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Performance of Integrated Orthogonal Columns with and Without FRP Wrapping Subjected to Localized Corrosion

Sneha C Raj
Post Graduate Student
Department of Civil Engineering
Sree Narayana Guru College of Engineering
& Technology Payyannur, Kannur, Kerala, India

Shilpa Valsakumar
Assistant Professor
Department of Civil Engineering
Sree Narayana Guru College of Engineering
& Technology Payyannur, Kannur, Kerala, India

Abstract- A numerical model was created with the aid of the commercial finite element programme ANSYS in order to investigate the impact of local corrosion on the ability of orthogonal concrete filled steel tube (CFST) columns to support loads under axial and eccentric loads. To fulfil the structural design requirements, a T-shaped column is utilised. Construction of bridges frequently makes use of it. Non-symmetrical columns include those in the L and T shapes. The likelihood of corrosion is considerable if a column is damaged since they are not symmetrical. All of the columns' faces and corners are examined for corrosion effects. Analogously, determining how the damage manifests itself in the column when corrosion is at the middle. A decrease in the load-bearing capability of an orthogonal CFST column was demonstrated with the same corrosion rate. Look into how the CFST column will ultimately behave under corrosion and coupled sustained load. The structure can be strengthened by layering a carbon fibre reinforced polymer (CFRP) system around it. The test's findings indicate that using CFRP boosts a column's ability to support loads.

Keywords-CFST, L- shaped column, T- shaped column, Localized corrosion, ANSYS software, CFRP.

I. INTRODUCTION

The concrete filled steel tubular (CFST) structure has advantages of high bearing capacity, good plasticity and toughness, convenient construction and high economic benefit. It is widely used in high-rise buildings, long-span highways, high-speed railway bridges, offshore platforms, boiler towers, TV stations and other civil engineering structures. At the same time, the CFST column in service is exposed to environment, which induces different corrosion damage. Corrosion could weak the cross-sectional area of steel tube and steel mechanical properties; Pit corrosion could also penetrate steel tube walls, allowing harmful corrosive media to penetrate into concrete, and further causing concrete damage. These lead to structural resistance degradation over time, affecting the safety, durability and applicability of in-service structure, and even trigger engineering accidents in serious cases, resulting in huge losses of people's lives and property. Therefore, the study of corrosion on the mechanical properties of CFST structures is required in academic value and practical engineering reference significance for accurate evaluation of the reliability of CFST structures. Rectangular cross-sectional columns in traditional frame structures, with extended corners to indoor space, normally have larger cross-sectional depths than those of adjacent infilled walls, leading to reduction of usable indoor space and disturbance to indoor environment. Recently, special-shaped columns, as an improved architectural approach, have been increasingly introduced into residential and official buildings. Smooth connection between special-shaped columns and adjacent infilled walls guarantees increased efficiency of indoor space and availability to furniture arrangement [1-5].

Special-shaped columns have been widely applied as the load carrying portion at corner of rooms in multi-story buildings in recent years. The special-shaped columns have satisfied the requirement of the architects and save more space to earn economic benefits. As the reinforced concrete (RC) structures are the most widely used in buildings, the special-shaped RC columns are firstly applied in structures. The action of L-shaped columns under the static load have been studied according to the extensive researches. The special-shaped RC columns possessed low load capacity and poor ductility according to the researches. As concrete filled steel tubes (CFSTs) can take good use of the concrete and the steel tube, special-shaped composite columns have been developed to avoid the weakness of special-shaped RC columns [6].

L- shaped columns may be the most frequently encountered reinforced concrete columns, since they can be used as a corner column in framed structures. Commonly L-shaped column is utilized in the corners of the boundary wall and has similar characteristics of rectangular or square column. L- shaped column has the advantages such as high bearing capacity, good ductility and high utilization rate of internal space. L-shaped columns are specially shaped concrete structures with asymmetric sections so the internal forced state is even more complex and creating large bending moments.

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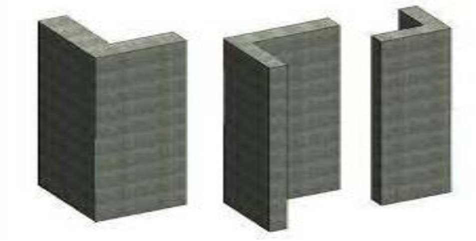

Fig 1. L-Shaped Column

The T-shaped column is used to meet the structural design criteria. It's commonly utilized in bridge construction. With high strength and good seismic performance, T-shaped steel reinforced concrete column is widely used in high-rise building structure. T-shaped concrete-filled steel tubular (CFST) columns have the advantage of avoiding protrusion from walls and can be used as edge columns.

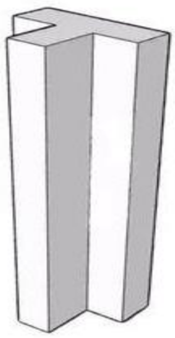

Fig 2. T- Shaped Column

In recent years, with the rapid development of material manufacturing technology and the reduction of production costs, fiber reinforced polymer (FRP) has been increasingly applied in construction engineering due to its high strength-to-weight ratio. Especially for carbon FRP (CFRP), it has better fatigue strength thanks to the property of not absorbing water. The carbon fiber is not sensitive to high temperatures, and not affected by ultraviolet rays. Moreover, such fiber behaves very well against creep deformation and relaxation. Because of its excellent corrosion resistance, CFRP can be used to wrapped on the surface of steel tube to prevent the steel corrosion. Due to their high strength, high modulus, high corrosion resistance and especially light weight, carbon fiber reinforced polymer (CFRP) have been regarded as a promising material to replace some traditional high strength metals. Hence, the related FRP confined concrete structure technology and FRP reinforced steel structure technology have made great progress in theory and design. Fibre Reinforced Polymer (FRP) is a composite material made of a polymer matrix reinforced with fibres. The fibres are the main reinforcing element but are bonded together by a polymer, such as an epoxy resin. This polymer protects the fibres and equally distributes the load between each fibre of material. Fibre Reinforced Polymer (FRP) bars have appeared as a preferable alternative to ordinary steel bars in reinforced concrete (RC) members due to their higher ultimate tensile strength-to-weight ratio and corrosion resistance. FRP composites have a series of advantages, such as light weight, high strength, high modulus, good corrosion resistance, good impact resistance and so on [16,19].

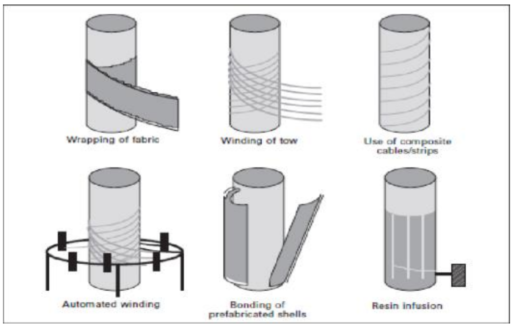

Fig 3. FRP Wrapping

Localized corrosion refers to the hastened attack of passive metals in corrosive environments. It is characterized by an intense attack at confined areas on surface components, while the remaining area of the surface corrodes at a much slower rate. This can be due to environmental effects or the component material's inherent properties, like in the creation of protective film oxide. In a localized corrosion, the material's surface may be fundamentally under suitable corrosion control, with the corrosion confined at localized sites where the corrosion protection has stopped working [15,17,25].. There are several types of localized corrosion:

- Crevice corrosion: The assault may take place there as well as on metal surfaces that are vulnerable to corrosives.

- Pitting corrosion: This form of attack results in metal holes. In such cases, the holes may be large or small in diameter. Pits can be close together or isolated, and may appear as a coarse surface. In general, it can be described as cavities with surface diameter almost the same size as their depth.
- Inter granular: Effects of grain boundaries have little or no effect in almost all metal applications. In such cases, metal corrosion results in a uniform attack, since grain boundaries are more reactive compared to the matrix. In some circumstances, grain interfaces are extremely reactive, leading to corrosion.

II. VALIDATION

A. Description of experimental model

The experimental result was corroborated numerically using data from an experiment on a T-shaped CFST column that was subjected to axial compression [1]. The T-shaped CFST column had dimensions of 300 mm x 300 mm and a height of 900 mm. The outcomes of the modelling of the T-shaped CFST column analysis under

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axial load were taken. From the experimental data, material attributes were extracted.

B. Finite element model

Using ANSYS Workbench 2022 R2, the T-shaped CFST column is validated. Normal strength concrete with a 36.9 MPa compressive strength was employed. The steel constitution uses a perfect uniaxial elastic-plastic relation curve, and the tangent modulus of strain-hardening is equal to 1% of the elastic modulus. 2.06×10^5 MPa is the elastic modulus of steel. A steel object has a 0.3 Poisson's ratio.

The interaction between the steel tube and the concrete of the column is described as a surface-to-surface contact interaction, with a hard contact property in the normal direction and a friction property in the tangential direction with a friction coefficient of 0.25. Following local tube buckling, the interaction enables separation of the concrete and steel tube. The boundary condition and loading criterion in the FE model are completely replicated from the experiment. 50 mm mesh size is chosen for the analysis. The FE model is used to calculate axial load-displacement curves, which are then compared to experimental findings. It is evident that the FE model is trustworthy since the axial load-displacement curves of FE are in reasonably good agreement with the experimental findings. In the experiment, the maximum load and deflection were 2812 kN and 2.80 mm, while in the finite element calculations, they were 2674.70kN and 2.90 mm.

TABLE 1 COMPARISON OF RESULTS

	Experimental model	FEA model	Error percentage
Load (kN)	2812	2674.70	4.88
Deflection (mm)	2.80	2.90	3.57

III. PARAMETRIC STUDY

Multiple parameters were taken into account when conducting the study. The first one in this context involves analysing a T-shaped CFST column that has been axially loaded while exhibiting corrosion on various faces of the column, examining the load-deflection curve, and contrasting it with a control column that has not undergone corrosion. In a different investigation, carbon fibre reinforced polymer was used to enhance the functionality of a corroded T-shaped CFST column. The T-shaped CFST columns with locally grooved corrosion on steel tubes were the main subject of this investigation. The artificial notches served as a representation of the localised corrosions in the specimens' steel tubes.

The axially loaded uncorroded T-shaped CFST column and the corroded T-shaped CFST column (faces) are shown in Fig.2 and Fig. 3, respectively.

A 300x300mm, 900mm-long T-shaped CFST column was used to conduct the finite element study. The fake notches were chosen to be 300 mm x 100 mm and 3 mm thick.

A carbon fibre reinforced polymer with tensile strength of 1240 MPa, a young's modulus of 9 1700 MPa, and a poisson's ratio of 0.30 can be used for strengthening. 1.27 mm was chosen as the CFRP layer thickness.

FRP strengthening in this study is achieved by the external wrapping of unidirectional CFRP sheets in the corrosion region. As of right now, the stress in other directions has been ignored, and it was anticipated that the FRP sheets would only be under tension in the fibre direction. Taking into account the FRP sheets' anisotropic elastic characteristics, which cause them to behave linearly elastically under tension but not much under compression.

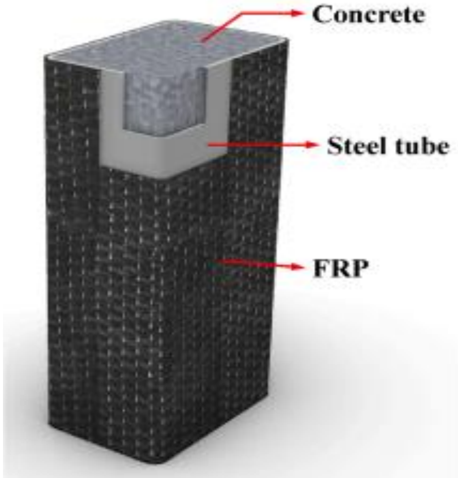

Fig. 1 FRP-CFST column

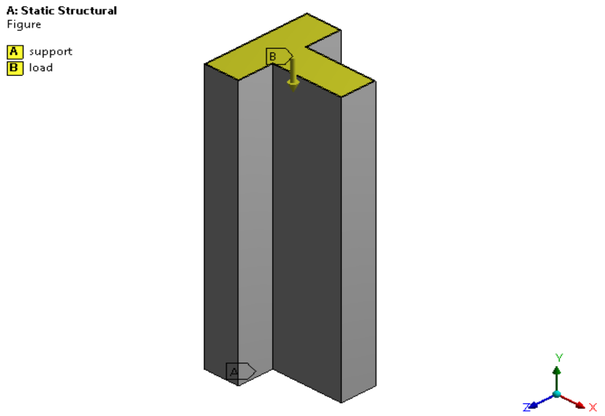

Fig.2 Uncorroded T-shaped CFST column (Axially loaded)

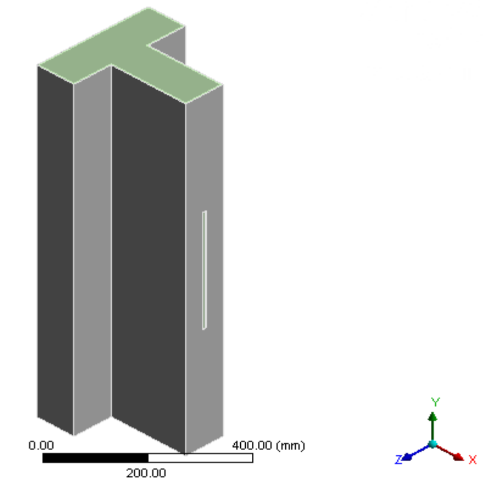

Fig.3 Corroded T-shaped CFST column (Axially loaded)

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The T-shaped CFST column's stress distributions under peak load are depicted in Fig. 4 (the other columns have a similar mechanism of failure). The concrete achieves or even exceeds the compressive strength before reaching peak bearing capacity, and the steel tubes essentially yield, which is in good conformity with the results. The fact that the compressive strength of the core concrete is greater than the measured value shows that the steel tube has a real constraining impact on the core concrete.

Fig.5 shows the load- deflection curve of axially loaded T- shaped CFST column when the column faces are locally corroded. Localised corrosion may cause the T-shaped CFST column to buckle locally.The ultimate strength for a corroded T-shaped CFST column is reached on face 5 with a value of 2856 kN, whereas it is 2939.80 kN for an uncorroded T-shaped CFST column. The ultimate strength is reduced by 10% as a result of corrosion damage. The findings significantly vary depending on where the corrosion is located on the different faces of the column.

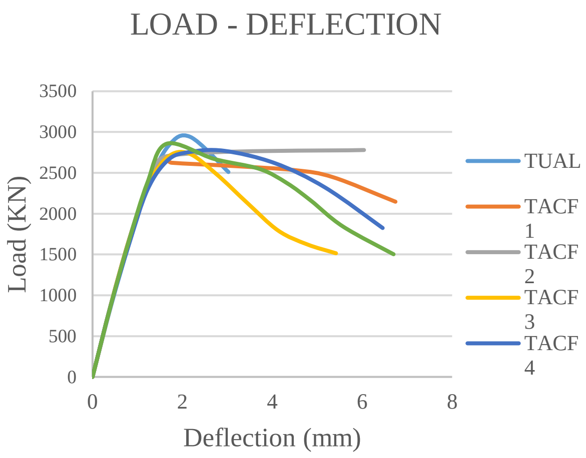


Fig.5 Load- deflection Curve (Axially loaded)

Fig. 6 shows the load curve of strengthening of corroded axially loaded T- shaped CFST column by CFRP. In this study, FRP strengthening is accomplished by externally wrapping unidirectional CFRP sheets in the corrosion zone. Strengthening the column resulted in increased overall strength. Axially loaded T-shaped uncorroded CFST column has an ultimate strength of 2939.80 kN. A maximum value of 3354.23 kN on face 5 is found for a corroded, axially loaded, T-shaped, CFRP-strengthened CFST column. Increase of 17.42% is made to the final strength.

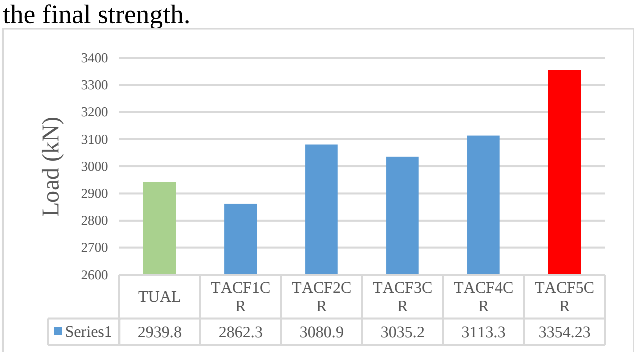
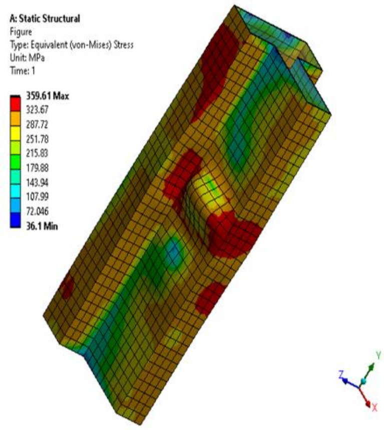
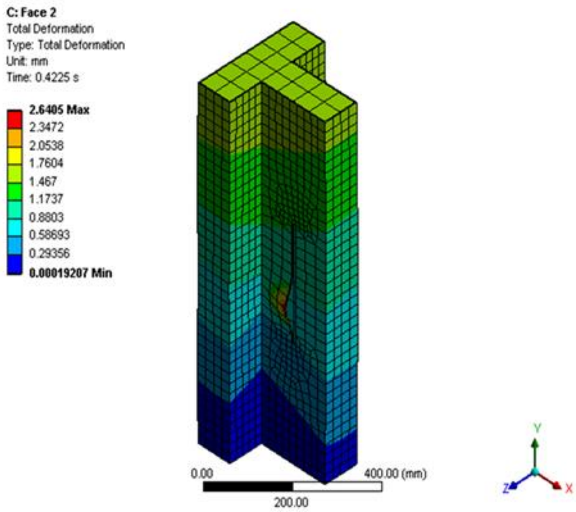
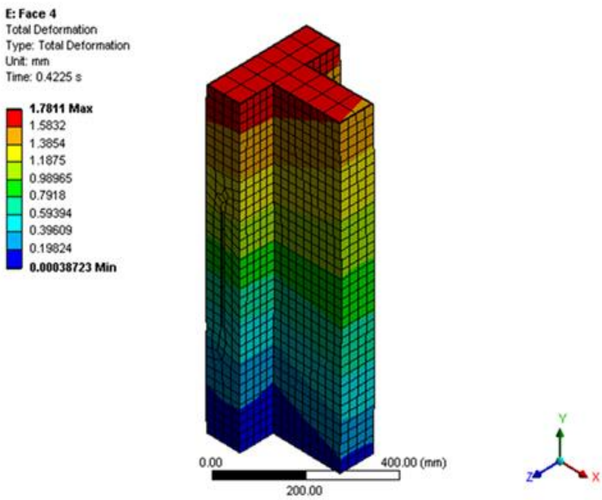


Fig.6 Load Graph of Strengthened Axially Loaded T-shaped CFST column (Faces)







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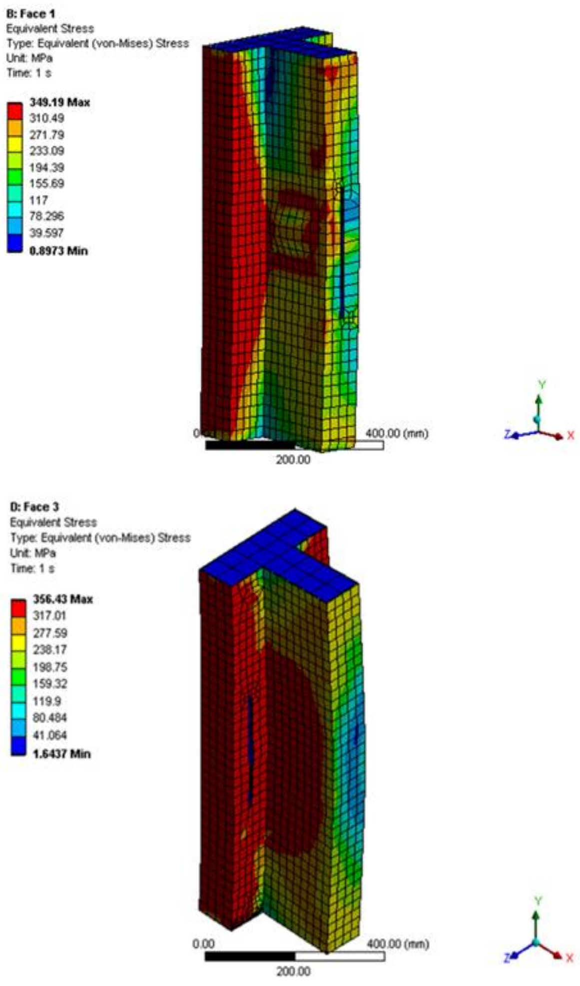

Fig.4 Stress distribution of T-shaped CFST column-Axially loaded (Faces)

Fig.7 shows the eccentrically loaded uncorroded T-shaped CFST column. When a column is loaded eccentrically, it has an offset load. It will be either in the right or left corner of the column, a little ways from the centre. Distance between the line of action that would provide a consistent stress across the specimen's cross section and the actual line of action of compressive or tensile loads. Columns buckle as a result of eccentric loading. Direct stress and bending stress are both caused by the eccentric load.

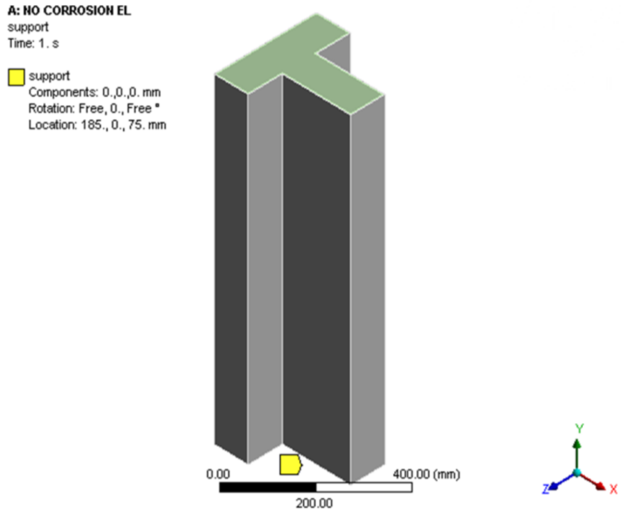

Fig.7 Uncorroded T- shaped CFST column (Eccentrically loaded)

Fig.8 shows the corroded T-shaped CFST column's stress distributions under eccentric loading. The corrosion along the faces of the T-shaped CFST column under eccentric loading enables the steel and concrete to cooperate. Eccentric loading increases the column's bending by causing it to bend even more.

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Fig.9 shows the load- deflection curve of eccentrically loaded T- shaped CFST column when the column faces are locally corroded.The column bends and experiences axial tension when the load acting on it is displaced from its centroid. The ultimate strength for a corroded T-shaped CFST column is reached on face 3 with a value of 1293.30 kN, whereas it is 1408 kN for an uncorroded T-shaped CFST column. The ultimate strength is reduced by 12% as a result of corrosion damage. Depending on where the corrosion is on each of the column's faces, the results show significant variation.

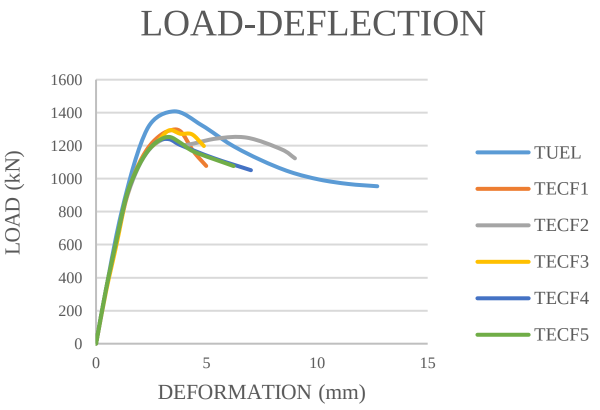


Fig.9 Load- deflection Curve (Eccentrically loaded)

Fig.10 shows the load curve of strengthening of corroded eccentrically loaded T- shaped CFST column by CFRP. The maximal strength of an eccentrically loaded, T-shaped, uncorroded CFST column is 1408 kN. On face 3, a corroded, eccentrically loaded, T-shaped, CFRP-strengthened CFST column is found to have a maximum value of 1523.40 kN. Strength is increased by 17.79% in the end result.

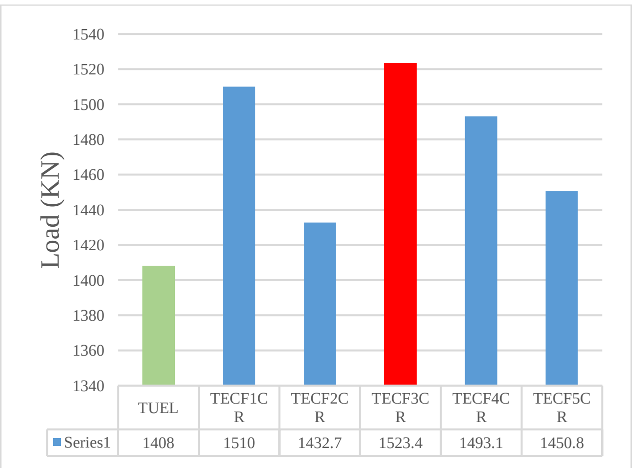
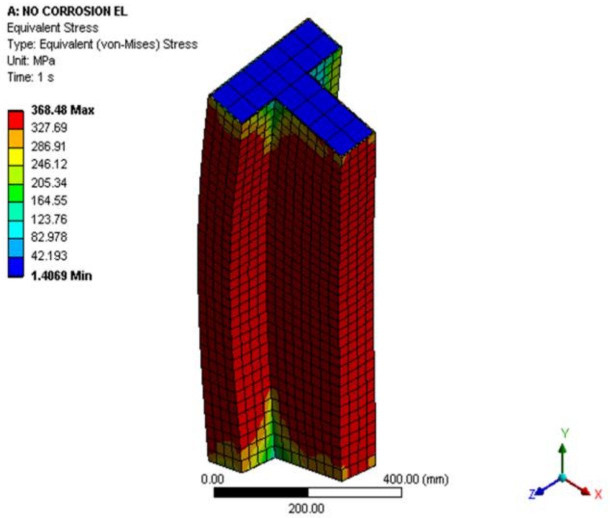
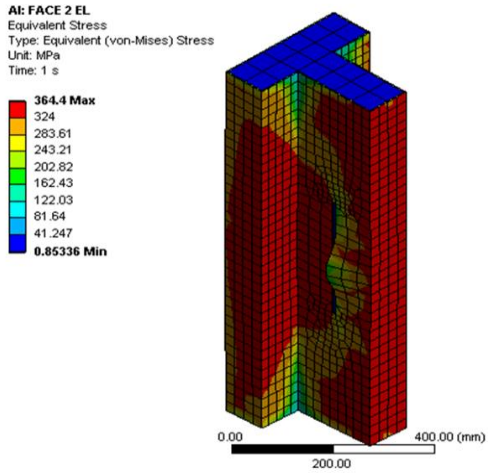
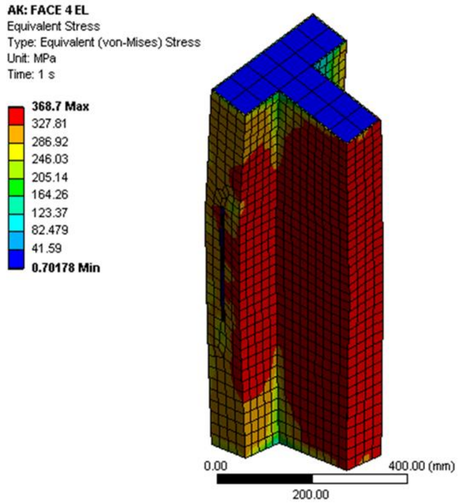


Fig.10 Load Graph of Strengthened Eccentrically Loaded T-shaped CFST column (Faces)







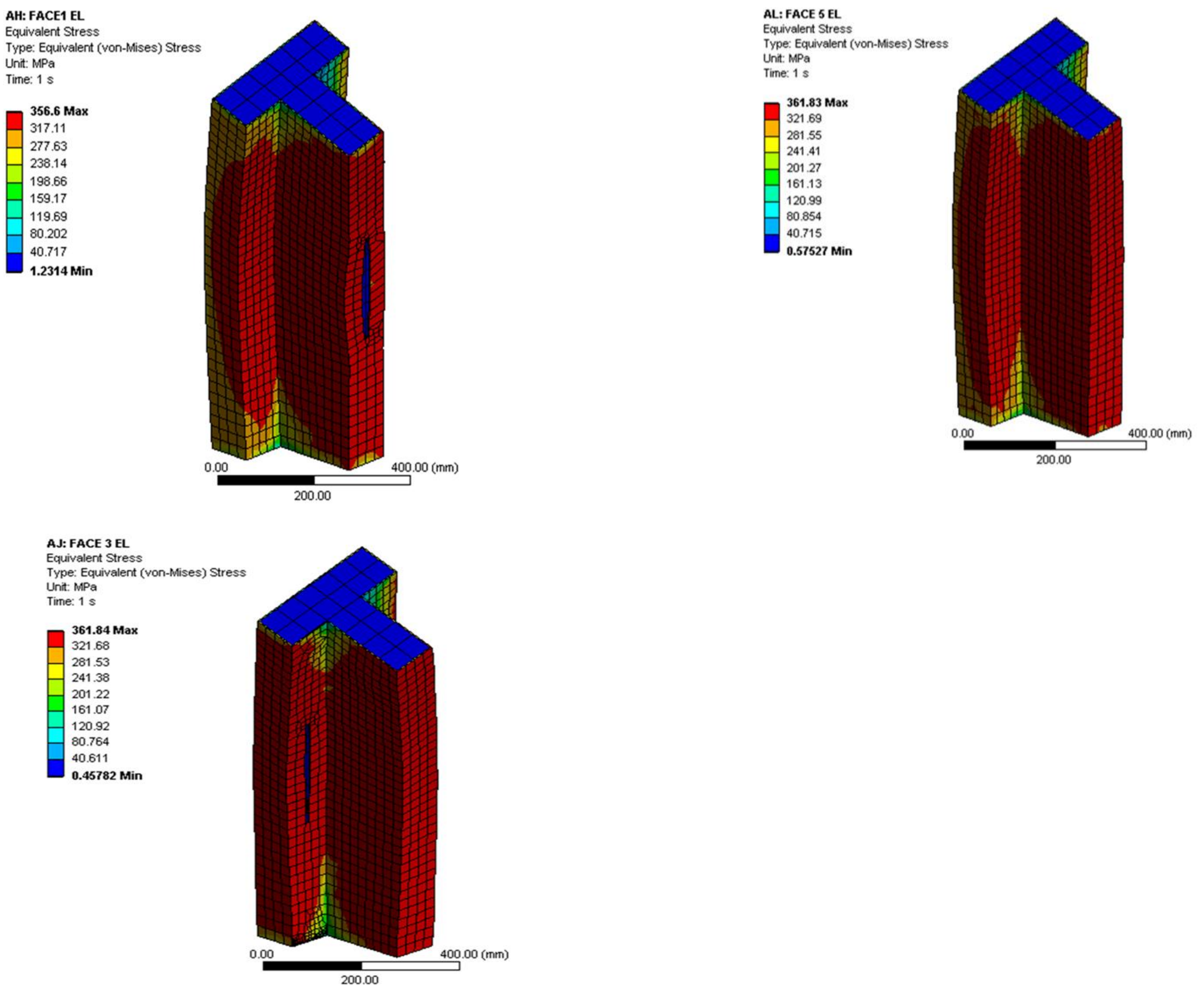


Fig.8 Stress distribution of corroded T-shaped CFST column-Eccentrically loaded (Faces)

IV. CONCLUSION

The goal of this study is to examine the structural behaviour of a corroded T-shaped CFST column under axial and eccentric loading, as well as the effectiveness of wrapping CFRP sheets around the corroded T-shaped CFST column. The following results are reached from the study after a numerical model was tested against an experimental model developed by Xianggang Liu et al. (2018).

- Uncorroded T-shaped CFST performs worse than corroded T-shaped CFST when wrapped in CFRP sheets.
- The wrapping of the CFRP sheets can increase the ultimate strength of the corroded, axially loaded, T-shaped CFST column by 15%.
- The CFRP sheets can be used to increase the ultimate strength of the corroded eccentric loaded T-shaped CFST by more than 18%.
- When corroded T-shaped CFST columns are strengthened with a single layer of 1.27 mm thick CFRP sheet, the results are superior to the corroded T-shaped CFST columns in terms of performance.

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