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Mechanical analysis of a cowcatcher for a high-speed train in crashing

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Abstract. A finite element model of a cowcatcher mounted at the front of a high-speed train is established and the processes when the head car crashes a rigid wall or an obstacle at different speeds are simulated by using ANSYS/LS-DYNA software. The results show that with the cowcatcher the passenger deceleration would decrease and the kinetic energy can be absorbed more quickly when the head car crashes a rigid wall. When a train crashes an obstacle on the track at a low speed, say 10m/s, the obstacle is turned up, which may destroy upper structures of the train. When the speed is high, say 50m/s, the obstacle will crash into the cowcatcher and the kinetic energy of the train will be absorbed by the front part of the cowcatcher.

Introduction

Although a train collision is a rare occurrence, causalities and property losses are unavoidable [1]. To protect passengers and reduce the probability of destroy, some devices with specific functions have been developed for trains. For example, a cowcatcher plays an important role as a buffer as well as an energy-absorber of a high-speed train when to clean up an obstacle from the track [2].

Hu et al. [3] found the weakened points of a cowcatcher on a 200km/h passenger locomotive through numerical strength analysis and improve the design. Elmarakbi and Zu [4] investigated two smart front-end structures to enhance the crashworthiness of vehicle-to-vehicle full and offset frontal collisions. Kim et al. [5] developed a virtual testing model to predict nonlinear collision behaviors and to meet several design purposes. Llana and Stringfellow [6] developed a deformable anti-climber and a push-back coupler to mitigate the effects of a collision and to prevent override between lead vehicles.

Finite element models of a head car with/without a cowcatcher are developed in this paper to simulate the processes of a train crashing a rigid wall or a small obstacle at different speeds. The mechanical behavior influenced by the cowcatcher is investigated.

Finite Element Models

The finite element models of a head car and a cowcatcher are established by using ANSYS/LS-DYNA software, as shown in Fig. 1. Due to the symmetry of the head car model, we only use a half of the model in simulations. A half model of the head car includes more than 4500 faces, 2100 lines and 58 entities. Some unimportant structures, such as welding parts, electric wire and lights, are ignored. Element types are SHELL163 (4-node quadrilateral element) for main structures of the train and SOLID164 (8-node hexahedron element) for the bogies. The bilinear isotropic elastic-plastic material model is used in simulations. The thickness of different parts of the FEA model is consistent with a true train. We simulate that a train with/without a cowcatcher travels at 10 m/s and 50 m/s to crash a rigid wall or an obstacle.

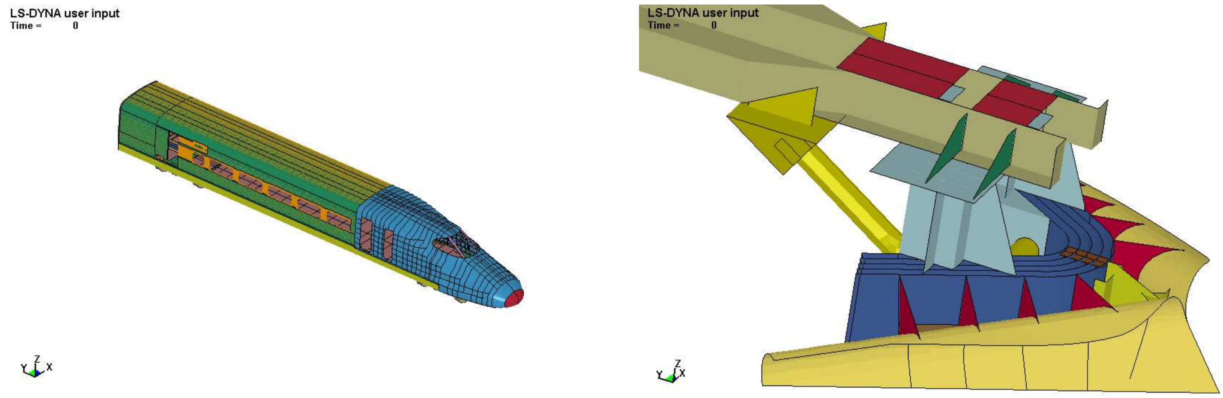

Fig. 1. The finite element models of a head car (left) and the structures of a cowcatcher (right).

Results and Discussion

Crashing a rigid wall. The kinetic energy of a train with/without a cowcatcher when crashing a rigid wall at different speeds is shown in Fig. 2. The results show that the effect of a cowcatcher on dissipating the kinetic energy is more obvious at v = 10m/s than that at v = 50m/s. At a low speed, a cowcatcher can absorb the kinetic energy before being destroyed, but at a high speed, the kinetic energy is rather large and the cowcatcher is destroyed at the instant a crash happens.

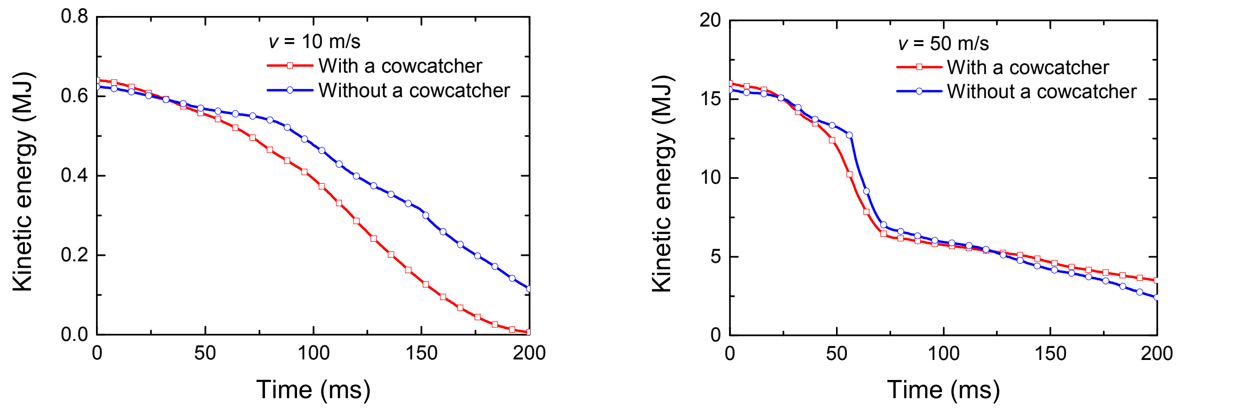

Fig. 2. The kinetic energy of a train with an initial speed of v = 10 m/s (left) or v = 50 m/s (right).

The force on the rigid wall is shown in Fig. 3. The results show that the cowcatcher has an important effect on reducing the peak force at both the low and high speeds. At v = 10 m/s, the peak force reduces from 1.1 MN to 0.78 MN. At v = 20 m/s, the peak force reduces from 13 MN to 8 MN. The reducing of the peak force will help to protect passengers from injure.

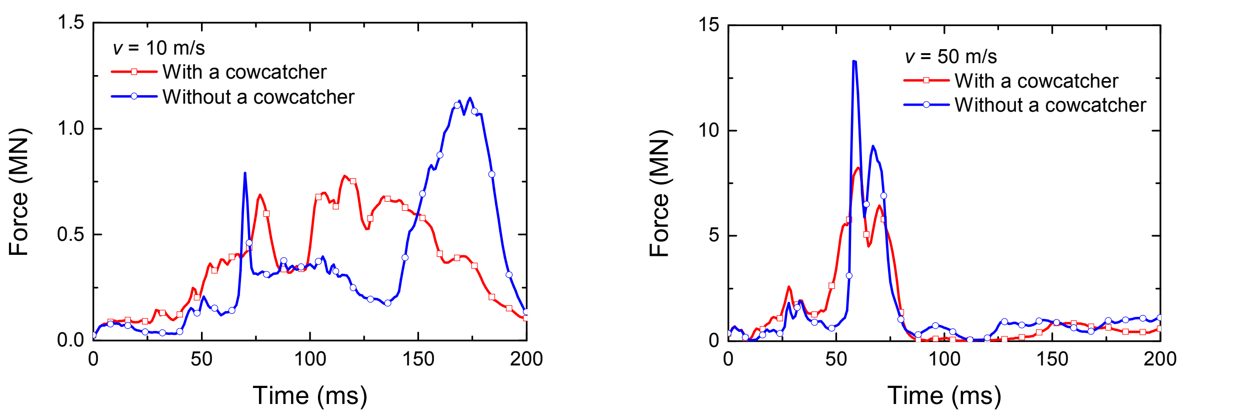

Fig. 3. The force on the rigid wall when a train crashes at v = 10 m/s (left) and v = 50 m/s (right).

The passenger deceleration when a train crashes a rigid wall at v = 10 m/s is shown in Fig. 4.

The Head injury criteria (HIC) is currently the most widely used indicators of head injury. The formula is given by

$$\mathrm{HIC} = \max\left\{(t_2 - t_1)\left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,\mathrm{d}t\right)^{2.5}\right\} \tag{1}$$

where t_1 and t_2 is the initial and end times in seconds of the interval in which HIC attains a maximum value, $a(t)$ the resultant acceleration. In Appendix A7 of the UK ATOC AV/ ST 9001(railway vehicle crashworthiness standard), HIC more than 1000 is considered life-threatening.

From Fig.4 we can calculate HIC in cases of a train with/without a cowcatcher crashes a rigid wall. After calculation, we get the results that at v = 10 m/s, HIC = 703.4 with a cowcatcher; while HIC = 1825.26 without a cowcatcher. Comparing these results, we found that a cowcatcher plays an important role in reducing the HIC value from ~2000 to ~700.

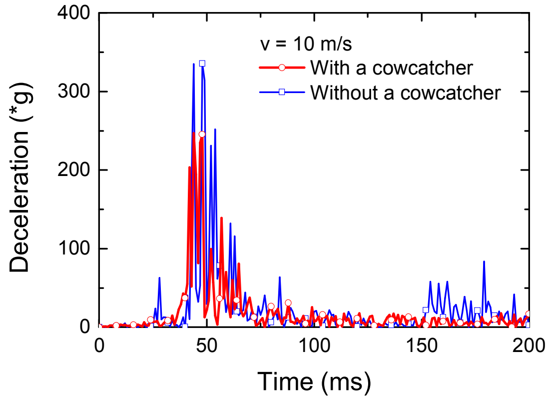

Fig. 4. The passenger deceleration when a train crashes a rigid wall at v = 10m/s

Crashing an obstacle. When a train crashes an obstacle of a small size at a low position, it cleans up the obstacle and absorbs the kinetic energy through plastic deformation. In this simulation, an obstacle of 100 kg in mass, 0.4×0.5×0.5 m^3 in dimensions, frontally crashed at v = 10m/s and 50m/s is considered, as shown in Fig. 5.

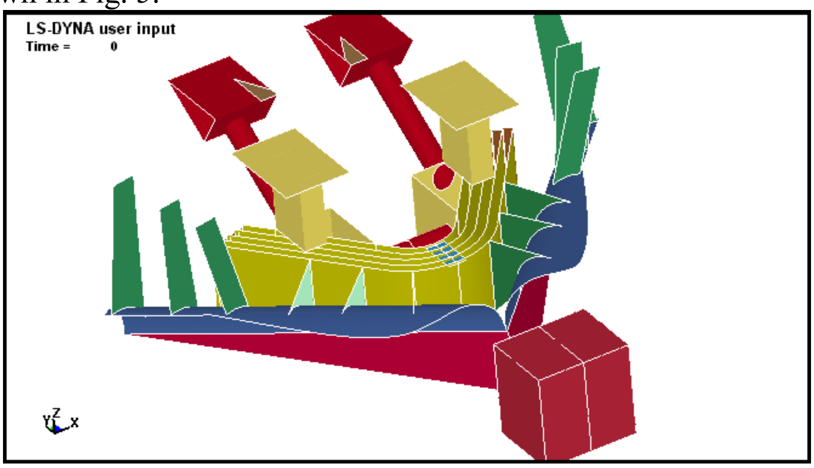

Fig. 5. A cowcatcher crashes an obstacle

Because the obstacle is of a small mass and the impact happens in a short time, the cowcatcher is assumed to connect a rigid body instead of the main structure of the head car. Different responses of the cowcatcher are shown in Fig. 6. The results show that at a low speed, the obstacle will turn up into other structures of the head car, such as the cab. When the speed is as high as 50m/s, the obstacle will crash into the cowcatcher directly in a very short time, resulting in some damage of the cowcatcher itself. Typically, the probability of frontal impact is rather low. In most cases, oblique impact will happen, which may cause less damage. It is suggested that the front angel of the cowcatcher should be increased in order to prevent the obstacle from turning up, according to our simulation.

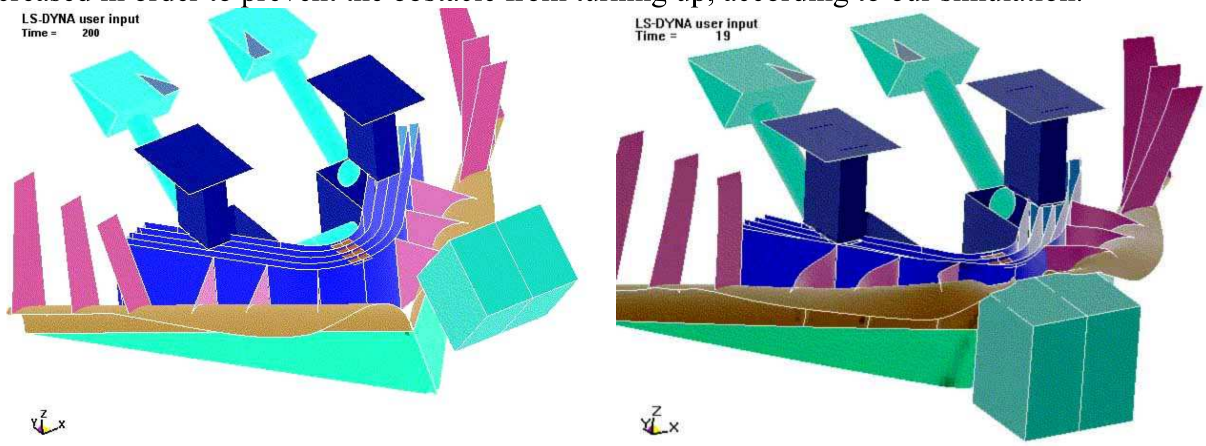

Fig. 6. A train with a cowcatcher crashes an obstacle at v = 10 m/s (left) or v = 50 m/s (right).

Summary

In this paper, the finite element models of a high-speed train with/without a cowcatcher have been established. The processes when the head car crashes a rigid wall or an obstacle at different speeds are simulated by using ANSYS/LS-DYNA software. The results show that with a cowcatcher, the kinetic energy of the train can partly be absorbed at v = 10 m/s, and the peak force and the HIC value will reduce obviously at the speeds investigated. When the train with a cowcatcher crashes an obstacle on the track at v = 10 m/s, the obstacle may be turned up to destroy the upper structures of the train, such as a cab. When the speed is 50 m/s, the obstacle will crash into the cowcatcher and the kinetic energy of the train will be absorbed by the front part of the cowcatcher. We suggest that the front angle of the cowcatcher should be increased properly in order to avoid further destruction.

Acknowledgements

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