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Research Article

Explicit Finite Element Analysis of Dynamic Response of Protection Frame System Subjected to Impact Loading

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Abstract: Height limit protection frame of railway bridges apply to the road crossing the railway bridge, its role is to ensure the safety of the railway bridge to prevent road motor vehicles to hit the bridge beam, causing beam damage and even endangering the safety of the railway lines. Therefore, it is necessary to do in-depth discussion of collision mechanism and failure mode of height limit protection frame of railway bridges under the impact of the over-high vehicle, in order to improve the survivability of protection frame to protect the safety of the railway bridge and rail transport. Some rules and characteristics were obtained by establishing collision model of height limit protection frame of railway bridges and the over-high vehicles using the software of ANSYS/LS-DYNA and studying the dynamic response of protection frame impact loading by the vehicle under the different parameters. Thus for the similar protection frame structure design, maintenance and damage assessment provide theoretical support.

Keywords: ANSYS/LS-DYNA, dynamic response, explicit finite element model, protection frame system, railway bridges

INTRODUCTION

In recent years, China's railway transport enterprises develop rapidly. By the end of 2009, China Railway operating mileage reached to 86000 km and leaped to the world's second. Railway has been in position of the backbone in our country's comprehensive transportation system. It's the artery to connect between each big economic region and between urban and rural areas and played an irreplaceable role on the development of the national economy

Therefore, the safety of railway transportation is particularly important. Height limit protection frame of railway bridges apply to the road crossing the railway bridge, its role is to ensure the safety of the railway bridge to prevent road motor vehicles to hit the bridge beam, causing beam damage and even endangering the safety of the railway lines.

Since the present stage of the Collision mechanism of action for the collision of high truck and bridge collision avoidance facilities (such as the size of the impact force, the size of the collision impulse, how to use the buffer device to extend the role of time, energy absorption, the device energy absorption mechanism, etc.) and other key issues are not enough, the design of many anti-bumping lacks of scientific guidance, the evaluation of the protective effect also lacks of the necessary basis, which extremely limits actual engineering application results. Currently, our existing norms of the railway bridge do not limit the high protective frame structure. The hit load values and the design have no corresponding regulations. Researches about collision analysis of over-high vehicle with protection frameworks for height limit are still lacking. And corresponding foreign norms can not be entirely applicable to the work of ours (Wu *et al*., 2007; Bai *et al*., 2011; Li *et al*., 2002). So research in this area should make reference to research resulting for further in-depth study.

In this study, we use the collision process of height limit protection frame of railway bridges and the over-high vehicles as an example, built its model and conducted its analysis of the collision process based on ANSYS/LS-DYNA and the general rules and characteristics were summarized in order to provide some theoretical basis for subsequent research.

EXPLICIT FINITE ELEMENT ANALYSIS MODEL

The collision process between high protection frame and motor vehicle is a complex transient physical process, which involves material nonlinearity and geometrical nonlinearity. The combined effect of nonlinear physical processes makes protection frame of the collision problem becomes very difficult to solve. Therefore, the numerical solution is often used in such problems.

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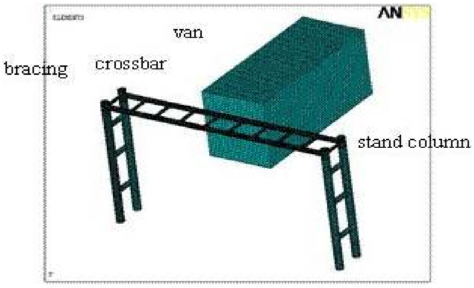

Fig. 1: Whole finite element model

The general equation of motion collision problem can be expressed as Eq. (1):

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F^{ex}\} \tag{1}$$

In which,

[M], [C], [K] : The mass matrix, damping matrix and stiffness matrix respectively
$\{\ddot{u}\}$, $\{\dot{u}\}$, {u}: The acceleration vector, speed vector and displacement vector
$\{F^{ex}\}$: The outer force vector which including the impact force

Explicit central difference method is often used for calculate the dynamic response of such collision problem. And this method does not require matrix decomposition or matrix inversion, without solving simultaneous equations, fast calculation speed, time step can be calculated through the automatic control and accurate and stable solution is guaranteed (Song *et al*., 2009).

Finite element collision model of protection frame and vehicle main title: The finite element collision model is built based on the following assumptions using ANSYS/LS-DYNA analysis software (Wu *et al*., 2008; Xu and Zhang, 2010).

Basic assumption:

- Simplified the vehicle model into a van model which has the same quality and the same size
- The bottom of protection frame and foundation is treated as rigid connection and without considering the interaction between foundation and protection frame
- The impact angle is 90°
- Assume that car has no displacement in the vertical direction

MATERIAL MODEL

The collision process of protection frame and car is a transient process and material damage has a certain rate, so this study selects the plastic material model which related with strain rate (Tao *et al*., 2007; Bai, 2005; Bao, 2005; Ray *et al*., 2006). The specific material parameters are as follows: material density p = 7.8×10^3 kg/m^3, elastic modulus E = 2.0×1011 N/m^2, tangent modulus E_{tan} = 7.63×108 N/m^2, the initial yield stress σ_0 = 3.1×108 N/m^2, Poisson's ratio υ = 0.27. The strain rate is considered with Cowper-Symonds model and the yield stress as shown in Eq. (2):

$$\sigma_Y = \left[1 + \left(\frac{\dot{\varepsilon}}{C}\right)^{\frac{1}{P}}\right]\left(\sigma_0 + \beta E_P \varepsilon_P^{eff}\right) \tag{2}$$

In which,

σ_0 : The initial yield stress
$\dot{\varepsilon}$: Strain rate
ε_P^{eff} : Effective plastic strain
C & P : Strain rate parameter of Cowper Symonds model
E_p : Plastic hardening modulus, expresses as E_p = $E_{tan}E/E\text{-}E_{tan}$

Finite element model: Protection frame is welded using hot- rolled seamless steel pipe. Assume that the sizes of each part of the components are as follows: the height of stand column is 4.74 m, size of cross-section is ϕ 280×10 mm; the length of bracing between stand column is 1.0 m, size of cross-section is 180×10 mm; the length of crossbar is 9.0 m, size of cross-section is ϕ 180×10 mm; the length of bracing between crossbar is 1.0m, size of cross-section is ϕ 110×5 mm Song *et al*. (2009).

Referencing of the geometry of the container of land transport, van model dimension is taken as 6.0×2.5×2.5 m; bottom plate thickness is 50 mm, the remaining thickness is 10 mm. The material models and element types used were consistent with protection frame (Zhao and Liu, 2012; Bi and Zhang, 2011).

The whole finite element model is shown in Fig. 1. The models were divided into grids using the method of sweep (He *et al*., 2012; Lu *et al*., 2007). As the dynamic response become larger due to the upper crossbar, bracing and car in contact partly, so the mesh size of the upper crossbar of protection frame, bracing and the front of the car is 30 mm in the process of meshing and the remaining is 60 mm.

CALCULATION RESULTS AND ANALYSIS

The destruction of protection frame is analyzed respectively in the initial velocity 4, 7 and 10 m/s three conditions.

The equivalent stress cloud of protection frame at the end of collision is shown in Fig. 2. From the figure

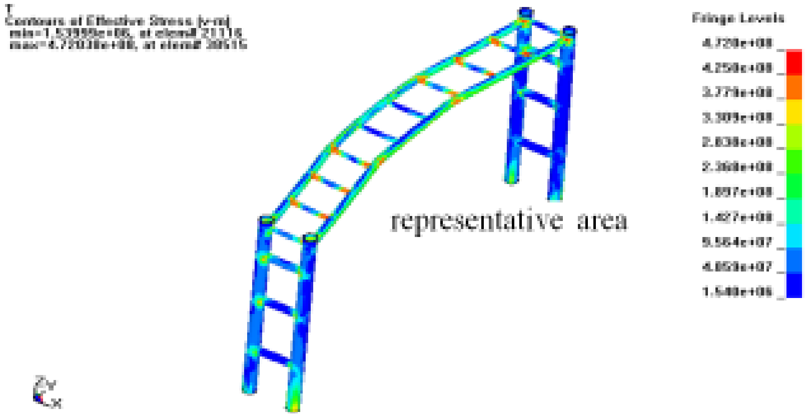

Fig. 2: Equivalent stress cloud of protection frame

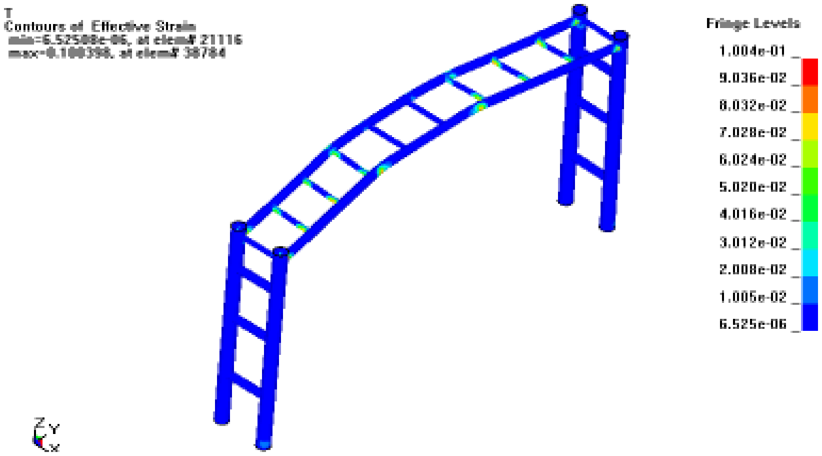

Fig. 3: Plastic strain cloud of protection frame

it can be seen that: the corresponding maximum equivalent stress at the end of collision is 472 MPa which goes beyond material yield stress 310 MPa. It suggests that part of protection frame has got into yield state (Griengsak and Eric, 2004). At the same time it can be seen that: the equivalent stress cloud of the upper crossbar's concave area and node area of support at both ends is displayed in red. It means that the stress here is in the 377.9~472 MPa section. It shows that this part has entered into plastic state, the stress of the rest part is small and the most are in the elastic range.

The plastic strain at the end of collision is shown in Fig. 3. From the figure it can be seen that: the plastic strain of the most of protection frame approximates zero. But the location of large plastic strain basically focuses on both ends of the upper bracing, the contact region of car and upper crossbar.

Take Condition 2 as an example to analysis the energy changes of collision process. At the beginning of the collision, the total energy (as shown in Fig. 4) of the system was carriage kinetic energy $E_k = 1/2\ mv^2 = 2.527\times10^5$ J. The whole process may be divided into three stages: 0~0.21s; 0.21s~0.32s; 0.32s later.

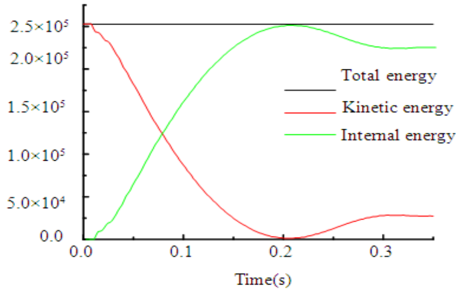

Fig. 4: Total energy-time curve

In the 0~0.21s stage, the system kinetic energy changed into the system internal energy, which includes elastic strain energy and plastic strain energy.

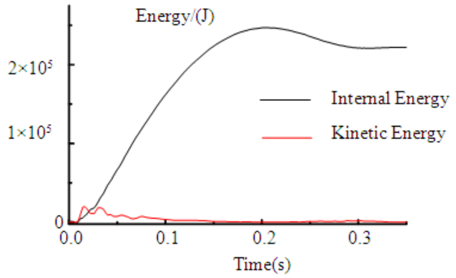

Fig. 5: The total energy-time curve of protection frame

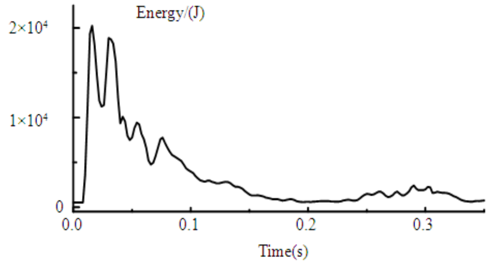

Fig. 6: The kinetic energy-time curve of protection frame

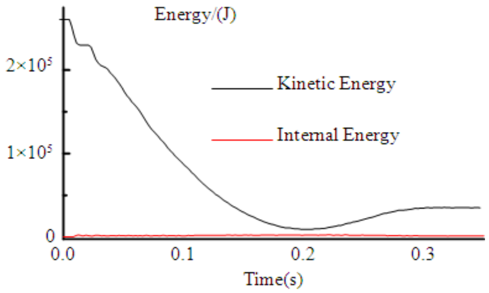

Fig. 7: The total energy-time curve of the van

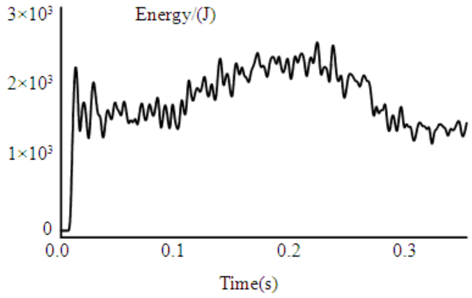

Fig. 8: The internal energy-time curve of the van

In 0.21s moment, the speeds of protection frame and the car were zero and at this time the kinetic energy of the system completely transformed to internal energy.

In the 0.21s-0.32s stage, the car began to do reverse accelerated motion and the elastic strain energy of protection frame transformed to the kinetic energy of protection frame and the car.

In 0.32s moment, they broke away from each other and most of the elastic strain energy transformed to kinetic energy of the both.

The 0.32s later, Car itself has no energy exchange and in protection frame, only a small amount of energy transformed between the elastic strain energy and the kinetic energy.

After the collision, the kinetic energy of the system was 2.758×104J, the internal energy of the system was 2.237×105J. Most of the internal energy was the plastic deformation energy of protection frame and it accounted for about 88.5% of the total energy.

Total energy-time curve of protection frame is shown in Fig. 5 and the kinetic energy of protection frame-time curve is shown in Fig. 6.

As the charts showed: In the 0~0.21s stage, the internal energy of protection frame trended to increase and the kinetic energy relative to the internal energy was smaller and which trended to reduce.

In the 0.21s~0.32s stage, the internal energy of protection frame reduced and the kinetic energy increased slightly. The reason is that the release of elastic strain energy transformed into the kinetic energy of the car and protection frame.

The 0.32s later, the elastic strain energy and the kinetic energy of protection frame changed into each other.

Total energy of the van-time curve is shown in Fig. 7 and the internal energy of the van-time curve is shown in Fig. 8.

It can be seen from the graph that the kinetic energy of the van firstly decreased and then increased and finally stabilized in the process of collision. In the whole process, the kinetic energy lost bigger and the absorption of the internal energy was smaller. Combined with the energy-time curve of protection frame, it can be known that the loss of kinetic energy of protection frame mainly transformed into the plastic deformation energy of protection frame.

CONCLUSION

The collision process of protection frame and van is simulated based on the ANSYS/LS-DYNA software and the following conclusions are obtained:

- The stress of the upper support has the following basic rules: the middle region has small stress and is in a state of pull and pressure exchanged constantly; two nodes of region have large stress and a similar stress state.
- The kinetic energy and internal energy obtained by protection frame is very small in the collision and

the most system energy was converted into the plastic deformation energy of the protection frame.

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