

Dynamic responses of concrete-filled steel tubular member under axial compression considering creep effect

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Abstract. The finite element model of concrete-filled steel tubular member was established by the numerical analysis software considering material nonlinearity to analyze concrete creep effect on the dynamic responses of the member under axial compression and lateral impact. In the model, the constitutive model of core concrete is the plastic damage model, that of steel is the Von Mises yield criterion and kinematic hardening model, and the creep effect at different ages is equivalent to the change of concrete elastic modulus. Then the dynamic responses of concrete-filled steel tubular member considering creep effects was simulated, and the effects of creep on contact time, impact load, deflection, stress and strain were discussed. The fruits provide a scientific basis for the design of the impact resistance of concrete filled steel tubular members.

1. Introduction

The concrete creep will occur in concrete-filled steel tubular member under compressive stress at normal service stage, which destroys the cooperative work of concrete and steel tube and leads to internal force redistribution including concrete stress relaxation and steel stress increase. If the member encounters impact load at this time, the steel will enter plastic stage in advance. Creep also has a great influence on the natural frequency and dynamic response of concrete-filled steel tubular member [1].

At present, there is less research about creep influence on the structural dynamic performance. Sapountzakis' [2] researches show that the creep has a great influence on the natural frequency and dynamic response of the structure. The study of Zhou [1] also shows that the creep can change the natural frequency and dynamic response of the structure. Based on the B3 model, Mao [3] calculated the effect of creep on Guangzhou Yajisha CFST arch bridge, and the results show that the natural frequency and dynamic response of the arch bridge have a larger change after one year of creep. Many scholars have done a lot of experiments and numerical simulation on the dynamic response of concrete-filled steel tube [4, 5, 6, 7], however, it seldom took its responses under the combined action of axial compression and creep into account.

After the creep of concrete, the dynamic properties of the structure and member are significantly affected, therefore, it is important and necessary to study the dynamic performance of structures and member at service stage. In this paper, ABAQUS/Explicit software is used to establish the finite element calculation model of concrete-filled steel tubular member under axial impact and lateral impact, and analyze the influence of creep on the dynamic responses of concrete-filled steel tubular member.



2. Equivalent elastic modulus of core concrete

In practical engineering, the service load of concrete-filled steel tubular member under axial compression is generally 50%-60% of the ultimate load, that is to say that steel and concrete both work at the elastic range. It is assumed that the stress-strain relation still satisfies linear proportional relation after concrete creep. $\tilde{E}_\varphi(t, t_0)$ is defined as equivalent elastic modulus of the core concrete at calculating age considering the creep effect, and the formula can be expressed as:

$$\tilde{E}_\varphi(t, t_0) = \frac{\sigma_c(t)}{\varepsilon_c(t)} \quad (1)$$

where t is the calculated age of concrete-filled steel tube; t_0 is the initial loading age of concrete-filled steel tube; $\sigma_c(t)$ is the stress of the core concrete under long-term load; $\varepsilon_c(t)$ is the strain of the core concrete under long-term load. It needs to be explained that Huo model is used to calculate the creep coefficient of concrete for $\sigma_c(t)$ and $\varepsilon_c(t)$ [8], and the aging coefficient is 0.8 as suggested by Trost [9].

The creep effect of core concrete in concrete-filled steel tubular member is equivalent to the change of its elastic modulus, and $\tilde{E}_\varphi(t, t_0)$ is brought into the follow-up lateral impact analysis for concrete-filled steel tubular member under axial compression in order to realize its force analysis under the combined action of axial compression, creep and lateral impact.

3. Finite element model

3.1. Specimen geometric model and impact parameters

The geometric model of the specimen is shown in figure 1. The specimen parameters are shown in Table 1, where, α is the steel ratio, ξ is the confinement coefficient.

Table 1. Concrete filled steel tube parameters

D/mm	t/mm	α	ξ	M/kg
63	1.5	0.103	1.20	10.0

The steel tube is Q235. And core concrete is C30 using standard curing.

The lateral impact parameters of concrete-filled steel tubular member under axial compression are shown in Table 2, where λ is the slenderness ratio, n is the axial compression ratio, N is the axial pressure; x is the mass ratio, and V is the impact velocity of the impact block. According to Eq.(1), the equivalent elastic modulus of core concrete at different ages is shown in Table 2.

Table 2. Specimen impact parameters

Age	Equivalent elastic modulus/MPa	α	λ	N/kN	n	m/kg	x	$V/\text{m/s}$	Impact position
28 days	30000	0.103	44.4	27.1	0.4	20.0	2.0	10	midspan
4months	17592	0.103	44.4	27.1	0.4	20.0	2.0	10	midspan
6months	16745	0.103	44.4	27.1	0.4	20.0	2.0	10	midspan
1 years	15681	0.103	44.4	27.1	0.4	20.0	2.0	10	midspan
5 years	14355	0.103	44.4	27.1	0.4	20.0	2.0	10	midspan
30 years	13780	0.103	44.4	27.1	0.4	20.0	2.0	10	midspan

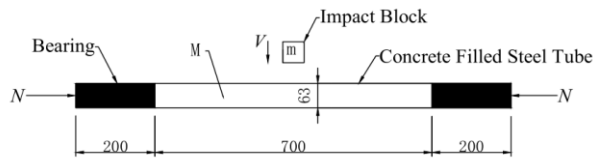


Figure 1. The geometry model

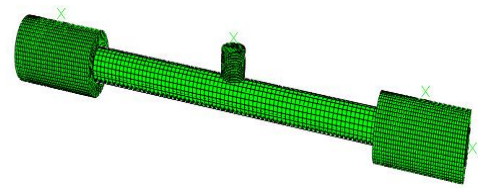


Figure 2. The finite element model

3.2. Material model and element type

The constitutive model of steel is the Von Mises yield criterion and kinematic hardening model. Plastic damage model is used for concrete. C3D8R is adopted to simulate the steel tube and core concrete in this paper. Rigid impact block, support and end plate all use R3D4 simulation.

3.3. Boundary condition and interface treatment

Fixed support is used to realize the constraint condition of the end part of the concrete-filled steel tube member. The connection mode of steel tube and core concrete is binding style. The finite element model of the specimen is shown in figure 2. The contact between the steel tube and the support uses surface-surface contact. The interface between steel tube and concrete and that between steel tube and impact block is both defined by “general contact” model.

4. Results and analysis

4.1. Energy analysis of impact process

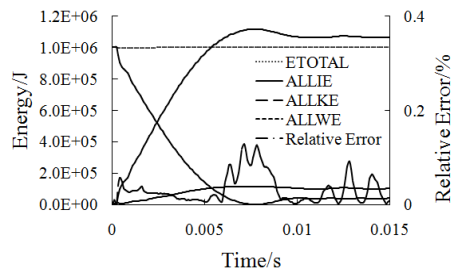


Figure 3. The energy of collision

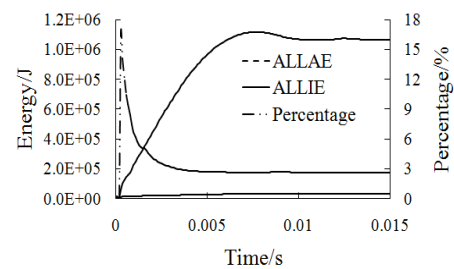


Figure 4. The internal energy of collision

In the finite element model, the error of the energy of whole model should be less than 1% [10]. It is necessary to control the pseudo strain energy E_A produced by shear deformation. In this paper, taking the age of 28 days in table 2 as an example, whether the model unit division and the hour glass control meet or not the precision requirement is to be analyzed.

As can be seen from figure 3, the total energy error is less than 1% during the whole process. From figure 4, the proportion of the pseudo strain energy of the model is less than 3% in addition to the shock initiation time. Therefore, it can be considered that the finite element model is reasonable.

4.2. Creep effect on impact load

It can be seen from figure 5 that the impact load rises rapidly to a peak value in a short time after the impact, and then form the second peak after the shock, and then decreases to zero value, and then reach the platform stage of the impact load, finally enter the unloading phase. The impact load time history curves of different ages showed the same trend. From figure 6 that with the development of the core concrete creep, the peak value of the lateral impact load decreases gradually, and the peak value of the impact load at the age of 30 years is less than the peak value of the impact load at the age of 28 days and it is about 25% reduction.

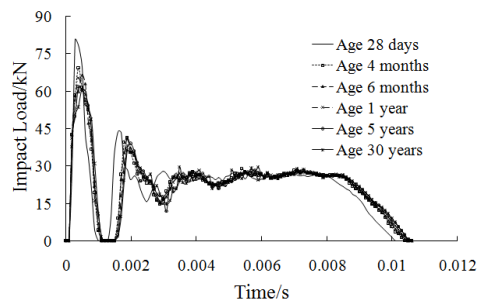


Figure 5. Time history curve of impact load in different ages

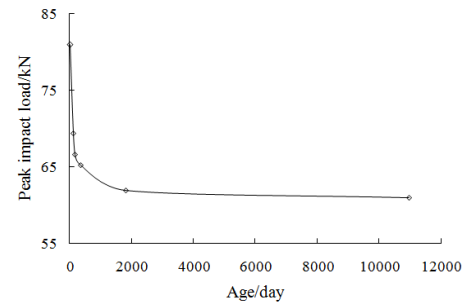


Figure 6. Peak value of impact load in different ages

4.3. Creep effect on contact time

It can be seen from figure 7 that the impact contact time is about 10ms. With the increase of core concrete age, the contact time increases gradually. It increases rapidly when the concrete age is short, and the contact time keeps constant after 1 year.

4.4. Creep effect on impact deflection

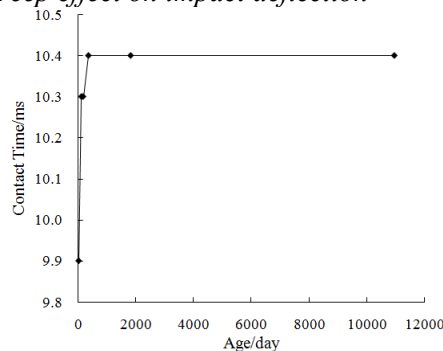


Figure 7. The time of impact contact in different ages

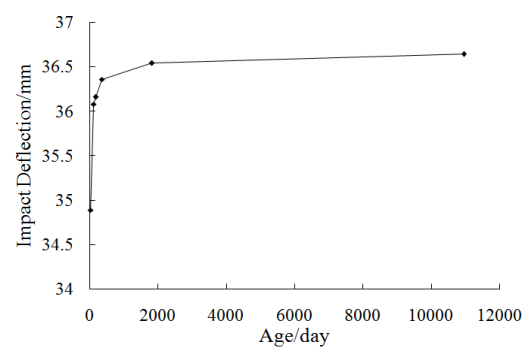


Figure 8. The peak value of impact displacement in different ages

As can be seen from figure 8, with the increase of the concrete creep, the peak value of the lateral impact deflection increases. This is because with the increase of the concrete creep, the integral stiffness of the member decreases gradually, and the impact deflection increases. The peak value at the age of 30 years increases 5% than that of 28 days.

4.5. Creep effect on stress and strain of steel tube

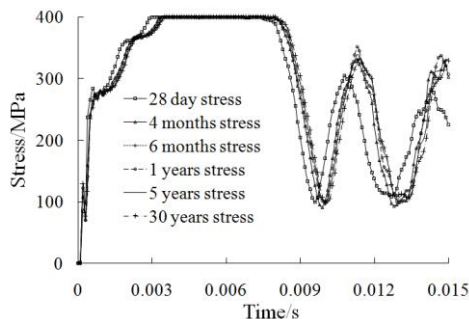


Figure 9. The time history curve of impact steel stress at different ages

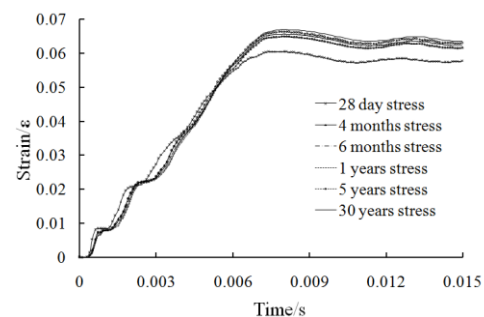


Figure 10. The time history curve of impact steel strain at different ages

It can be seen from figure 9 that the stress of the steel tube increases rapidly after the impact, and finally reaches the ultimate strength of the steel tube 400MPa. This is consistent with the constitutive model of steel in this paper. The steel tubes have been destroyed because all steel tubes reach ultimate strength in the process of impact. The stress of steel tube increases or decreases slowly with the growth of concrete age. It can be seen from figure 10 that the strain growth of all the steel tubes keep consistent at the early stage, and gradually separate after 0.006 seconds. With the increase of creep, the peak value of impact strain increases. The peak strain of the steel tube at 30 years increased 11% than that at the age of 28 days.

4.6. Creep effect on concrete stress and strain

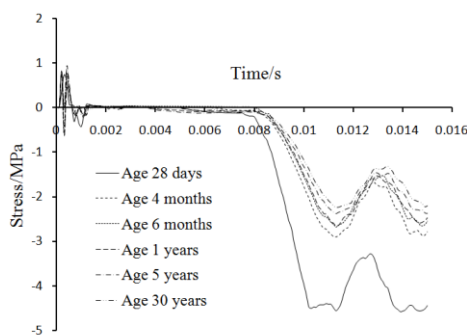


Figure 11. The time history curve of impact concrete stress at different ages

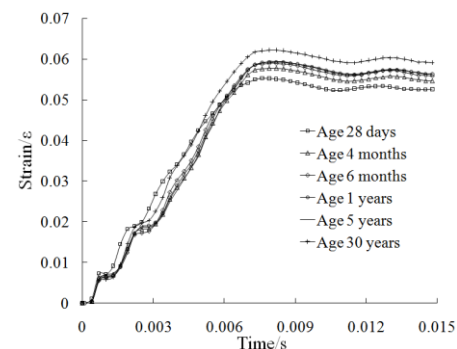


Figure 12. The time history curve of impact concrete strain at different ages

It can be seen from figure 11 that the changes of concrete stress at different ages are consistent at the early stage, and after 0.009 seconds it has a big difference. At the age of 28 days, the maximum stress is 4.54MPa, and it is 2 times larger than the maximum stress of concrete at the age of 30 years. This is mainly caused by redistribution of internal force due to concrete creep. It can be seen from figure 12, with the increase of age, the peak strain of core concrete increases gradually, the maximum strain of core concrete at the age of 30 years increased 11% than that at the age of 28 days.

5. Conclusions

By taking ABAQUS/Explicit software as analysis tool, the creep effect of core concrete at different ages is equivalent to the change of its elastic modulus to realize the dynamic response under the combined action of axial compression, creep and lateral impact. The conclusions are as follow:

- (1) The creep of core concrete has a great influence on the peak value of impact load. From 28 days to 30 years, the peak value of impact load decreased from 80.9kN to 61.0kN.
- (2) With the increase of age, the impact contact time and impact deflection of concrete-filled steel tubular member under axial compression subjected to lateral impact gradually increase.
- (3) When the concrete-filled steel tubular member under axial compression are subjected to impact, the maximum stress of concrete decreases with the increase of age, and when the age is short, it decreases faster. The impact strain of steel tube and concrete increases with the increase of age.

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