the grade of infill concrete where medium strength concrete is for concrete below 50Mpa whereas concrete above 50Mpa is considered as high strength concrete. The relationship between the thickness of confining steel and the ultimate load carrying capacity is showcased in Fig. 1.

4.2. Relationship within slenderness ratio and the Ultimate loading Ratio

The relationship within the slenderness ratio and the ultimate loading ratio for different shapes of confined specimens comparing the estimated values from different codal provisions is presented in table below. The sections are devided into long column and short column based on slenderness ratio. For slenderness ratio less than 12 it is considered as short column, whereas for sections having slenderness ratio greater than 12 is considered as long column as per IS-456.

The details of specimens considered for the study is shown in Table. 1. and illustrated in Fig. 2. and Fig. 3. shows the graph indicating the Mean, Median, Mode and Standard Deviation of ultimate loading capacity ratio of different codes for different shapes of confined specimens.

4.3. Failure mode of specimens:

The steel tubes in all of the confined specimens generally exhibits localized buckling near the centre, caused by axial shortening of the entire specimen. Fig. 4 and Fig. 5 shows the failure pattern of concrete filled confined stub columns, where Fig. 4 shows the prediction by finite element software, whereas Fig. 5 shows the experimental failure analysis of confined sections. It can be seen the failure is mainly by local buckling of confining steel, followed by crushing of columns. Also the prediction of finite element software is in agreement with the experimental failure mode.

4.4. The highlighted points based on the above study are as follows:

- The thickness of the steel tube plays significant proportional role for the ultimate axial load of the concrete infilled steel confined stub specimens.
- The compressive strength carrying scope is directly proportional to the thickness of confining material in case of specimens with low and medium grade concrete.
- For specimens with high strength concrete, the compressive is lesser depended on the thickness of confining material.
- The prediction of different codal provisions is independent of the shapes of the columns.

4.5. The highlighted points based on the above figure Fig. 2 and Fig. 3 are as follows

- GB50936 shows the most conservative predicting methodology.
- The prediction of FEM shows inconsistent agreement compared to experimental results for some specimens.
- Design method proposed by AIJ2008 and Vrcelj & Uy predicts lower load carrying capacity compared to experimental result.
- The prediction of ANSI/AISC-360 slightly more than the actual experimental results, whereas Eurocode-4 is more accurate compared to other codal provisions.
- The load carrying scope of short stub specimens is more as compared to long column specimens irrespective of shape.
- Eurocode-4 and American Code AISC-360 can predict the compressive strength of all shapes of specimens, whereas the others are limited mainly to square and circular shapes.

5. Conclusion

The following interpretations are drawn from this study:

- Confinement of concrete stub columns improves the load carrying capacity of the column and prevents bond failure.
- Buckling is the primary mode of failure of the confined specimens.
- Finite element software can accurately predict the failure mode and failure load of confined specimens.
- Circular columns have more load carrying scope as compared to oval or elliptical columns, square and rectangular columns being the least.
- The projection of axial load carrying scope of specimens by Eurocode-4 is more accurate compared to other codal provisions.

CRediT authorship contribution statement

Pranoy Roy : Conceptualization, Methodology, Investigation, Writing – original draft. **Amiya Kumar Samanta :** Supervision, Writing – review & editing.

Declaration of Competing Interest

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Acknowledgements

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