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Numerical Simulation Study on Axial Compression Performance of Concrete-Filled Circular Steel Tubular Columns with Local Pitting Corrosion Loss

Raoya Shi

Key Laboratory of Urban Security and Disaster Engineering of Ministry of Education, Beijing University of Technology, Beijing, 100124, China

Keywords: Concrete-filled steel tube (CFST), Local pitting corrosion, Finite element analysis, Axial compressive bearing capacity, Failure mode, Volume loss rate

Abstract: Concrete-Filled Steel Tube (CFST) columns are widely used in high-rise buildings and bridge structures due to their excellent load-bearing capacity, ductility and construction convenience. However, under the action of corrosive media such as marine environment, industrial pollution or deicing salt erosion, local pitting damage is prone to occur on the surface of the steel tube, resulting in non-uniform thinning of the wall thickness and significant stress concentration, which leads to a serious degradation of the axial compression bearing capacity and durability of the components. To reveal the influence mechanism of random local pitting on the axial compression performance of high-strength CFST columns, a three-dimensional fine finite element model considering multiple random corrosion pits was established based on the Abaqus platform in this paper, and a systematic parametric analysis was carried out using the control variable method. The study focused on the influence of key factors such as volume loss rate (*DoV*), circumferential corrosion angle, mean corrosion depth, axial height of corrosion and compressive strength of concrete and yield strength of steel on the load-displacement response, stiffness degradation law and failure mode evolution of the column. The results show that local pitting damage significantly weakens the load-bearing capacity of the steel tube section and the constraint effect on the core concrete, leading to the premature local buckling in the corrosion area and the gradual transformation of the column failure mode from overall buckling to local instability control. With the increase of volume loss rate and corrosion depth, the bearing capacity and ductility of the column decrease significantly, while the symmetrical distribution of circumferential corrosion can to some extent alleviate the stress concentration effect. In addition, increasing the strength of steel and concrete can effectively improve the overall stability of the component, delay the development of buckling and improve the later deformation capacity.

1. Introduction

Concrete-Filled Steel Tube (CFST) columns have been widely used in modern structures such as high-rise buildings and long-span bridges due to their excellent mechanical properties and convenient construction. However, in corrosive environments such as marine, industrial, or deicing salt environments, the surface of the steel tube is prone to local corrosion. Such accidents caused by local pitting account for more than 80% of the corrosion-related events in structures [1]. Local corrosion leads to non-uniform thinning of the steel tube wall thickness, local weakening of the cross-section, and significant stress concentration, thereby seriously weakening the axial bearing capacity and long-term durability of the component. Given that CFST columns are often used as the main compression components, the degradation of their bearing capacity due to local corrosion directly threatens the overall structural safety. Therefore, it is crucial to conduct research on the performance degradation mechanism and assessment methods. In the recent years, scholars at home and abroad have conducted a large number of experiments and numerical simulation studies on the performance degradation of CFST columns under local corrosion. These studies have initially revealed the influence laws of parameters such as corrosion depth, corrosion area, and corrosion location on the ultimate bearing capacity, stiffness, and failure mode of the components. For example, Li et al. [2] pointed out through numerical analysis that local pitting would significantly reduce the bearing capacity of CFST columns and the constraint effect of the steel tube on the concrete; Zhao et al. [3] proposed a calculation formula for the bearing capacity reduction coefficient considering parameters such as corrosion thickness and mass loss rate; Jia et al. [4] confirmed through axial compression tests that the volume loss rate of the corrosion pit has a decisive influence on the bearing capacity of short columns; Li et al. [5] proposed a practical calculation method considering random pitting for slender columns.

Although significant progress has been made in the experimental and numerical studies on the axial compression performance of CFST columns under local corrosion in recent years, there are still obvious deficiencies in the existing research, which are still difficult to fully reflect the influence mechanism of corrosion damage on the mechanical properties of components in actual engineering. First, most studies use regular, uniform or single corrosion pit models to simulate local corrosion, while the corrosion in actual engineering often presents a complex form with multiple randomly distributed corrosion pits and significant differences in depth and scale. The interaction between corrosion pits and the local stress concentration effect caused by it have not been systematically quantified, which to some extent limits the engineering applicability of the research conclusions. Second, most existing studies focus on the influence of a single corrosion parameter (such as corrosion depth or corrosion area) on the bearing capacity, and lack in-depth exploration of the failure mechanism under the coupling effect of multiple parameters such as volume loss rate, circumferential distribution, axial position, and mean corrosion depth, making it difficult to reveal the internal mechanism of the transition from cross-sectional weakening to failure mode due to local corrosion. In addition, there is no unified understanding of the coupling effect between corrosion damage and material strength parameters (such as steel yield strength and concrete compressive strength), and the relevant conclusions are somewhat scattered. Finally, some numerical studies lack sufficient physical explanations in the process of model establishment and parameter analysis, and the evolution process of local buckling, overall instability, and their coupling failure mechanisms is still not well understood.

This paper adopts a refined numerical simulation method to focus on exploring the influence of multiple random local pitting on the axial compressive performance of CFST columns. The study will systematically analyze the comprehensive influence of key parameters such as the degree of local corrosion (volume loss rate), the length-to-diameter ratio of the component, the depth distribution characteristics (mean) of the corrosion pit, the circumferential distribution position, and the axial distribution along the column height on the axial compressive strength, load-displacement curve characteristics, and failure mode of the column, with the aim of providing a more accurate theoretical basis for the durability assessment and safe design of such structures.

2. Establish a finite element model

2.1 Material Composition and Mesh Division

Based on the Abaqus software platform, a three-dimensional finite element model of a circular concrete-filled steel tube column was established. The model mainly consists of three parts: the outer steel tube, the core concrete, and the rigid end plates at both ends to ensure uniform load transfer. In terms of material constitutive relations, the core concrete is simulated using the plastic damage model proposed by Lin et al. [6], which can effectively reflect the compressive behavior of concrete under monotonic loading, size effect, and damage accumulation process. The elastic modulus of the concrete is determined according to relevant specifications, and the Poisson's ratio is taken as 0.2. To balance computational efficiency and nonlinear convergence stability, the viscosity coefficient of the concrete is set to 0 in the analysis. For the steel tube material, the classical elastic-plastic constitutive model [6,7] is adopted, with an elastic modulus of 200 GPa and a Poisson's ratio of 0.3. The meshing of the model is all done using tetrahedral elements. For the steel tube part, different order tetrahedral elements such as C3D20R, C3D15, and C3D10 are selected based on the geometric complexity and calculation accuracy requirements. The meshing strategy adopts the free meshing technology, and the mesh density is controlled by setting the global seed size (average element size of 20.0), which can flexibly adapt to the geometric shape and ensure mesh quality. The mesh generation of the core concrete part adopts a similar strategy to that of the steel tube.

2.2 Contact Type and Boundary Conditions

In the finite element modeling, the top and bottom rigid end plates are simulated using four-node discrete rigid shell elements (R3D4). The steel tube and core concrete are uniformly selected as eight-node reduced integration solid elements (C3D8R). The interface behavior between the steel tube and concrete is defined by surface-to-surface contact: normal contact is set as "hard contact" allowing separation; tangential contact adopts the Coulomb friction model, with a friction coefficient of 0.6, and is implemented using the "penalty function" algorithm [8]. The end plates and the upper end face of the steel tube are connected by "binding" constraints to ensure deformation coordination. To simulate actual corrosion damage, this study directly performs Boolean operations on the intact steel tube model at the geometric level to cut out randomly distributed pits, representing local defects in the wall thickness. Considering that the effective constraint provided by the core concrete to the steel tube can largely suppress the sensitivity of initial defects, the influence of welding residual stress and overall initial geometric curvature of the component is not considered in the model for the time being. In terms of load application, axial displacement is applied at the reference point of the top rigid end plate for loading, while the bottom rigid end plate is subjected to complete fixed constraints. The modeling information for the tube with simulated corrosion-induced pits is presented in Figure 1.

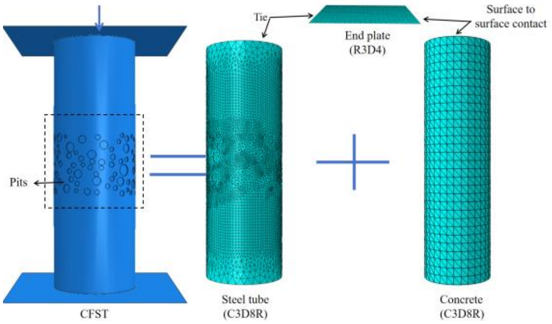


Figure 1: Modeling information for CFST.

2.3 Random Corrosion Pit Modeling Process

To simulate the random corrosion pits on actual steel tubes, this paper adopts a pseudo-random process to generate corrosion pits of different sizes and distributions. Firstly, the basic parameters of the CFST column, such as height, outer steel tube diameter and wall thickness, are set. To describe the distribution of the corrosion pits, boundary vectors (longitudinal range lv and circumferential range Φ) are introduced. Then, based on statistical data, the diameter-to-depth ratio of the corrosion pits (4:1 to 6:1 and 8:1 to 10:1) anad the depth range of the pits (0 to t times the wall thickness) are determined, and it is assumed that the depth of the pits follows a normal distribution [9].

By randomly generating parameters such as the depth, radius, and position of the pits, ensuring no overlap between the pits, the degree of volume loss caused by these non-overlapping existing pits in the distribution area can be calculated using Equation (1). The modeling process ends when the volume loss of the generated corrosion pits reaches the preset target, as checked by Eq (2). Finally, a steel tube model with random corrosion pits is created in ABAQUS using these parameters. Through Boolean operations and merging functions, these corrosion pits are integrated into the steel tube geometry model to obtain the final finite element model.

$$DOV_i = \frac{V_{\mathrm{p}its}(i)}{V_S} \tag{1}$$

$$|DoV\text{-}DoV_i| \leq 0.1\% \tag{2}$$

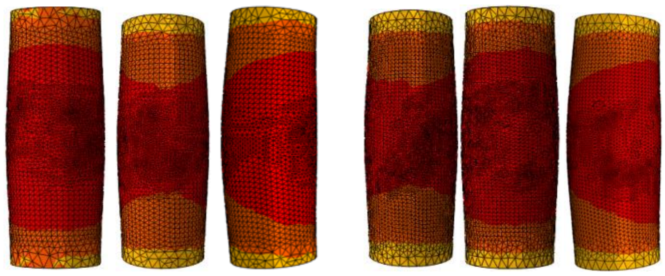
Where $V_{\mathrm{p}its}(i)$ represents the sum of current i pits' volumes.

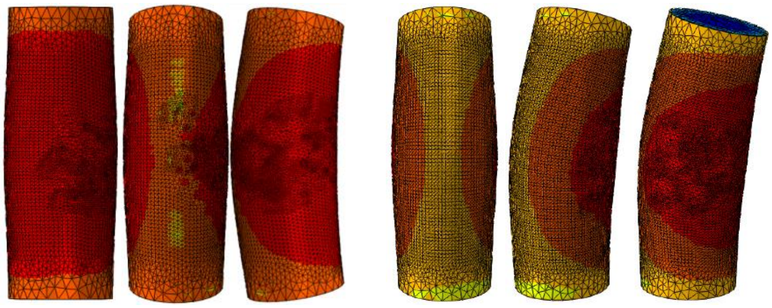
3. Parameter Analysis and Analysis

3.1 Parameter Design

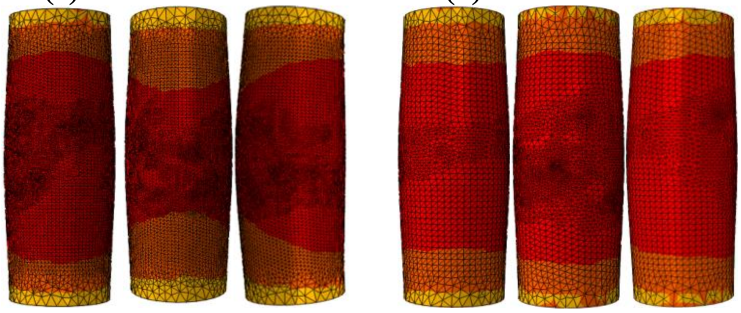
To reveal the mechanism of the influence of key design variables and damage parameters on the axial compression performance of high-strength concrete-filled steel tubes (CFST) columns, this study has developed a systematic parametric analysis scheme, aiming to quantitatively evaluate the effects of individual and coupled parameters on the column's bearing capacity, stiffness, deformation mode, and failure mechanism through the control variable method. The analysis mainly focuses on the following key parameters: volume loss rate (*DOV*), circumferential corrosion angle, mean corrosion depth, axial height of corrosion, concrete compressive strength, and steel yield strength, etc. The naming rule for specimens is: volume loss rate - circumferential corrosion angle - mean corrosion depth - axial height of corrosion - concrete compressive strength - steel strength. For example, 1-360-3.2-200-40-300 indicates a volume loss rate of 1%, a circumferential corrosion angle of 360 degrees, a mean corrosion depth of 3.2mm, an axial height of corrosion of 200mm, a concrete compressive strength of 40MPa, and a steel strength of 300MPa.

3.2 Failure mode

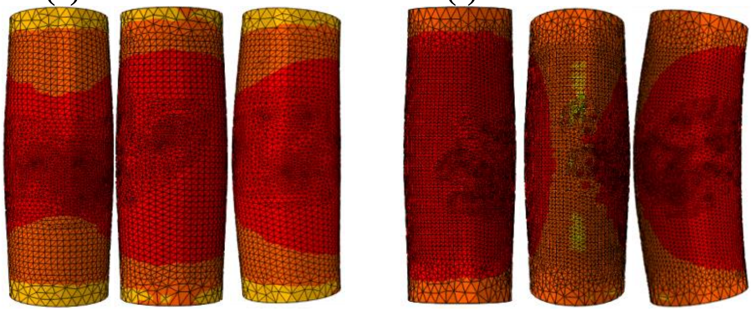

(a) 1-180-3.2-200-40-300 (b) 3-180-3.2-200-40-300



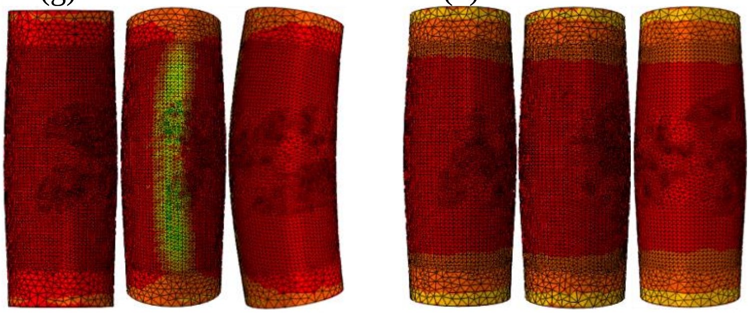
(c) 5-180-3.2-200-40-300 (d) 3-90-3.2-200-40-300



(e) 3-360-1.6-200-40-300 (f) 3-360-2.4-200-40-300



(g) 3-360-3.2-200-40-300 (h) 3-180-3.2-200-40-500



(i) 3-180-3.2-200-40-700 (j) 3-180-3.2-200-80-300

Figure 2: Failure mode diagram of the specimen

Through finite element analysis of the failure modes of specimens under different local corrosion parameters, a deeper understanding of the impact of local corrosion on structural performance can be achieved. By analyzing the force distribution and local deformation of the column, the failure mode and mechanism of the specimen can be predicted. Designers can identify the most vulnerable areas to corrosion, thereby optimizing the design and reinforcement measures. At the same time, finite element analysis can simulate the mechanical behavior of CFST columns with corrosion damage in a computer, reducing the need for experimental research and significantly saving experimental costs and time. Overall, this not only helps to enhance the safety and durability of structures, but also effectively reduces maintenance costs and provides a scientific basis for anti-corrosion design and construction. Figure 2 shows the front view, left view, rear view and right view of the failure modes of each specimen. From the finite element simulation results, it can be seen that the failure modes of CFST short columns under different local corrosion parameter combinations are generally characterized by overall bending buckling under axial compression accompanied by local bulging in the corrosion area. However, the differences in corrosion characteristics and material strength significantly affect the degree of deformation concentration and failure mode. For specimens with a larger volume loss rate (such as Figure 2(c)), the corrosion leads to a significant weakening of the steel tube cross-section, with stress concentration near the corrosion zone, and local buckling occurs earlier, resulting in more pronounced asymmetric bulging and lateral instability of the column. In contrast, when the volume loss rate is smaller (such as Figure 2(a)), overall instability still dominates, and the local deformation is relatively mild, indicating that the higher the degree of corrosion, the more likely it is to trigger local buckling-controlled failure. Additionally, an increase in the circumferential corrosion angle makes the corrosion distribution more symmetrical, and the stress transfer in the column becomes more uniform, resulting in a more stable overall bulging failure mode and a reduced sensitivity to local instability. As the mean corrosion depth decreases (such as Figure 2(e) and Figure 2(f)), the weakening effect of corrosion weakens, the constraint effect of the steel tube on the core concrete increases, the column deformation becomes more uniform, and the degree of damage is relatively lighter. Moreover, increasing the steel strength (such as Figure 2(i)) can effectively delay the yield of the steel tube and enhance the overall stiffness, thereby suppressing the development of local buckling; while increasing the concrete strength (such as Figure 2(j)) enhances the compressive capacity of the core concrete, further improving the overall stability of the column. Overall, local corrosion parameters cause a coupling of local buckling and overall instability mechanisms by weakening the steel tube cross-section and constraint effect. The higher the degree of corrosion and the more uneven the distribution, the more likely the column is to experience deformation concentration and premature failure.

3.3 Parameter Analysis

3.3.1 Influence of Volume loss rate

According to Figure 3, the volume loss rate (*DOV*) has a significant impact on the load-bearing capacity of concrete-filled steel tubular columns. Under different volume loss rate conditions (*DOV* = 1%, *DOV* = 3%, *DOV* = 5%), the deformation and load-bearing capacity of the columns show obvious differences. When the volume loss rate is 1%, the load-bearing capacity of the column is relatively high and the displacement is small, indicating that the structure of the concrete-filled steel tubular column is relatively stable and has strong load-bearing capacity under this condition. When the volume loss rate increases to 3%, the load-bearing capacity of the column decreases and the deformation increases, suggesting that a higher volume loss rate leads to an intensified local corrosion effect, thereby reducing the column's stiffness and load-bearing capacity. Further increasing the volume loss rate to 5%, the deformation of the column significantly increases and the load-bearing capacity drops sharply, indicating that at a higher degree of corrosion, the structure of the concrete-filled steel tubular column is more severely damaged and the overall load-bearing capacity is significantly weakened. This phenomenon indicates that the volume loss rate has a direct impact on the load-bearing capacity and stiffness of concrete-filled steel tubular columns, and as the degree of corrosion deepens, the load-bearing capacity of the column gradually decreases.

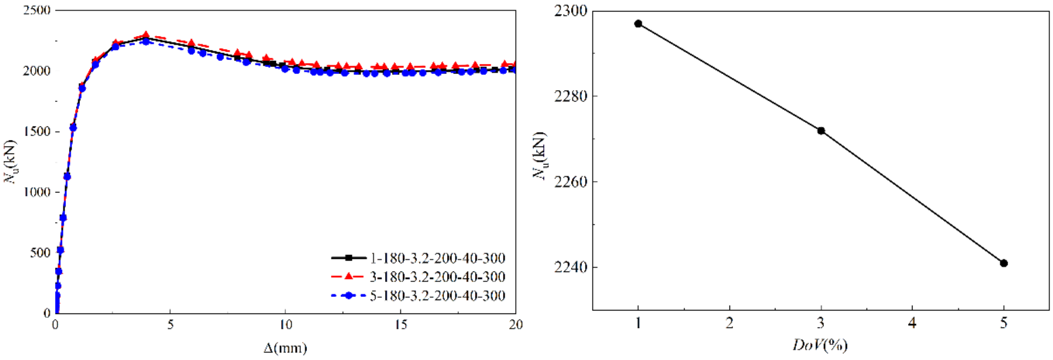


Figure 3: Influence of DoV

3.3.2 Influence of Circumferential Corrosion Angle

According to Figure 4, the circumferential corrosion angle has a significant impact on the bearing capacity of concrete-filled steel tubular columns. Specifically, when the corrosion angle is 90 degrees, the column experiences greater deformation and relatively lower bearing capacity, indicating that at this position, the corrosion effect has the most pronounced influence on the structure, making the column prone to significant deformation. As the corrosion angle gradually increases to 180 degrees and 360 degrees, the column's displacement gradually decreases and its bearing capacity gradually increases, suggesting that the influence of the corrosion effect gradually weakens. At these angles, the column demonstrates better stiffness and stability. This phenomenon may be related to the distribution of the corrosion location; a larger corrosion angle may lead to more uniform force distribution in the column, thereby reducing local deformation.

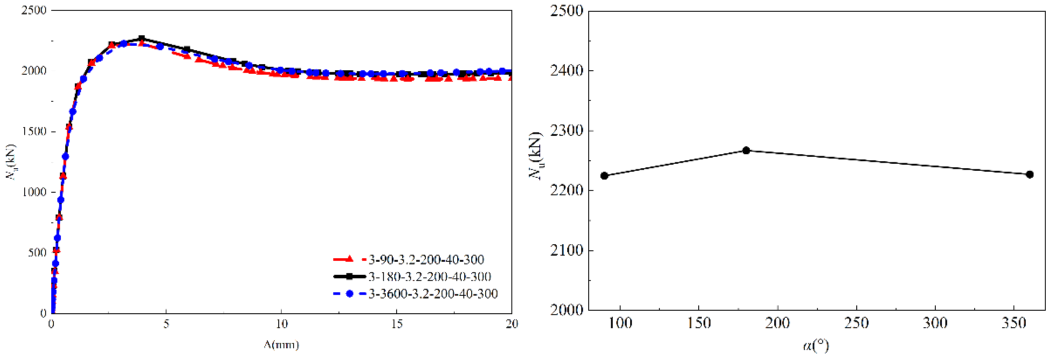


Figure 4: Influence of α

3.3.3 Influence of the Mean Corrosion Depth

According to Figure 5, the mean depth of pitting corrosion has a significant impact on the load-bearing capacity of concrete-filled steel tubular columns. Under different pitting depths (0.4t, 0.6t, 0.8t), the columns exhibit distinct variation patterns in their load-bearing capacity. When the pitting depth is 0.4t, the column's load-bearing capacity is relatively high and its displacement is small, indicating that at this depth, the concrete-filled steel tubular column demonstrates good structural stability and strong compressive resistance. As the pitting depth increases to 0.6t and 0.8t, the column's deformation gradually increases and its load-bearing capacity gradually decreases, suggesting that deeper pits lead to a reduction in the local stiffness of the column, thereby affecting its overall load-bearing capacity. This trend indicates that the depth of the pits directly influences the structural performance of the concrete-filled steel tubular column; the greater the depth, the more pronounced the deformation and damage when the column is subjected to loads.

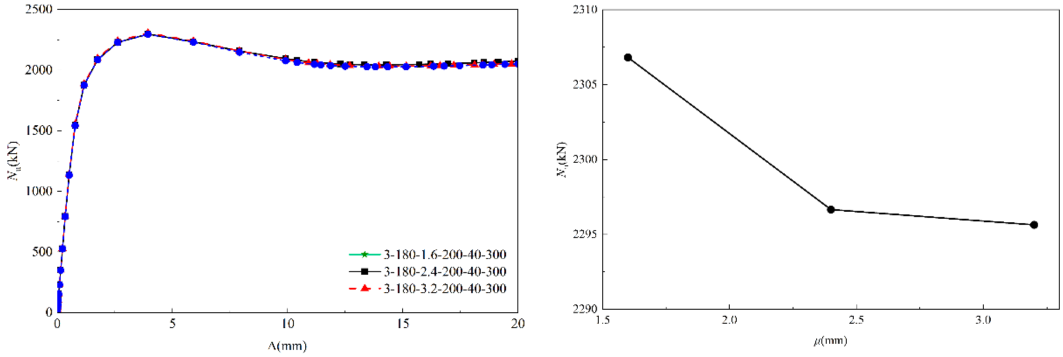


Figure 5. Influence of μ

3.3.4 Influence of axial Height

According to Figure 6, through the analysis of the load-displacement curves at different corrosion zone heights (*H*/3, *H*/4, *H*/5), it is observed that the height of the corrosion zone has a significant impact on the bearing capacity of concrete-filled steel tubular columns. Specifically, when the corrosion zone is located at a higher position of the column (such as *H*/3), the displacement of the column is relatively large, indicating a lower bearing capacity at this position and a greater likelihood of significant deformation in the structure. Conversely, when the axial height of the corrosion zone is lower (such as *H*/5), the deformation of the column is smaller, the bearing capacity is higher, and the structure shows better stability. This phenomenon indicates that the axial height of the corrosion zone directly affects the deformation and bearing capacity of the column. When the corrosion is located at a higher position (such as *H*/3), the corrosion effect may lead to a reduction in the local structural stiffness, thereby affecting the overall bearing capacity.

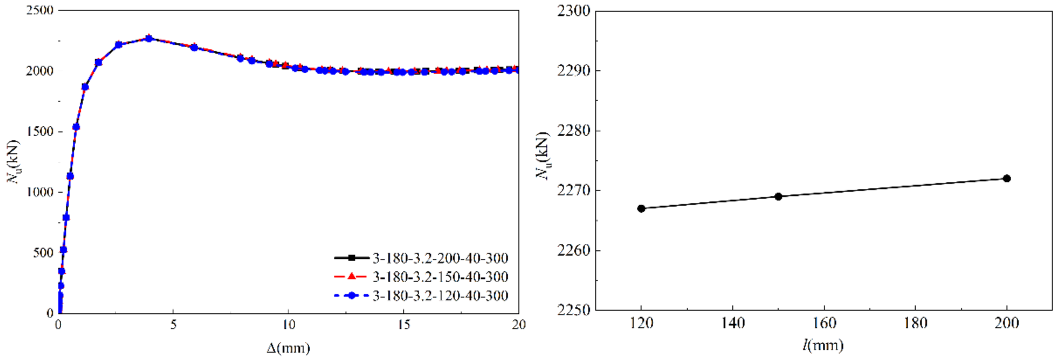


Figure 6. Influence of l

3.3.5 Influence of strength of concrete

According to Figure 7, the compressive strength of concrete has a significant impact on the load-bearing capacity of concrete-filled steel tubular columns. Under different compressive strength conditions ($f_c = 40, f_c = 80, f_c = 120$), the deformation and load-bearing capacity of the columns show distinct variation patterns. When the compressive strength of the concrete is 40 MPa, the column displacement is relatively large and the load-bearing capacity is relatively low, indicating that at this strength level, the compressive capacity of the concrete is insufficient, resulting in significant deformation of the column under load. When the compressive strength increases to 80 MPa, the load-bearing capacity of the column significantly enhances and the deformation is relatively small, suggesting that a higher compressive strength can effectively increase the overall stiffness of the concrete, reduce deformation, and improve the load-bearing capacity of the column. When the compressive strength reaches 120 MPa, the load-bearing capacity of the column further increases and the deformation further decreases, indicating that the increase in the compressive strength of the concrete helps the column better resist external loads, demonstrating stronger stability and higher load-bearing capacity. These results show that the compressive strength of concrete has a significant influence on the mechanical properties of concrete-filled steel tubular columns, and a higher compressive strength can effectively enhance the load-bearing capacity and stiffness of the columns.

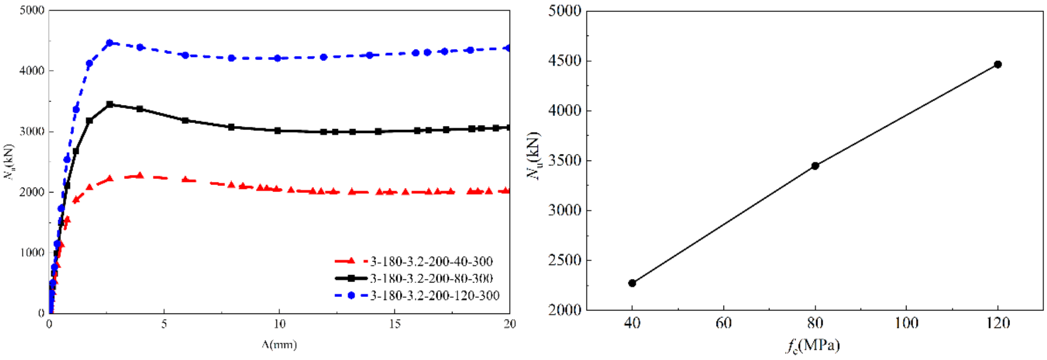


Figure 7: Influence of fc

3.3.6 Influence of strength of steel

According to Figure 8, the compressive strength of concrete has a significant impact on the load-bearing capacity of concrete-filled steel tubular columns. Under different conditions of concrete compressive strength ($f_y = 300$, $f_y = 500$, $f_y = 700$), the deformation and load-bearing capacity of the columns show obvious differences. When the yield strength of the steel bars is 300 MPa, the load-bearing capacity of the column is relatively low, and the deformation is large, indicating that under this condition, the column has poor stiffness and the structure shows significant deformation. When the yield strength of the steel bars is increased to 500 MPa, the load-bearing capacity of the column significantly increases, and the displacement decreases, indicating that a higher yield strength enhances the tensile capacity of the steel bars, thereby improving the overall stiffness and load-bearing capacity of the column. When the yield strength is further increased to 700 MPa, the load-bearing capacity of the column increases again, and the deformation further decreases, indicating that a higher yield strength of the steel bars can effectively improve the compressive capacity and stability of the column, making the structure more capable of resisting external loads. These results show that the yield strength of the steel bars has an important influence on the load-bearing capacity of concrete-filled steel tubular columns, and a higher yield strength can significantly improve the stiffness and load-bearing capacity of the column.

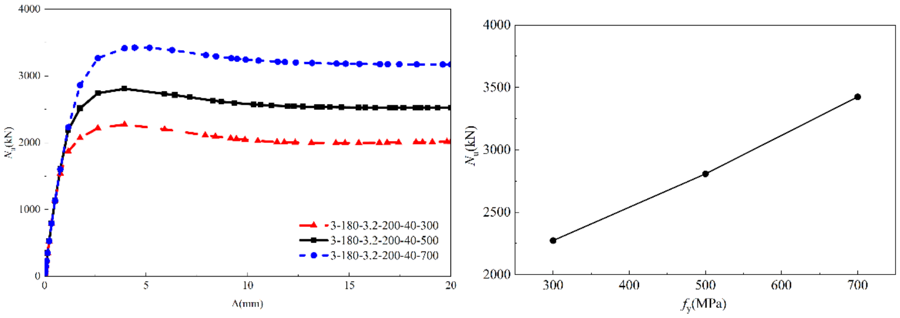


Figure 8: Influence of fy

4. Conclusion

(1) Local pitting corrosion significantly weakens the load-bearing capacity of steel tubes, especially under higher volume loss rates and corrosion depths, where the load-bearing capacity of the column decreases markedly. As the degree of corrosion deepens, the confinement effect of the steel tube on the core concrete weakens, causing premature local buckling of the column and accelerating overall instability.

(2) Changes in corrosion depth, corrosion angle, and corrosion location have a significant impact on the failure mode of the column. A larger corrosion angle (such as 360°) leads to a more uniform corrosion distribution, making the failure mode of the column more stable; while local corrosion (such as 90°) causes local buckling and deformation concentration, affecting the stability of the column.

(3) Increasing the yield strength of steel and the compressive strength of concrete can enhance the load-bearing capacity and stiffness of CFST columns. The increase in steel strength can delay the yielding of the steel tube, improving the compressive capacity of the column, while high-strength concrete enhances the confinement effect of the core concrete, thereby increasing the overall stability of the structure.

(4) The increase in volume loss rate and corrosion depth leads to a degradation of the local stiffness of the steel tube, which in turn affects the deformation and load-bearing capacity of the column. The higher the volume loss rate, the more pronounced the local buckling effect, causing the failure mode of the column to shift from overall buckling to being controlled by local buckling.

References

[1] Xu SH, He YL, Qin GC, Shi B, Wei LH. Relationship between Steel Corrosion Ratio and 3D Surface Roughness Parameters (in Chinese). J Mater Sci Eng 2016;34: 292–295.

[2] Li G., Hou C., Shen L., Combined compression-bending performance and design of CFST with localized pitting corrosion[J]. Journal of Constructional Steel Research, 2022, 192: 107247.

[3] Zhao Z.W., Gao T., Jian X.Y., Mo S.J., Liu B.B. Eccentric compression capacity of circular CFST columns under random pitting corrosion[J]. Ocean Engineering, 2023, 288: 115975.

[4] Jia C., Li J.W., Guo L.H., Zhong L. Behavior of stub SCFST columns with localized pitting corrosion damage[J]. Engineering Failure Analysis, 2024, 156: 107824.

[5] Li J., Jia C., Huang H., et.al. Performance of eccentrically loaded slender circular CFSTs subjected to localized pitting corrosion[J]. Journal of Constructional Steel Research, 2024, 219: 108792.

[6] LIN S, ZHAO Y-G. Numerical study of the behaviors of axially loaded large-diameter CFT stub columns[J]. Journal of Constructional Steel Research, 2019, 160:54–66.

[7] Liu J-P, Xu T-X, Wang Y-H, Guo Y. Axial behaviour of circular steel tubed concrete stub columns confined by CFRP materials. Constr Build Mater 2018;168:221–231.

[8] Han, L.H., Hou, C., Hua, Y.X., 2020. Concrete-filled steel tubes subjected to axial compression: life-cycle based performance. J. Constr. Steel Res. 170, 106063.

[9] T. Nakai, H. Matsushita, N. Yamamoto, Effect of pitting corrosion on local strength of hold frames of bulk carriers (2nd Report)—Lateral-distortional buckling and local face buckling, Mar. Struct. (2004) 17612–17641.