Study on Mechanical Properties of Concrete-Filled Aluminium Alloy Tube Column under Lateral Impact

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Abstract: Concrete-Filled Aluminium Alloy Tube (CFAAT) column may be damaged by lateral impact. Based on general finite element analysis software, the dynamic analysis and performance of lateral impact of CFAAT columns with different tube wall thickness are studied in this paper. The results show that when the outer diameter of the columns is constant, the impact resistance of the columns can be improved by increasing the thickness of the aluminium alloy (Al alloy) tube, and the reinforcement of the core concrete constraint by increasing the strength and thickness of the Al alloy tube is the main reason for the enhancement of the impact resistance.

1. Introduction
At present, Concrete-Filled Steel Tube (CFST) is widely used in civil engineering, but it has the disadvantages of poor corrosion resistance and large weight. In view of these shortcomings, CFAAT came into being. Al alloy has the advantages of corrosion resistance, low density and beautiful appearance than steel. Therefore, CFAAT can reduce the weight of members by comparing traditional reinforced concrete with CFST. The advantages of corrosion resistance also make it save a lot of cost in later maintenance. In addition, CFAAT retains the advantages of high bearing capacity of CFST and strong resistance to local buckling and instability caused by longer members. At present, the research on CFAAT is less and concentrated in static field. The structural performance of CFAAT short column has been studied, and the design strength calculated by American code and Australian/New Zealand aluminium and concrete structural standards have been evaluated. [1] In addition, the method with constraint effect coefficient as parameter is put forward, and the calculation method of bearing capacity of CFAAT columns under axial compression is obtained. [2] The research on Concrete-Filled metal tube (CFMT) under dynamic load mainly focuses on CFST. ABAQUS has been used to study the influence of axial compression ratio on lateral impact performance of CFST column. [3] It is inclined to explore the impact properties of different structural forms of CFST, taking new materials as core concrete to carry out experiments, and using finite element simulation to verify each other. [4-5] CFAAT is not equal to CFST, but the similarity between the two is high. In view of the lack of experimental data support and the lateral impact problem of CFAAT column, the finite element analysis of the lateral impact problem of CFAAT column can be carried out by drawing lessons from the experience and results of the concrete tube column.

2. Finite element model and output of data
This paper refers to the literature on finite element simulation of CFMT. [3,6-7] The finite element model of CFAAT columns with different thickness and height under lateral impact is established by ABAQUS. Materials, specimen parameters are shown in Table 1, Table 2. The length of columns is 1.6
and 0.8m, and the outer diameter is 80mm. The thickness of Al alloy tubes is 3, 6 and 9mm. Core concrete is C40 concrete. The Al alloy tube and concrete in the model are all three-dimensional solid elements (C3D8R) with 8-node reduction integral scheme, and the impact rigid sphere is modified with ten junctions to modify the secondary tetrahedron element (C3D10M). The ball is constrained to a rigid body by setting a reference point at the center of the ball. The interaction between concrete and Al alloy tube is defined as hard contact in the normal direction and penalty function in the tangential direction. In order to improve the efficiency of calculation, the initial distance between the rigid ball and the column is set to 0, and the initial state of the contact surface between the ball and the Al alloy tube is defined as the form of no friction and no pressure to prevent the error caused by contact. The rigid ball is given initial velocity to impact the CFAAT column. The CFAAT columns are restrained by two ends fixed, which will provide axial support reaction force for the core concrete during the impact process.

Table 1. 6063-T5 Al alloy parameters table.

| Category                  | Density (kg/m³) | Yield strength (MPa) | Young's modulus (N/mm²) | Poisson's ratio |
|---------------------------|-----------------|----------------------|-------------------------|----------------|
| 6063-T5                   | 2700            | 145                  | 70000                   | 0.32           |

Table 2. Ball (rigid body) information table.

| radius (mm) | Density (kg/m³) | Initial velocity (m/s) | Mass (kg) |
|-------------|-----------------|------------------------|-----------|
| 50          | 60000           | 40                     | 31.4      |

In the process of axial compression, the core concrete shows the characteristics of increasing peak stress and increasing plastic deformation ability of concrete due to the constraint of Al alloy tube. In the finite element analysis of this paper, reference is made to the constitutive model of CFST core concrete.[6] The stress-strain curve is shown in figure 1:

![Core concrete stress-strain curve.](image)

\[ \xi_0 = 1.12. \]

For the strain rate effect of concrete under dynamic load, the method in CEB is used.[8,9] By means of material Dynamic Increasing Factor (DIF) and static stress-strain relationship, the constitutive relation of concrete with high strain rate under dynamic action is obtained. The dynamic increase coefficients of compressive strength and tensile strength are calculated according to the above methods.

3. Process Description and Results Analysis

Deflection value and impact force value are two commonly used indexes in the study of impact resistance of CFST column.[3] This paper studies the movement changes in the process of impact and
the impact of concrete. By analysing these data, the influence of different Al alloy tube thickness on the impact performance of the column is obtained. The stress cloud after impact is shown in Figure 2:

Figure 2. Model cloud image after impact.

3.1. Deflection analysis:
The mid-span deflection of CFAAT column with different tube thickness of 1.6m and 0.8m is shown in Figure 3 and Figure 4. It shows that under the condition of constant column outer diameter, the greater the thickness of Al alloy tube, the smaller the mid-span deflection; the longer the column, the larger the deflection caused by impact.

Figure 3. 1.6m columns Mid-span deflection. Figure 4. 0.8m columns Mid-span deflection.

Source analysis of deflection data difference is as follows. Material gap caused by 3mm, 6mm and 9mm tube thickness is as follows: 1. The strength of the Al alloy tube is larger than that of the concrete. Increasing the thickness of the Al alloy tube will directly enhance the bending resistance of the column. 2. Al alloy tube makes CFAAT under vertical uniaxial compression, it will show triaxial compression of concrete, and the Al alloy tube will have the effect of confining pressure on the core concrete. This phenomenon is called the hoop effect of CFMT. With the increase of the thickness of Al alloy tube, the bending resistance of the column can be improved significantly. It shows that the mid-span deflection of the column decreases greatly from 3mm tube thickness where the hoop effect is not strong to 6mm tube thickness where the hoop effect plays an active role. From 6mm tube thickness to 9mm tube thickness with stronger ferrule effect, the deflection decreased.

3.2. Impact analysis:
In the whole impact process, the impact force develops with time in the form of contact force between ball and column. From Figure 5 and Figure 6, the ball starts to act at the speed of 40 m/s, the increase and decrease of the impact force, thus forming the first wave of the impact force time history diagram. In the comparison of CFAAT columns with tube thickness of 3mm, 6mm and 9mm, it can be found that with the increase of Al alloy tube thickness, the maximum impact force will increase. Then the impact force will increase again to form a second peak impact force. The second impact peak is also positively correlated with the thickness of Al alloy. Then, an obvious impact force platform section will be formed after the peak. The time when the impact force reaches the maximum is almost the same.
The maximum impact of the ball is shown in the following Table 3:

| Length (m) | Thickness (mm) | Fmax (kN) | Fmax/ Fmax(3mm) |
|------------|----------------|-----------|-----------------|
| 0.8        | 3              | 942.65    | 1               |
|            | 6              | 1185.25   | 1.26            |
|            | 9              | 1340.38   | 1.42            |
| 1.6        | 3              | 933.34    | 1               |
|            | 6              | 1110.71   | 1.19            |
|            | 9              | 1288.19   | 1.38            |
| 2.4        | 3              | 919.38    | 1               |
|            | 6              | 1108.65   | 1.21            |
|            | 9              | 1270.72   | 1.38            |

It can be found that the maximum impact force ratio of 1.6m and 0.8m columns is 0.99, 0.93 and 0.96 under the same Al alloy tube thickness. The impact force of 1.6m long column is slightly lower than that of 0.8m column. It shows that the material constitutive is the dominant factor affecting the impact force, and the length has little effect on the impact force. For verification of this statement, 2.4m long column is calculated, and the results are shown in Table 4. The maximum impact force ratios of 2.4m and 0.8m columns were 0.98, 0.94 and 0.95. It shows that under the same tube thickness, the constitutive law of core concrete is the same, and the impact force transmitted to the column is basically the same. This shows that impact force is less affected of the deflection when columns with different length.

### 3.3. Velocity analysis:

The velocity law of 0.8m column is consistent with that of 1.6m column. So only 1.6m column data are analysed. When the impact started, the velocity of ball continues to decrease. Velocity of the column mid-span will increase in a short time due to the impact of ball. When both speed come to the same level, the velocity of column mid-span comes the peak. Because of the stiffness and constraint of the column, then velocity of column mid-span begins to drop rapidly which falls faster than ball. The velocity of ball will exceed the velocity of column mid-span again, making the impact force to the second peak. The speed data shows that at 0.0025s to 0.0031s for 3mm tube thickness, 0.002s to 0.0029s for 6mm tube thickness and 0.0017s to 0.0021s for 9mm tube thickness, the ratio of mid-span velocity to ball velocity is less than 1. This coincides with the height of the second peak climbing time of the impact force.

The mid-span velocity will be consistent with the ball velocity, which makes the impact force show the phenomenon of platform segment. When the deflection of column reaches the maximum, the velocity decreases to 0. Because the ball no longer impacts the column, the column begins to recover.
part of the elastic deformation, driving the ball to rebound in the opposite direction. The air resistance is not involved in the whole simulation experiment. The ball will move away from the CFAAT column in a uniform straight line. The whole process speed diagram is shown in Figure 7, Figure 8, Figure 9.

Figure 7. The velocity of ball and 3mm column mid-span.
Figure 8. The velocity of ball and 6mm column mid-span.
Figure 9. The velocity of ball and 9mm column mid-span.

3.4. Concrete analysis:
CFAAT column is combined structure, which work together in the normal use of the structure. It is necessary to investigate the interaction between Al alloy tube and core concrete under lateral impact. The concrete in the middle of the column is the most affected under the impact action, and the maximum impact force, stress and strain data of the concrete in the middle of the column are shown in Table 4.

| Thickness | 3mm | 6mm | 9mm |
|-----------|-----|-----|-----|
| $F_{\text{max}}$ (kN) | 2.74 | 6.31 | 8.48 |
| $\sigma_{\text{max}}$ (MPa) | 37.62 | 56.40 | 80.84 |
| $\varepsilon_{\text{max}}$ | 0.0112 | 0.0182 | 0.0122 |

Figure 5 and Figure 6 that with the increase of tube thickness, the impact force of the ball on the column increases. Table 4 shows that the impact force transmitted from the tube to concrete mis-span increases. The stress corresponding to the force also shows the same law. The mid-span strain of 6mm tube column continues to increase compared with that of 3mm tube column, but the strain of 9mm tube column decreases compared with that of 6mm tube column. Figure 1 shows that, when $\xi > 1.12$, the stress-strain curve still shows an upward trend in the original descending stage. Therefore, $\xi > 1.12$, the core concrete is restrained more strongly. Taking advantage of simulation, the core concrete constitution with 9mm tube is defined as the core concrete constitution with 3mm tube. The results show that strain of core concrete of this model is 0.01842, which is higher than the original 9mm thickness column. It is proved that the hoop effect can obviously reduce the damage of core concrete caused by impact.

4. Conclusions
The influence of the thickness of Al alloy tube under lateral impact of the column is studied in this paper. The following conclusions are drawn:

1: After being hit by same object at same initial velocity, the maximum impact force of the CFAAT column with same outer diameter increases with the increase of the tube thickness. The mid-span deflection of CFAAT column decreases with the increase of Al alloy tube thickness.

2: The constitutive curve of core concrete under axial compression is divided into three sections with $\xi = 1.12$ as the boundary. It is found that impact force on the surface of the core concrete is consistent with that of the Al alloy tube. It increases with the increase of the thickness of the Al alloy tube. The
characteristics of stress are consistent with the impact force. But the surface strain of core concrete is different. When $\xi < 1.12$, the surface strain of concrete increases with the increase of Al alloy tube thickness, which means that although the increase of Al alloy tube thickness can reduce the overall damage of CFAAT column, it may increase the damage of core concrete surface. However, when $\xi > 1.12$, the surface strain of core concrete also decreases, which means that thicker Al alloy tubes can reduce the overall and local damage of CFAAT structure.

3: Impact resistance caused by the increase of tube thickness comes from the increase of Al alloy strength compared with concrete and the enhancement of concrete constraint caused by tube thickness.

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