Proceedings of the 12th International Forum of Automotive Traffic Safety, 2015, pp 269- 273
No. ATS.2015.S3A18

A study on the impact between car to circular concrete pole

Fang CHEN[1], Chaoqun TANG[2], Jianwei Zhang[3]

([1]Changsha Electric Power Technical College, Changsha,410131
[2] Bosch Automotive Products (Changsha) Co. Ltd., Changsha, 410100
[3] Changsha economic development zone xiangyuan energy supply Co. Ltd., Changsha, 410100)
Email: fmtianxia@163.com

Abstract: The impacts between car to concrete pole occurred frequently in traffic accident, those accidents usually result in severe car damage and widespread power failure. In order to learn the dynamic response of car to concrete pole impact and fracture mechanics of concrete pole, a finite element model of vehicle-pole collision was developed and validated. Then, three impacts between car and concrete pole under the different speed was carried out. The results show that the maximum longitudinal intrusion of the vehicle increased 13.9% as the speed increasing from 30 to 70km/h, while the proportion of absorbing energy by car to the total kinetic energy decreased from 43.6% down to 14.6%. The concrete poles are damaged in all cases due to the shear force, and the damage degree and break-point of pole are different at three speeds. This provides a helpful reference to the design of frontal car body and the concrete pole strength design in impact loading.

Keywords: concrete pole; pole impact; fracture; finite element methods; the reliability of power supply

1 Introduction

Nowadays, concrete pole is a wild used equipment of low-voltage transmission and distribution lines of China's power grid, many concrete poles erected along the road because of the restriction of terrain. The car to concrete pole crash happens frequently. According to the statistics, more than 50 crashes between car to concrete pole occurred in Harbin in 2005. Those accidents not only result in widespread power failure caused by the concrete pole damage, but also result in severe damage to the vehicle and occupants injury. It is necessary to conduct in-depth study of this type of collision.

The pole impact traffic accidents divides into lateral impact and frontal pole impact. This paper would focus on the frontal pole impact. Because of the width of concrete pole, the frontal impact between the car to concrete pole belongs to the small overlap crash. There are many researches has been carried out on frontal pole crash. To investigate the crashworthiness characteristics in different overlap frontal impact, Hong [1] observed the car acceleration, intrusion magnitude and location of passenger compartment in three type frontal impacts (full width frontal impact, 40% and pole frontal impact) by crash tests and FE model. Yang Jikuang [2] and Ahmed Elmarakbi [3] studied the deformation and injury risk of occupants in the collision between car and tree or poles through the finite element method. In those studies, the tree or pole were regarded as a rigid component [4], it would not reflect the actual collision to the crashworthiness and occupant safety.

Little research has carried out to learn the concrete pole damage in impact loading, in the normal condition, the prosperity of deflection and crack resistance are attended in concrete pole design [5-9]. In order to explores the failure mechanics of concrete pole in impact loading, Walte[10,11] carried out 11 group tests of concrete pole trolley crash test to research in 1986, the experimental result implied that the shear fracture is the main form of concrete pole damage in a collision, and advised that increasing the number of ribs spiral wall thickness and encryption pole collision zone can increasing the fracture force of shear.

Based on the detail pole and car FE model，this paper aims to learn car crashworthiness and fracture mechanical of concrete pole in the real frontal concrete pole impact. The dynamic response and fracture were observed in three different speed pole impacts.

2 the FE model building and validating

This paper developed a finite element model of a car on the market by pre-processing code-Hyperworks, it consists of the body in white, chassis, engine, internal trim, etc. And the dummies in car crash are replaced by concentrated mass. The car model contained 1067392 nodes and 1109385 elements.

The detail concrete pole model was built based on the data of GB 4623-2006[12], according to the standard, the length of pole is 7 meter, the root diameter is 223mm, tip diameter is 130mm, and wall thickness is 40mm. The diameter of longitudinal and lateral reinforced steel bar is 6 and 3.4mm. The strength rating of concrete is not less than C50, the total mass of concrete pole is 284kg. In the concrete pole model, the steel bar component and concrete were meshed by using deformable solid elements, the elements representing the steel bar were connected to the elements of the concrete by using the share node method.

In the virtual tests, the accuracy of the FE method will be greatly influenced by the chosen material constitutive. The concrete were modeled by using a material model of MAT_PLASTICITY_COMPRESSION _TENSION in LS-DYNA code. These concrete material parameters in pole FE model were derived from the literature [13-14], the density of concrete is 2400kg / m^3, the elastic modulus is 41GPa, Poisson's ratio is 0.2, the compressive yield stress is 32.8 MPa, tensile yield stress is 3.5 MPa. The steel bar was treated as an isotropic elastic-plastic material (MAT_PLASTIC_KINEMATIC); and the elastic modulus is 202GPa, yield stress is 1100MPa, tensile strength is 1570MPa [10, 15]. A Flanagan-Belytschko stiffness form was used to control the hourglass of solid elements, and the model ran with a minimum time step at 0.7 μs in explicit solver of LS- DYNA 971. The failure of concrete pole material was based on a plastic strain, and the elements were removed when they exceeded a prescribed strain value.

The car model was validated by using a 50km/h full frontal impact test. The comparison of the results between simulation and test was conducted in terms of car deformation and acceleration-time history curves of B-pillar in impact.

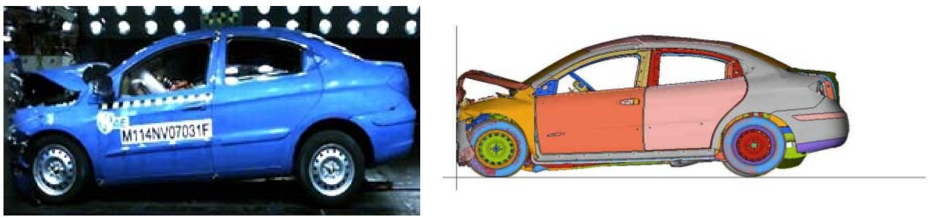

Fig. 1 Comparison of deformation between crash test and simulation

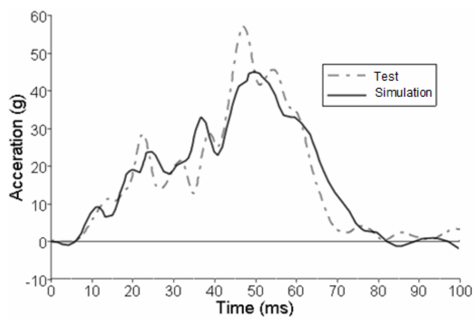

Fig. 2 Comparison of the vehicle acceleration curve (at B pillar) in experiment and Simulation

As shown in Figure 1, The car deformation of simulation is similar as test. In test, the value of whole car deformation is 512mm in longitude, while it is 508mm in simulation. The comparison of acceleration-time curve at the button to B-pillar between test and simulation was shown in figure 2, it could be observed that the curve shape and peak value show good correlation consistency. The agreement of deformation situation and acceleration pulse replied that the car FE model was assumed as validated and could be further used for the purpose of current study.

A cantilevered deflection standard was employed to verify the concrete pole model. According to the GB/T 4623-2006, the test setup is shown in figure 3, the root of concrete pole was fix on the test table with U-shaped hardwood supporter in point A and B, and the radial load at the top of pole was increasing until the pole fracture.

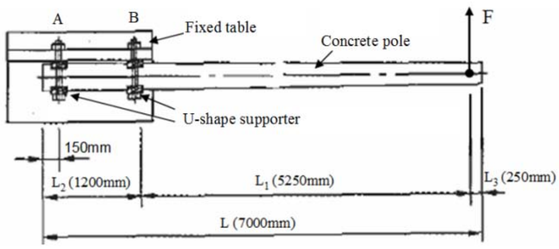

Fig. 3 The cantilever deflection diagram of experimental setup (unit: mm)

When the radial load up to the 2.64kN, fracture happens at point which with the distance of 2025mm to the tip of concrete pole, the cause of concrete failure is tension stress is beyond the tension strength stress. when the fracture happens, the maximum of compression stress is 5.595MPa, Linear beam theory was used to calculate the maximum mid-shaft moment (M), which can be determined by multiplying the peak force of reaction, and the distance fix point B was 13860Nm, which is 2.52 times to the B-class standards (5500Nm), bigger than the demand of GB/T 4623-2006 (11000kN). Moreover, the maximum deformation of concrete pole is 36.5mm, it is less than the standard of 96.4mm （L_1+L_2/70）. So the concrete pole strength of the FE model in the cantilevered deflection test was reasonable.

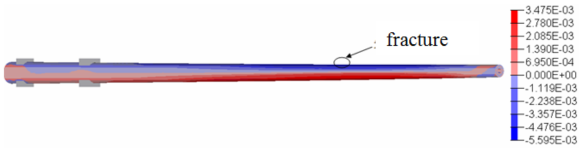

Fig. 4 The stress contour of cantilever deflection test at failure time (unit: GPa)

According to the two validations, there are reasonable agreement between the model and experimental results. The car and concrete pole FE model were assumed that the choice of material constitutive is reasonable and the models have a good simulation accuracy. In general, they could be further used for the purpose of current study.

3 Results

Based on the validated model, the virtual impact test between car and concrete pole was developed. The test setup shown as figure 5, the pole was buried below the ground 1.2m, and the buried part was fixed. The velocity of car impact is set at 30, 50 70 km/h respectively, and the impact area is in the middle of car. The time of simulation process is 100ms.

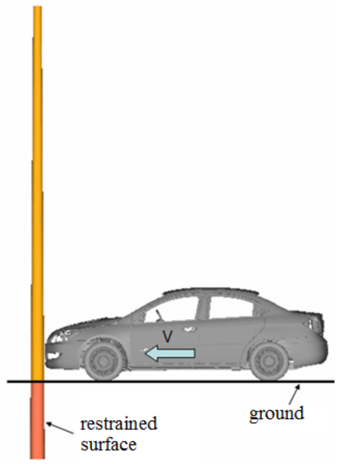

Fig. 5 the simulation setup of car-pole collision

In three virtual car-concrete pole impact tests, the fractures are occurred in all simulations. when the car-pole collision happens, firstly, the bumper and radiator contact to the pole and absorb the impact energy, as the intrusion increasing, the engine collision to the pole, and contact force expand strictly because of its great inertia and rigidity, and the concrete pole fracture until to push down.

Under the different speed impact, the fracture mode of concrete pole is not the same. As shown in figure 6, in the 30 and 50km/h speed impact simulations, the failure occurred in the contact surface of bumper and engine firstly, as the impact load increasing, the crack of concrete appears in the non-collision side interface area to ground, then crack extension to the opposite side made the pole broken down. The maximum contact forces are 116.5 kN and 144.7 kN respectively. In the 70km/h speed impact simulations, when the engine impact to the pole, the contact area and the non-collision side interface area to ground are failure at the same time, as the car keep moving forward, the concrete pole fall toward car. Due to the bending moment, the third fracture was observed in the point 2050mm away from tip of pole, and the maximum contact force was 169.9kN appeared in 25.1ms. In three impacts, failure element did not occurred in steel bar of pole, which is agreement on the experiment result in literature[11].

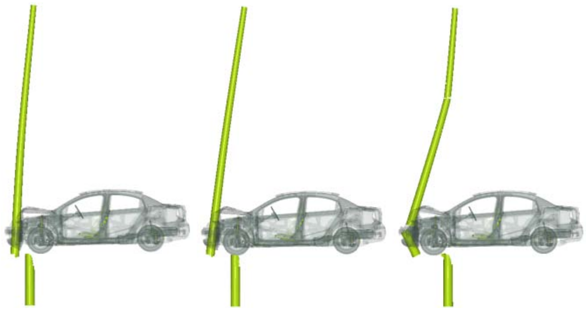

Fig. 6 The dynamic response of collision at different speeds

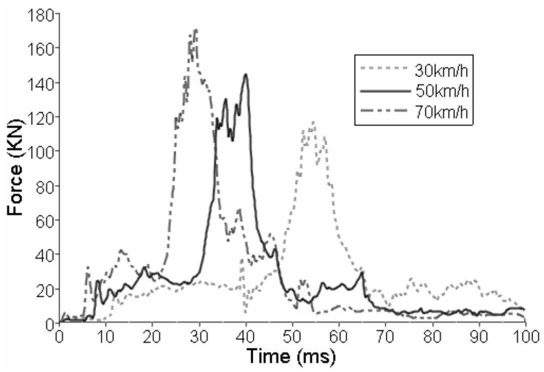

Fig. 7 Pole fractures at different speeds

Tab.1 simulation results of car-pole collision

Impact velocity (km/h)	car intrusion (mm)	max impact force (kN)	failure time (ms)	total energy Absorbing (kJ)	Pole fractures distribution
30	475	116.5	52.3	27.9	contact area，non-collision side interface of ground
50	502	144.7	33.6	35.1	contact area，non-collision side interface of ground
70	541	169.9	25.1	54.4	contact area，non-collision side interface of ground The point 2050mm away from top

Plastic deformation of car body is main part to absorb impact energy. For instance, in the 70km/h car to pole impact, the car body absorbed 45.5kJ kinetic energy, and concrete pole only absorbed 8.9 kJ by fracture. It just counts at 14.6% and 2.8% in total kinetic energy respectively. Which is much less than the absorbing energy in car to rigid pole impact test. In literature [4], the car absorbing 84.7% of kinetic energy in 56km/h car to rigid pole test. While the maximum longitudinal intrusion of the vehicle increased 13.9% as the speed increasing from 30 to 70km/h. Assumed that the car absorbing energy in 30km/h impact is equal to the kinetic energy of car, and then the car velocity is 20.8km/h. In contrast, there is a speed limited in road, if we do not want the concrete pole fall down in car impact, we should reinforce the strength of concrete pole by increasing size or using more steel bar. Certainly, the method of reinforce concrete pole to prevent the pull down will result in the car intrusion in impact, because litter absorbing energy will expand with the intrusion increasing. The injury risk of occupant always follows the large car intrusion.

The collision process of car to concrete pole could be regard as dynamic three point bending test, the dynamic loading is from the contact force of car bumper(the high is 450-560mm) and engine(the high is 645mm), the lower supporter is the constrained of ground, and the upper supporter is inertia of pole. the resistant force from ground is the main reaction force of impact loading, so the crack of concrete were observed in the non-collision side interface area to ground in three impacts. Moreover, as the impact speed increasing, the inertia force expands linearly, it makes the pole managed in the contact point and 2050mm away from pole tip. The situation of crack occurred and extended in simulation is agreed with the test carried by traffic department of Ontario, Canada.

4 Conclusions

To learn the dynamic response and fracture mechanics of concrete pole in car-pole collision, this paper has established the FE model of vehicle collision with the poles based on a CAD data of a domestic car and standard GB/T 4623, and the full frontal impact and cantilevered deflection test were used to verify the models.

In three speed impacts, the concrete poles were damaged and pulled down by shear force. Due to the fracture of concrete pole, the seriousness of car damage is less than car to rigid pole and less sensitive to the impact speed. the maximum longitudinal intrusion of the vehicle increased 13.9% as the speed increasing from 30 to 70km/h, while the proportion of absorbing energy by car to the total kinetic energy decreased from 43.6% down to 14.6%.

According to the research, some measures can be taken to reduce the damage in car-concrete pole accident.

(1) Enhanced the energy absorbing ability of the front of car, which could reduce the car intrusion in car-concrete pole impact.

(2) According to the fracture mechanics of concrete pole, decline the strength in failing area by reduce the thickness of pole and the density of lateral reinforced steel bar. Certainly, the widespread power failure caused by concrete failing should be considered either.

(3) Installed the reflective warning tape in pole was useful to reduce the car to concrete pole accidents, moreover, avoided to erect poles in the accident-prone area, such as intersection, large curvature road.

Due to the contact location and the mass, the dynamic response and fracture of pole will different in the impact by other vehicle (such as trucks), which will be discussed in further studies.

References

[1] Hong, S.-W. Chung-Kyu Park, Pradeep Mohan, et al. A Study of the IIHS Frontal Pole Impact Test [J], SAE paper NO: 2008-01-0507, SAE International: Detroit, Michigan.

[2] Fan Ting, Yang Jikuang, Chen Yong, et al. A Study of Driver Injury Risk Based on Reconstruction of Passenger Car to Tree Accident[J]. Microcomputer Information. 2010. 26(12-2): p.156-157, 217.

[3] Ahmed Elmarakbi, Khaled Sennah, Magdy Samaan, et al. Crashworthiness of motor vehicle and traffic light pole in frontal collisions [J]. Journal of transportation engineering, 2006. 132(9): p. 722-733.

[4] Qihui Li, Jikuang Yang. Study of Vehicle Front Structure Crashworthiness Based on Pole Impact with Different Position. in Measuring Technology and Mechatronics Automation (ICMTMA) [C], 2013 Fifth International Conference on. 2013. IEEE.

[5] Gao Rundong, Zhao Shunbo, Zhang Tianguang, et al. An Experimental Study on the Behavior of Steel Fiber Reinforced Concrete Pole Fabricated by Centrifugal Shaping Method [J] . China Civil Engineering Journal, 2005. 38(8): p.43-48.

[6] Li Fenglan, Li Xiaoke, Zhao Shunbo, et al. Design Method for Centrifugal Shaping Steel Fiber Reinforced Concrete Pole [J]. Journal of Basic Science and Engineering, 2007. 15(2): p. 190-195(in Chinese).

[7] Fang Yonghao, Dai Pin, Pang Erbo, et al. Mechanical Property Test and Finite Element Analysis for Tapered Reinforced Concrete Pole [J]. Journal of Hohai University (Natural Sciences), 2011. 39(6): p. 687-692.

[8] Xu Jinjun, Chen Zongping, Xia Kaiquan. Bearing Capacity Test and Stiffness Research on CFRP Strengthened Existing Reinforced Concrete Poles With Joint [J]. Journal of Natural Disasters, 2012. 21(6): p. 208-213.

[9] Chen Zongping, Xu Jinjun, Zhang Chaorong, et al. Experimental Study of Mechanical Properties of Existing Reinforced Concrete Poles With Connection Joint [J]. Journal of Experimental Mechanics, 2012. 27(6): p. 734-740.

[10] Walter H.Dilger, Amin Ghall, Zhao Li, et al. The performance of vehicle collision centrifugal pole(1)[J] . Railway Standard Design, 1989. (9): p.44-48.

[11] Walter H.Dilger, Amin Ghall, Zhao Li, et al. The performance of vehicle collision centrifugal pole(2)[J] . Railway Standard Design, 1989. (10): p. 44-47.

[12] Standardization Administration of the People's Republic of China, Circular Concrete Pole[S], GB/T 4623-2006, Standards Press of China.

[13] Ning Jianguo, Shang Lin, Sun Yuanxiang. Investigation on Impact Behaviour of Concrete [J]. Chinese Journal of Theoretical and Applied Mechanics. 2006. 38(2): 199-208.

[14] Fang Qin, Huan Yi, Zhang Yadong, et al. Investigation into static properties of damaged plasticity model for concrete in ABAQUS[J]. Journal of PLA University of Science and Technology. 2007. 8(3): p. 254-260.

[15] General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, Steel Wires for the Prestressing of Concrete[S], GB/T 5223-2002, Standards Press of China.