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Study on Mechanical Properties of Steel Shaped Columns Under Impact

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Abstract. Taking axial compression ratio and velocity as variables, using the general finite element software ABAQUS, this paper simulates the behavior of H-beam under impact, and analyzes the impact resistance of this component. The result is that changes in the axial compression ratio mainly cause local damage, which can lead to changes in the degree of damage to such components. The impact resistance of such components can be increased by appropriate axial compression ratios, but the damage to the components is more severe than excessive axial compression; The change in velocity directly leads to a change in kinetic energy, causing a change in the force acting on the component, thus having a significant impact on the impact resistance of the component, with overall instability damage as the final form of damage.

Keywords. H-shaped steel, axial compression ratio, speed

1. Introduction

At present, steel structures have become one of the most common and widely used structures in the construction industry. However, all buildings are inevitably subjected to unexpected collisions during normal service, such as vehicle collisions, falling rocks, and so on. Scholars at home and abroad have analyzed and studied the impact resistance of structures such as reinforced concrete [1,2] and steel pipes [3,4], while there is relatively little research on the dynamic response of steel columns under impact loads. With the development of the times, the application of steel structures in the construction industry is increasing, and further research is needed on their impact resistance. From the perspective of a large number of impacted steel columns, these steel columns are usually connected to the axial loads transmitted by upper plates, walls, beams, and other components, that is, the steel columns are subjected to both lateral impacts and axial loads.

This time, the finite element software ABAQUS will be used, while considering the effect of strain rate on the material, to study and analyze the numerical simulation analysis of H-shaped steel columns under lateral impact.

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2. Finite Element Model

Finite element analysis has been widely used in scientific research due to its precise and efficient characteristics. In this chapter, ABAQUS will be used to establish a model of H-shaped steel columns under impact loads.

2.1. Unit Type and Material Constitutive

The H-beam adopts an 8-node linear hexahedron element (C3D8R), while using reduced integration can reduce calculation time and improve calculation accuracy. Moreover, adding virtual stiffness through hourglass control can avoid the generation of zero energy mode. The drop hammer is usually regarded as not deforming, so it is considered as a "rigid body". The unit type is a discrete rigid body element (R3D4), which is considered not to deform and absorb energy during the entire impact simulation process. In terms of material, H-shaped steel adopts Q355, and its material adopts a three-fold model, as shown in Figure 1. Unlike static action, it is necessary to consider the strain rate effect of the material under impact action. Under impact action, the material will be in a strain strengthened state, and the yield strength of the material will be enhanced due to the strain rate effect [5]. This article adopts the Cowper Symonds model[6], The formula is as follows:

$$\sigma_{eq}=\sigma_0[1+(\frac{\dot{\varepsilon}_p}{D})^{\frac{1}{q}}]$$

In the above equation, σ_{eq} is the yield strength of the section steel under dynamic loadi, σ_0 is the yield strength of the section steel under static load,$\dot{\varepsilon}_p$ is the effective plastic strain rate of the section steel, and D and q are mainly parameters related to material type and strain strengthening. In this paper, the value of D is 6844s^{-1}, and the value of q is 3.91[7].

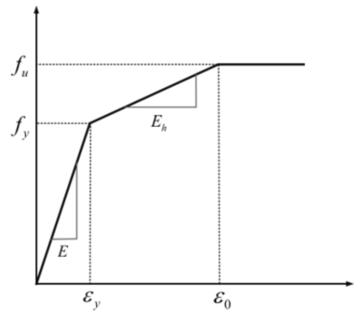

Figure 1. Material Model

2.2. Establishment of Finite Element Model

In Figure 2, this numerical simulation used H-shaped steel columns with a web width of 6mm, a flange height of 8mm, and a total length of 1500mm.

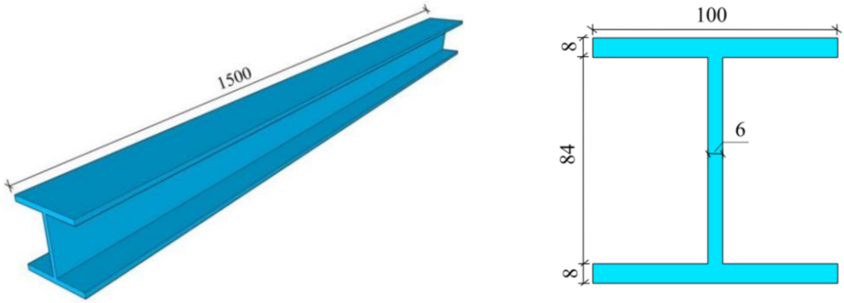

Figure 2. Structural Drawing of H-shaped Steel Structure

One end of the H-shaped steel column is fully fixed, and set constraints in all directions except the axial direction at the top. This simulation achieves different axial compression ratios by changing the magnitude of axial load. The ratio of axial force is selected as 0, 0.2, 0.4, 0.6, and 0.8 to explore the impact effect on the mechanical properties of steel columns under different axial compression ratios. At the same time, change the drop hammer speed to obtain the impact response of H-shaped steel at different speeds. The speeds are selected as 2.78 m/s, 5.56 m/s, 8.33 m/s, 11.11 m/s, and 13.89 m/s. When considering the impact of speed changes on the steel column, the axial compression ratio is selected as 0.2 [8].

This simulation adopts surface-to-surface contact, hard contact in normal direction, penalty function in tangent direction, and friction coefficient is set to 0.4[9]. Due to the greater stiffness of the drop hammer, the bottom surface is set as the main surface, and the upper surface of the H-shaped steel in contact with the drop hammer is set as the secondary surface. Position the drop hammer at a 1mm gap from the uppermost layer of the steel column, Figure 3 is a schematic diagram of the finite element model.

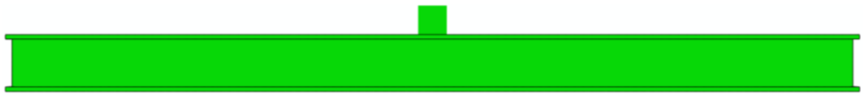

Figure 3. Schematic Diagram of Finite Element Model

3. Dynamic Response Analysis

To study the response analysis of H-shaped steel columns with initial axial load under dynamic load, the axial compression ratio is set to 0.2, the drop weight is set to 200kg, and the initial speed is set to 2.78 m/s as examples to conduct a detailed analysis of their dynamic response.

Throughout the entire dynamic load impact process, the dynamic load experienced three stages: peak value, platform value, and unloading. At the moment when the falling hammer contacts the H-beam, The collision force has reached its peak . At this moment, the location where the H-beam is impacted will sag downward, At this point, the steel column will immediately undergo deformation, which can be used to dissipate some of the kinetic energy brought by the falling hammer. After the instant, the impact force will decrease, and then the energy will be transmitted along the component to both ends to consume the remaining kinetic energy of the falling hammer. At this time, the dynamic load will increase again in a short period of time. After a short period of fluctuation, the falling hammer and the H-beam are separated, and the impact force is zero, Since then, the entire impact process has ended. The stress nephogram of the component is shown in Figure 4. When the falling hammer strikes the H-shaped steel, due to the law of conservation of energy, the velocity of the falling hammer will decrease at this time, and the lost kinetic energy will be transformed into the deformation energy of the H-shaped steel column, make relative concentrated stress on the upper flange of the impact site, and local deformation tends to be obvious. In addition, The farther away from the point of impact, the weaker the remaining deformation will be, indicating that the component can still maintain better stability under this axial load.

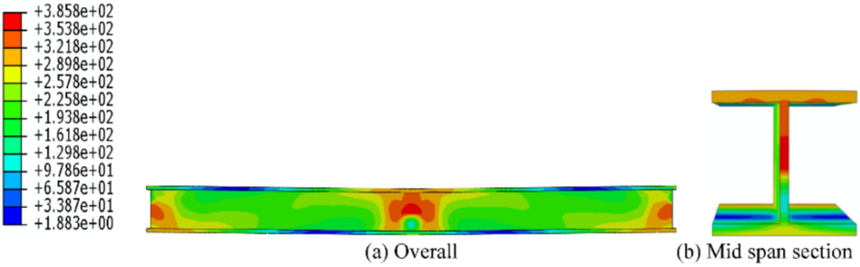

Figure 4. Component Stress Cloud Chart

4. Parameter Analysis of H-shaped Steel Columns under Dynamic Load

In the study of lateral impact resistance of columns, axial compression ratio, slenderness ratio, mass, speed, etc. are all factors that affect their performance. This section selects two parameters, axial compression ratio and velocity, and each parameter is used as a variable to explore the impact resistance performance of H-shaped steel columns.

4.1. Analysis of Effects under Different Axial Loads

The magnitude of axial load is one of the main factors affecting the lateral impact resistance performance of columns. By changing the magnitude of the axial load, From the results of numerical simulation, it can be seen that when the axial load is small, the overall failure mode of the steel column is relatively not obvious, mainly due to local deformation. As the axial load increases, the downward depression of the steel column increases, and the local deformation of the column becomes more obvious to the naked eye.

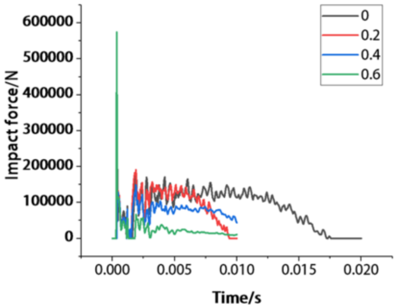

Figure 5. Time history curves of impact force under different axial loads

In Figure 5, when the presence of axial pressure reduces the percussive force, when the axially oriented compression ratio is small, The peak values of the interaction forces do not differ significantly, and the overall trend is generally the same, indicating that the impact process is less affected by axial compression ratio axial load size at this time. When the ratio of axial load to the ultimate load of the component is 0.6, the peak value suddenly increases, and the degree of component damage increases, affecting the stability of the structure. Therefore, it is necessary to control the axial compression ratio of the component during the impact process to ensure the stability of the component.

Table 1. Maximum midspan displacement and peak stress at different axial compression ratios

Speed (m/s)	Axial compression ratio	Maximum displacement in midspan (mm)	Peak stress (MPa)
2.78	0	11.60	359.97
	0.2	7.91	361.07
	0.4	10.36	365.82
	0.6	20.38	378.88
	0.8	Non convergence	Non convergence

From Table 1, As the axial compression ratio increases, the peak stress increases slowly, and the peak stress is less affected by the axial compression ratio; When the ratio of axial pressure is not higher than 0.4, that midspan displacement ratio will decrease without axial load, but as the axial compression ratio gradually increases, the midspan displacement will also increase, when the magnitude of the axial compression ratio is less than 0.4, the presence of axial burden can reduce the midspan displacement value, that is, appropriate axial loads within a certain range can enhance the stability of such components; When the ratio reaches 0.6, excessive mid span displacement of components, and if the axial force continues to increase, it may even cause instability of the structure, eventually being washed out. This indicates that an appropriate axial compression ratio is beneficial to the stability of this component and improves the impact resistance of the steel column to a certain extent. In addition, when it reaches 0.8, ABAQUS does not converge at this time.

4.2. Impact Velocity Response Analysis

A change in speed will affect the magnitude of energy, thereby altering the magnitude of force. With the increase in velocity, both the overall deformation and local deformation of the H-beam become more apparent, and the impact position is depressed downward in a V-shaped shape. As shown in Figure 6, with the increase of speed, the overall trend does not change significantly, but the peak impact force and duration increase to varying degrees. According to literature [10], the peak stage of impact force is determined by local stiffness. Since the greater the impact speed, the more obvious the strain rate effect is, the greater the impact force peak value is as the speed increases. Speed will affect the power effect, and both will change together, the impact force plateau value increases in order to balance the impact force, so the time consumed will also increase, resulting in an increase in the impact force holding time. From Table 2, As the speed increases uniformly, the deflection value of the component also increases, which also increases the peak stress. Finally, the overall V-shaped instability failure occurs. Changes in velocity can lead to increased overall and local deformation. It can be seen that the increase in the speed of the falling hammer has a significant impact on the deformation and mechanical properties of the component. Therefore, The influence of force on the component should be fully considered when designing the component. Low velocity may cause local damage, while high velocity may cause overall instability.

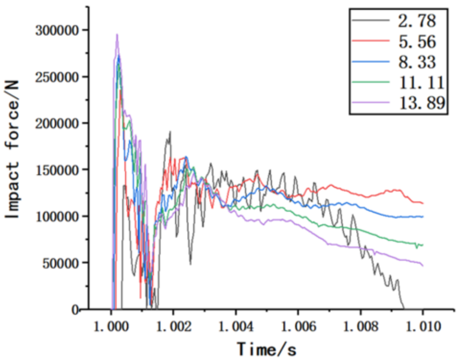

Figure 6. Time history curve of impact force at different speeds

Table 2. Maximum midspan displacement and peak stress at different speeds

Axial compression ratio	Speed (m/s)	Maximum displacement in midspan (mm)	Peak stress (MPa)
0.2	2.78	7.91	360.04
	5.56	25.00	434.833
	8.33	52.00	493.95
	11.11	80.75	494.0
	13.89	109.41	494.0

5. Conclusion

This article uses the finite element software ABAQUS to simulate the dynamic response of H-shaped steel columns under lateral impact resistance under different axial compression ratios and velocities. A brief analysis of this mechanical performance can be obtained, and the results are as follows:

(1) The change in axial compression ratio will affect the degree of damage to steel columns, but has little impact on the peak stress. An appropriate axial compression

ratio can effectively increase the stability of such components; When the axial load is small and the ratio is less than 0.4 the change of the axial compression ratio has no significant impact on the damage degree of the component; If the axial compression ratio is too high, it will accelerate the instability of the component, so the axial compression ratio of such components should be controlled within a certain range.

(2) Impact velocity has a significant impact on such components. When the velocity is too high, the component will collapse and the overall instability will occur; The increase in speed will lead to varying degrees of improvement in the peak stage, platform value stage, and unloading stage of the impact force time history curve, while the impact force holding time and peak stress will also increase.

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