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Numerical Simulation of Dynamic Response of Suspension Bridge Structure under Explosion Load

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Abstract

Bridges are buildings built over natural and artificial obstacles. They play an important role in China's modern transportation network. Suspension Bridges are widely used because of their strong spanning ability and high material utilization rate. In recent years, more and more attention has been paid to the safety of Bridges in explosion accidents, including the transportation of inflammable, explosive and chemical materials. Bridges will be damaged to a certain extent by the impact of explosion, which will affect the traffic and personal safety. Therefore, the anti-explosion research of Bridges is essential and has very important theoretical significance and use value for the design of bridge engineering. Therefore, by using the finite element software Hypermesh modeling, combined with the dynamic response theory of explosion load, this paper conducts the numerical simulation research on the dynamic response of self-anchored suspension bridge structure under the action of explosion load by changing the explosive equivalent.

Keywords

Explosion Load; Self-anchored Suspension Bridge; Dynamic Response.

1. Algorithm theory and material model

1.1 The ale algorithm

For lS-DYNA's explicit dynamic analysis, Lagrange columns are used in computational solid mechanics and Euler columns are used in computational fluid mechanics. However, when solving the fluid-solid coupling problem such as explosion, an algorithm combining the two methods is needed, which is called Arbitrary Lagrange -Euler algorithm, ALE algorithm for short [1].

1.2 Material model and equation of state of air

The air unit type is SOLID164, ALE grid is adopted, and the algorithm type is single point ALE multi-substance unit. The material model is lS-DYNA hollow material model, which is defined by keyword *MAT_NULL. The linear polynomial equation of state is used to describe the air state, and defined by the keyword *EOS_LINEAR_POLYNOMIAL [2], the linear polynomial is as follows:

$$p = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + (C_4 + C_5\mu + C_6\mu^2)E \tag{1}$$

Air material parameters were shown in Table1

Table 1. Air material parameters

Material	ρ	C_0	C_1	C_2	C_3	C_4	C_5	C_6	E_0	V_0
Air	0.00129	-1×10^{-6}	0	0	0	0.4	0.4	0	0	0

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1.3 Material model and state equation of explosive

The explosive unit type is SOLID164, ALE grid is adopted, and the algorithm type is single-point ALE multi-substance unit. The material model used high explosive material model, and modified the keyword *MAT_HIGH_EXPLOSIVE_BURN to define the density, explosive pressure and explosive velocity of the explosive. The LS-DYNA program uses the JWL equation of state to describe the relationship between pressure and volume of explosive detonation products [3] The JWL equation of state is as follows:

$$p = A\left(1-\frac{\omega}{R_1V}\right)e^{-R_1V} + B\left(1-\frac{\omega}{R_2V}\right)e^{-R_2V} + \frac{\omega E_0}{V} \tag{2}$$

Keyword *EOS_JWL was used to define the JWL equation of state in LS-DYNA, and parameters related to explosive unit and detonation time controlled by *INITIAL_DETONATION center position were shown in Table2.

Table 2. Parameters of explosive materials

Materials	$\rho\ (g/cm^3)$	D	PCJ	A	B	R_1	R_2	Ω	E_0	V_0
Explosive	1.6	0.993	0.255	5.409	9.373×10^{-2}	4.5	1.1	0.35	0.8	1

1.4 Bridge model

Hunan Road Bridge has a total deck width of 52m, which is the widest concrete self-anchored suspension bridge with main girder in China. The main bridge is a double-tower double-cable surface self-anchored suspension bridge with a total length of 218m, main span of 112m and side span of 53m. The main tower is h-shaped, with a solid rectangular section of the tower. The height above the bridge deck is 45m. The support between the lower beam of the west tower and the main beam is a one-way sliding support across the bridge, and the east side is a two-way sliding support. The main beam adopts the cast-in-place prestressed concrete stiffening beam, the main cable is a quadratic parabola, the cable plane spacing is 31.7m, the suspension cable spacing is 5m, a total of 37 pairs. The tower of Hunan Road Bridge is composed of the main tower and the secondary tower, using C40 concrete. The tower height above the cap is 57.68m, and the tower height above the bridge deck is 45m.

2. Finite element model and working condition

Considering the mechanical characteristics of self-anchored suspension bridge structure and the spatial mechanical effect, Hypermesh is adopted to establish the overall spatial model according to the actual completed state of Hunan Road bridge to study the dynamic response of the overall bridge structure. The finite element model is shown in Fig 1.

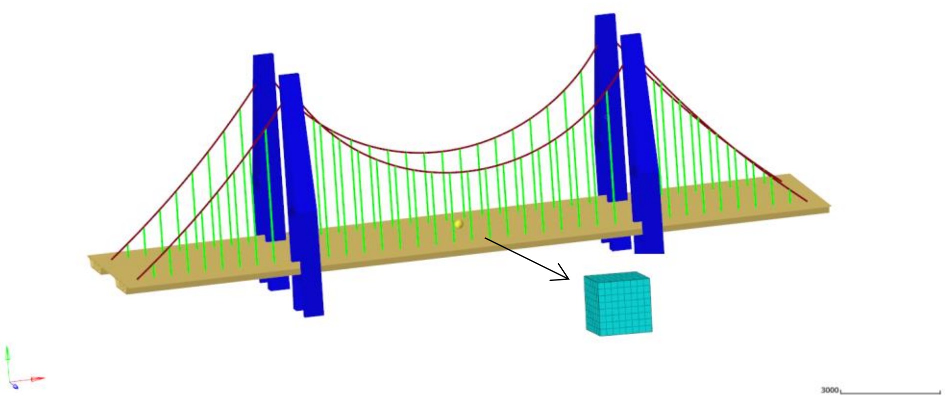

Fig. 1 Finite element model of Hunan Road Bridge

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Working condition 1: The explosive with an equivalent of 200kg TNT is applied in the middle of the suspension bridge. The explosive is set as a cube with a side length of 50cm. The center of the cube is the initiation point, and the vertical distance between the explosive initiation point and the bridge deck is 2m.

Working condition2: The explosive with an equivalent of 400kg TNT is applied in the middle of the suspension bridge, and the explosive is set as a cube with a side length of 63cm. The center of the cube is the initiation point, and the vertical distance between the explosive initiation point and the bridge deck is 2m.

3. Simulation results and analysis

Node no. 1523263, when the explosion load acts on the suspension bridge, node No. 1523263 also experiences corresponding displacement. The curve shows a trend of rising first and then falling. The crest of the displacement curve attenuates to a certain extent and eventually tends to be stable. The node displacement curve is shown in Fig. 2.

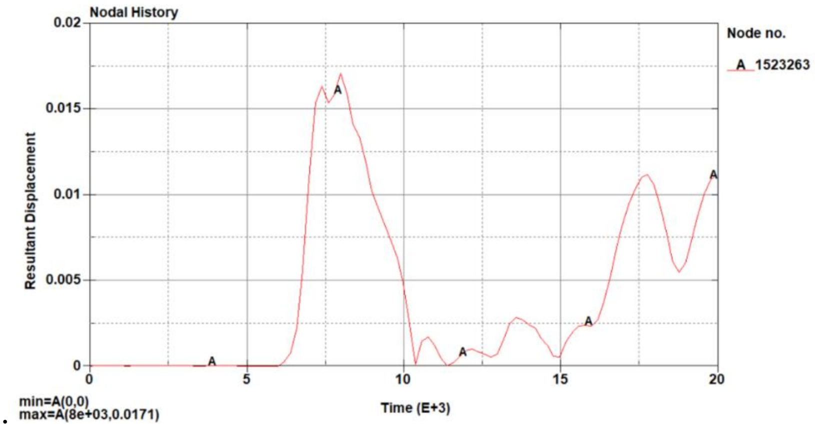

Fig. 2 Displacement diagram of node no. 1523263

In order to make a comparative study with working condition 1, nodes at the same position on the bridge deck are selected for node displacement and node vibration analysis. Node number is 715905. When the explosion load acts on the suspension bridge, node No. 715905 also has corresponding displacement. Its displacement reaches a maximum of 0.0352cm, and after this point, the wave crest of the displacement curve has a certain attenuation and eventually tends to be stable. The node displacement curve is shown in Fig. 3.

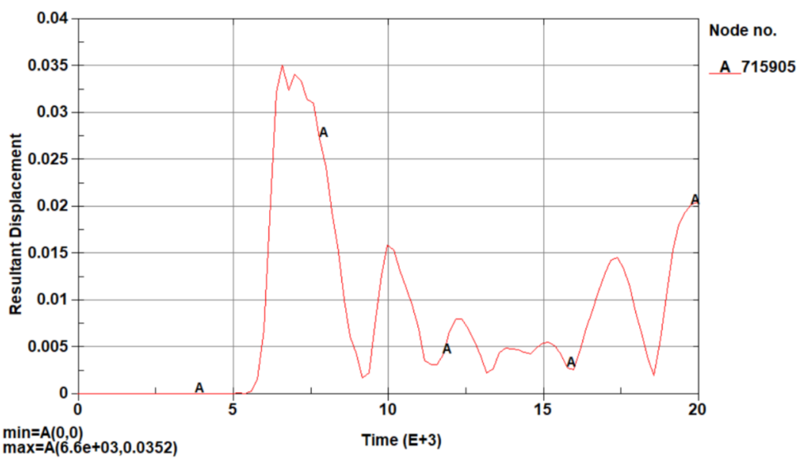

Fig. 3 Displacement diagram of node no.715905

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Compared with the test results, it can be seen that under the premise of control variables, the change of TNT equivalent will change the data results Compared with working condition 1, the TNT equivalent of working condition 2 is increased by 200kg. The node displacement of working condition 2 is 0.0352cm, and the node displacement of working condition 1 is 0.0171cm. The maximum displacement of the node is increased by 0.0181cm, or 105.8%.

4. Conclusion

In this paper, based on the basic theory of explosion, the suspension bridge model is simulated by finite element software, and the theoretical analysis of the bridge under the action of explosion load is carried out. The experimental study of different explosive equivalent is carried out, and the main influencing factors are obtained by analyzing the law of shock wave propagation in the bridge. At the same time, LS-DYNA/ANSYS is used to simulate the dynamic response of suspension bridge model, and the following conclusions are obtained: When the EQUIVALENT of 200kg and 400kg of TNT is applied at the mid-span, the greater the EQUIVALENT of TNT, the greater the displacement of suspension bridge node. Therefore, it is concluded that the larger the TNT equivalent is, the more obvious the dynamic response of suspension bridge structure is.

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