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A Study on the Development of Test Rig for High Speed Frontal Crash and Test of Members

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ABSTRACT

In this paper, a simple test rig of high-speed crash for the front members of vehicles was developed for the improvement of crashworthiness of vehicle's side rail. The cart hanging the specimen is accelerated up to 35 mph by the traction wire and by the force of freely dropping weight and 1:3 accelerating pulleys. The cart with shock absorbers travels on the rail roads, so it does not transfer any additional vibration to the specimen. In order to measure the energy absorbed by the specimen when it collapse to the wall and during it deform, the two strain gage type load cells are used at the wall place. The test rig rated good to test the specimen like a side rail of vehicle as developing the vehicle's structures in the early design stage.

Keywords : High speed crash, Crashworthiness, Accelerating pulley, Side rail, Wall force

1. Introduction

Now days, the means of transportation such as cars, trains and airplanes have an important roles so that many investigations are performed to improve the performance efficiency and to reduce the weights of it's body. Therefore, the safety of the vehicle body of reduced weight became an important issue. When the vehicles crash, the most of the dynamic energy should be absorbed by the front members of it's body to protect the passengers. So, it needs to clarify the dynamic deformation and energy absorbing characteristics of the crash members[1]. In the case of HEV (Hybrid Electric Vehicle), almost of all the vehicle body members have a shape of rectangular pipe that it is very important to verify the impact characteristics of them to design the HEV body with considering the safety for the passengers in the early stage of design. There are various types of crash test systems but almost all of them are traction style for the real passenger cars and it is very difficult to test the single element. The drop test is the most famous style for single element crash, but the speed at the impact varies and it is very difficult to decide the boundary conditions at the impact time[2]. The drop style test rig has an another drawback of the rebounding problems that the collapsed specimen is bounced and it collapse again to the impact wall. In this paper, we proposed the new types of crash test rig that the merits of horizontal traction style and drop style are combined and all the drawbacks of them are discarded[3,4].

The cart hanging the specimen is accelerated up to 35 mph by the traction wire and by the force of freely dropping weight and 1:3 accelerating pulley. The cart with shock absorbers travels on the rail roads, so it does not transfer any additional vibration to the specimen. cart with shock absorbers travels on the rail roads, so it does not transfer any additional vibration to the specimen. The traction wire is separated from the cart that the crash mass moves in a constant speed that it is very easy to decide the boundary conditions of the simulation data. In order to measure the energy absorbed by the specimen when it collapse to the wall and during it deform, the

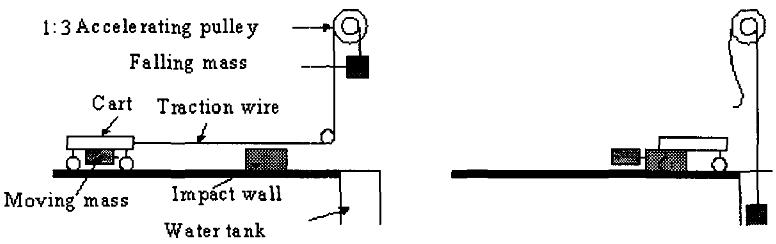


Fig. 1 The principle of crash test rig

two strain gage type load cells are used at the wall place.

2. Development of the crash test rig

We can divide the types of the crash test rig into two. One of them is the traction type in horizontal direction and the others is the drop style in vertical direction. In the former style, the cart is pulled by the traction wire and it is very easy to control the speed of the cart at the collapse time by controlling the rotational speed of the traction motor, but almost all of them are made for the test of passenger cars that it is very difficult to test the single element. In the latter style, the falling mass grasps the specimen at the bottom and falls down to the impact wall. In this type, it is very easy to test the single element and it is very easy to speed up and calculate the collapse speed by gravitation rule, but it has rebounding problems that the collapsed specimen is bounced and it collapse again to the impact wall. The speed of the falling mass increases by the gravitational force that it is not clear to determine the speed at the impact time.

To improve the drawbacks of the current crash test rig that have mentioned earlier, a new type of crash test rig was developed as shown in Fig. 1. In the new test rig, the drawbacks of the two styles are discarded and the merits are combined that we can make a speed up to 35mph in the quarter car model (240kg mass) and we can make the constant speed at impact stage by adopting the wire traction method in the horizontal direction.

The schematics of the test rig is shown in Fig. 2 that the test rig consists of seven parts. They are cart, moving mass, traction wire, impact wall, acceleration pulley, falling mass, and water tank. The moving mass is hanging under the cart by four rolling elements and fixed by the aluminum bar. The thickness of the aluminum bar is 2 mm and the width is 10 mm that it is cutaway very easily when the moving mass contacts the impact wall. The cart has four aluminum wheels and they are supported by the suspension system including the shock absorbers and moving on the railways whose flatness is adjusted under 1~2mm, that almost of all the vibration force induced by the railway conditions are removed and there is no vibration problems of the moving mass and cantilever style test specimen. The acceleration pulley is composed of three pulleys in the same rotational axis and two disk type hydraulic breaks. The diameters of the center pulley and two side pulleys are 3:1 ratio. The traction wire is connected between the center pulley to the cart and the wires at the side pulleys are wounded and connected to the falling mass. The hydraulic breaks hold the pulley from rotate. When the hydraulic break loses, the falling mass goes down and the acceleration pulleys start rotate that the cart moves at three times faster than the falling speed of the falling mass. The falling mass is about four times heavier than the weights of moving mass and cart that we can calculate the falling speed and the moving speed of the cart by using the Lagrange's equation. Just before the moving mass and the test specimen contact the impact wall, the traction wire is separated from the cart by some kinematic joint. There are some problems to slow down the falling mass without any demage to the system that we make the water tank of 2m depth to dissipate the moving energy to hydraulic damping. In order to maximize the energy dissipation by the water

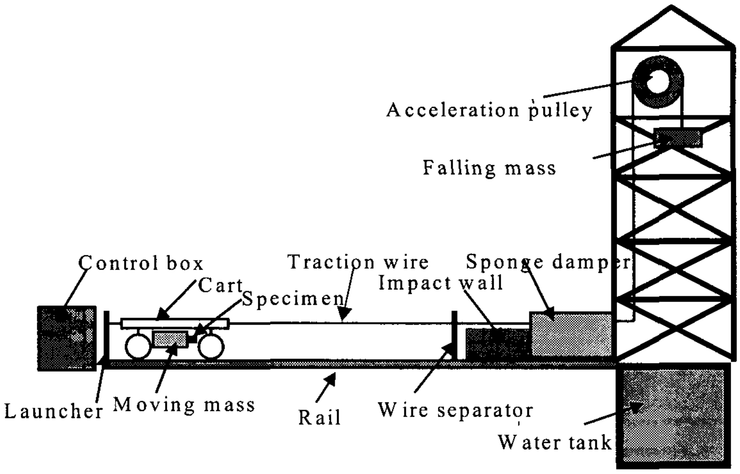


Fig. 2 A high-speed crash test rig

tank, the guide fins of cross shape are attached at the bottom of the falling mass and the depth of the tank is 2m from the ground level. At the moment of the test specimen contacts to the impact wall, the fixing element between the cart and moving mass is cutaway and the moving mass goes in inertial motion. At the same time, the running cart without moving mass hits to the sponge block.

According to the law of energy conservation, without considering the friction effect, only the potential energy of the mass exists before the cart starts moving and only kinetic energy of the mass exists at the moment of the crash. Also, when the ratio of the diameter of the wire drums is 3 to 1, the ratio of the cart velocity and the mass speed is 3 to 1. The initial potential energy of the mass is calculated by equation (1).

$$E_1 = m_1 g h_1 \tag{1}$$

where, m_1 is the weight of the falling mass and h_1 is the height of the tower, which is also the height of the falling mass. The kinetic energy of the cart and the falling mass just before the collision is calculated by equation (2).

$$E_2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 \tag{2}$$

where, m_2 is the weight of the moving mass, v_1 is the velocity of the falling mass, and v_2 is the cart velocity. The height of the tower calculated from equation (1) and (2) is 3.83m in order to make the speed of moving mass into 35 mph. For the ideal case, the height of the tower can be reduced by a factor of 1/3 compared to the previous crash test rig using the falling mass.

$$E_3 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 + \mu m_2 g (3h_1) \tag{3}$$

3. Experiment

Using this high speed crash test rig, we made the collapse tests for the rectangular shape pipe members and for the side members of the passenger cars, and we find out that we can make the test speed up to 35 mph with this test rig. The specimens for the collapse tests are the cylindrical pipe type energy absorber which has two slots at it's sides as shown in Fig. 3. The specimen is made from the pipe of carbon steel, which is generally used in the building structures.

The specimen is attached in front of the moving mass using the fixing zig as shown in Fig. 4. The specimen is welded on the fixing zig and the zig is bolted to the moving mass with four bolts. Fig. 5 shows the procedure of the collapse. The Fig. 5 (a) is just before the specimen contact to the impact wall and (b) is at the moment of collapse. When the specimen contacts to the impact wall, the connection bar between the cart and moving mass is immediately cut off and the moving mass flies in free condition that we can assume the speed of the moving mass at the moment of impact. The Fig. 5 (c) shows the rebound of the moving mass that the crash procedures are terminated.

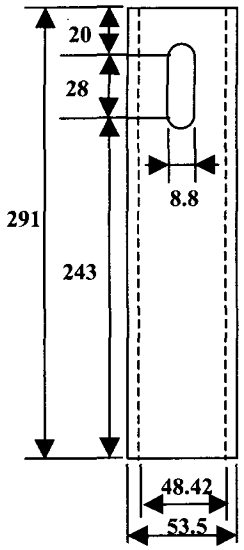
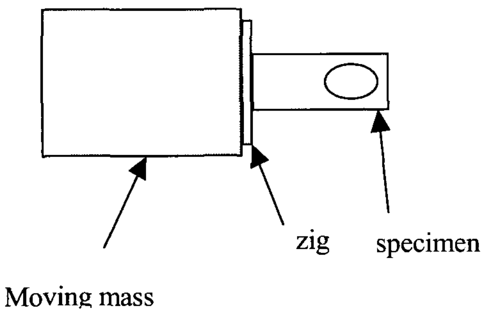
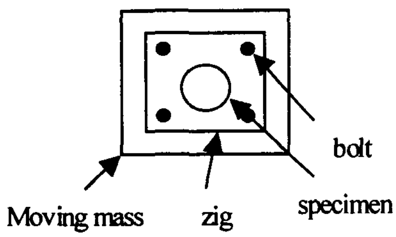


Fig. 3 Dimensions of the tube type energy absorber



(a) Side View

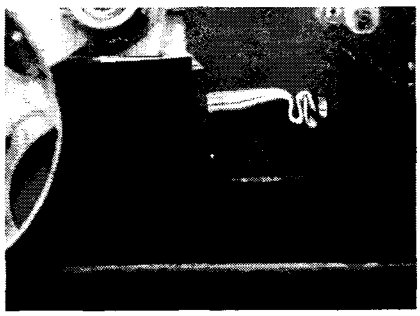


(b) Frontal View

Fig. 4 The attachment conditions between the moving mass and the specimen

(a)

(b)

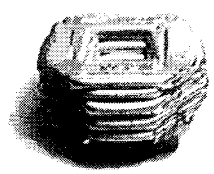


(c)

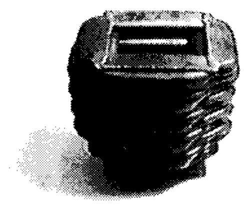
Fig. 5 The procedures of the crash test

Fig. 6 shows the deformed shapes of the various types of the specimens and it looks very similar to the deformed shapes by the quasi-static test. From their shape of deformation, we can find out that the specimens were collided with the impact wall vertically without any external error. The dynamic energy of the moving mass is dissipated by the deformation of test specimen that the dynamic energy in converted to the heat energy and the temperature of the specimen just after the collapse goes sharply up.

(a) Tube type energy absorber



(b) Aluminium specimen (50x50x2t)



(c) Steel specimen (50x50x2t)

Fig. 6 The deformed shapes of the various types of specimen

4. Measurement

4.1 Measurement of the cart speed

Two photo sensors were used to measure the speed of the cart, just after the traction wire is disconnected and just before the specimen contact to the impact wall. Fig. 7 shows the installation of the photo sensors and they detect the indicator plates which is attached on the cart in sequence that we can deduce the speed of the cart by the time delay between the two sensors. The detected signal by the two photo sensors is shown in Fig. 8 for the test of Fig. 5 that we can deduce the speed of the cart at that moment is about 45.72 km/h.

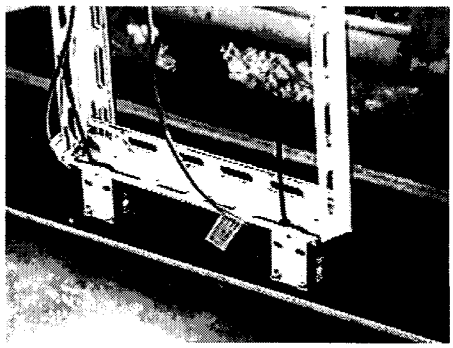


Fig. 7 Photo sensor installations

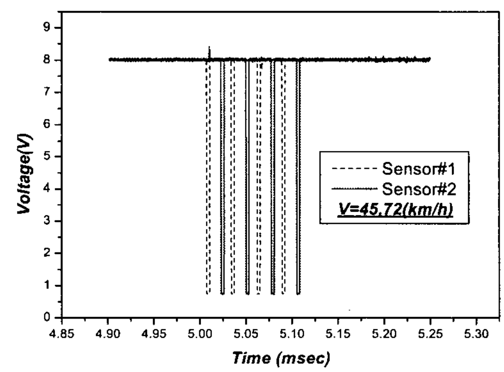


Fig. 8 The detected signals of the photo sensors for velocity calculation

4.2 Measurement System

To find the accurate impact velocity and the impact weight, a photo-sensor and a load cell were used. The data from the two sensors is converted to the digital signal by the A/D converter and transferred to a personal computer. The process is shown in figure 9 and the specifications for the photo sensor and the load cell are shown in Table 1. Table 1 Type of Load cell and Photo-sensor.

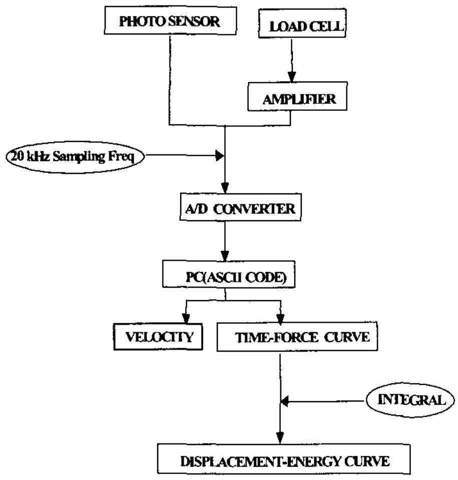


Fig. 9 Schematics of the signal processing instruments

Table 1 Type of Load cell and Photo-sensor

	Measuring condition		Model
Photo-sensor	Response time	0.7 ms	PD-RH09N
	detecting range	10-90mm	
Load cell	20 tonf		LC-20TV-P (KYOWA)

4.3 Measurement of the impulsive force

The impulsive force which is generated by the dynamic energy of the moving mass and converted to thermal energy by the deformation of the test specimens. It is very difficult to measure the energy absorbing characteristics directly when the test specimen crash the impact wall that we should measure some indirect parameters such as wall force or the deceleration. In this paper, we measure the wall force with using two strain gage type load cells as shown in Fig. 10. The load variations during the deformation of the test specimen proceeds are measured by strain amplifiers (KYOWA LC-20TV-P) and converted to digital data by A/D converters. After then the two signals from the two load cells are averaged to reduce the error which may be generated by the contact problems.

Fig. 11 shows the variations of the wall force which is measured by the load cells. In this figure, the force is rapidly increase up to 162 kN, and then the wall force is reduced. This reduction is generated by the buckling of the specimen and then the wall force grows again. In the Fig. 11 you can find out the three major peaks and one small peak. This signal is for the specimen in Fig. 6 (a) and there are three major folds. The deformed shape has some unsymmetrical folds and this may the reason of the small peak in Fig. 11.

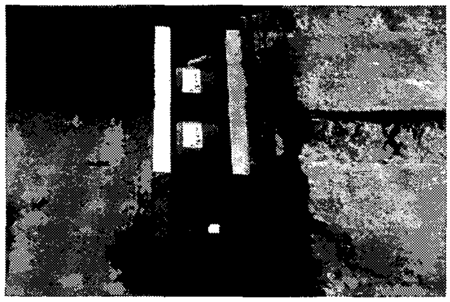


Fig. 10 Load cell installations

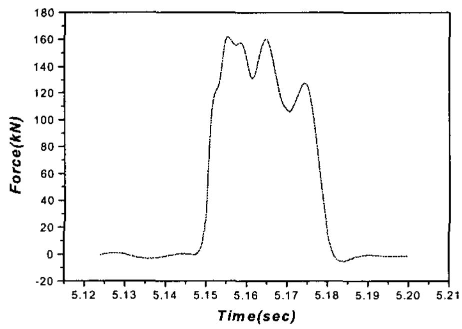


Fig. 11 The variations of the wall force during the deformations of the energy absorber

5. Conclusions

A high-speed crash test rig using a cart connected to a freely falling mass was developed and the tests for different specimen were performed. In this research, the high speed could be attained in a very short running distance, which was not possible before. Also the impact was fulfilled in a constant speed because the cart is disconnected from the traction wire just before the impact moment. The test for the side members of the vehicles was performed successfully and the force variations for the time is plotted to show the deformation characteristics of the energy absorbing collapse member.

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