REFINED CALCULATION AND SIMULATION SYSTEM OF LOCAL LARGE DEFORMATION FOR ACCIDENT VEHICLE

WangFang Yuan
Lecture of Automobile Engineering, School of Automobile, Chang'an University,
Xi'an, China, e-mail: autoyuanzi@163.com

Lang Wei
Professor of Automobile Engineering, School of Automobile, Chang'an University,
Xi'an, China, e-mail: qch_1@chd.edu.cn

ChunJun Yu

Researcher, Traffic Management Research Institute of the Ministry of Public Security,
Wuxi, China, e-mail: Yucj123@yahoo.cn

Tao Chen
Associate Professor of Automobile Engineering, School of Automobile, Chang'an University,
Xi'an, China, e-mail: chentao@chd.edu.cn.

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ABSTRACT

Determining the collision speed is the key to reconstruct vehicle crash accident and analyze the accident origin. The present paper aims to identify the process of vehicle crash and the local large deformation for accident vehicle. Based on the collected typical accident cases of the vehicle crash, we divide local large deformation into mesh using hexahedral mesh generation algorithm and ten node curved edge tetrahedral element. Based on the mesh chart of collision deformation energy of finite element theory, the relationship between vehicle collision speed and body deformation was analyzed quantitatively. Combined with the correlation between collision speed and residual body deformation, the equivalent speed loss was obtained. The model of the impact force and instantaneous speed for each meshing cell was created using vehicle dynamics model, elastic mechanics. According to the analysis for vehicle crash accident, the accurate values of speed and direction of the vehicle before the accident occurs have been calculated. This study provided a theoretical foundation for accident analysis and identification. According to the calculation model of the impact force and instantaneous speed, we build the analysis and reconstruction system of vehicle-fixity crash accidents on VC++ platform.The refined calculation and simulation system has been applied to analyze the actual vehicle-fixity crash accident on

Xianning Western Road in Xi'an. This system is an important component in analysis and reconstruction system of traffic accidents, which can enrich the analyses of traffic accidents.

Keywords: finite element method, local large deformation, refined calculation.

INTRODUCTION

In recent years, the accident reconstructions technology provided advanced means for accident analysis. Through the comparison between the deformation photo of actual accident and database photo, the instant speed before crash can be obtained. It is the key to determine the instant speed for accident reconstruction and the analysis of accident causes. The common methods are theoretical calculation (kinetic energy, momentum theorem, etc) and expirical judgment using tools. If the energy absorbed by vehicle deformation was gotten , it will be helpful for the calculation of speed. The standard of the Ministry of Public Security GA/T643-2006 provide the relationship between speed and deformation depth. In the 1970s and 80s, the national highway traffic safety administration approved that there is a linear relationship between crash speed and residual deformation from 180 times of vehicle crash test. The analysis of speed before accident is achieved through virtual frontal crash test of finite element model in Shanghai Jiao Tong University. The model of the speed before crash and deformation depth was established through 130 times of simulation analyses and calculation in Dalian University of Technology. Most studiesanalyzed the speed using rigidity coefficient. These research results are confined to a few collision forms and practical accident which is similar to test.

Because the vehicle types and collision ways of accident are varied, this study divides local large deformation into mesh using finite element method. Combined with the common point of various deformations, this study builds refined calculation model of the instantaneous speed and impact area using vehicle dynamics model, kinetic energy theorem, momentum theorem and elastic mechanics, when collision occurs. The finite element method can consider elasticoplastic deformation of the vehicle and collision objects, so that enhance the accuracy of accident reconstruction. In the process of the analysis for vehicle crash accident, this study got the speed value and direction of the vehicle before the accident occurs based on parallel computing of finite element method, which have higher computational accuracy. Therefore, this study can provide scientific theoretical foundation for accident analysis and identification. Based on collecting the typical accident cases related to the vehicle crash, this study build refined calculation and simulation system of local large deformation for accident vehicle using vehicle dynamics model, elastic mechanics and finite element method.

STRUCTURE AND CHARACTERISTIC OF VEHICLE DEFORMATION

According to research situation at home and abroad, this study research on the structure characteristic of collision position before accident happened and the deformation characteristic after crash at first. Through collecting the accident cases, we collect the structure and characteristic of the main accident types, which include front、profile、rear position, structure characteristic and material of many types(cars, buses, and trucks). Through using handheld positioning 3d laser scanner EXASCAN, we can scan the deformation characteristic of the vehicle, then extract relevant information which include the deformation position、maximum deformation depth and deformation width. Therefore, this study built the computation mode of local large deformation for accident vehicle based on finite element.

MESH GENERATION OF VEHICLE DEFORMATION AREA

Finite-element Analysis Process of Deformation Area

The basic idea of finite element method is that disperse continuous area into assembly of the units which is limited and connected together. Because the unit can be combined by different ways, and the shapes of the units are different, the complicated solving domain of geometry shape can be modeled. Furthermore, when the unit is small enough, and the mesh is close enough, the approximation error will be gradually convergence as meshs are refining, so that calculation accuracy can also be fully guaranteed.

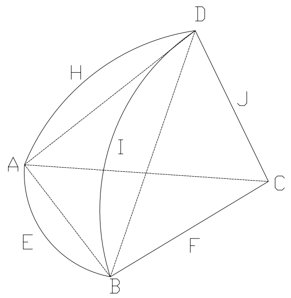
The solution of static nonlinear problem can be gotten by showing and calculating steady-state condition. This method is applied to the content of finite difference, which is named dynamic release of static nonlinear problem. The deformation of vehicle crash is a large three-dimensional problem, and the solution is gotten by using a dynamic scheme. The showing program provides the valid solution of crash problem.

The steps of the method are as follows (using approximation principle):
Step 1: Dividing the non-individual body into “finite element” using imaginary lines and faces.
Step 2: Suppose that these unit are connected by discrete points which lie in boundary and inner.
Step 3: Define the displacement state in the inner and boundary of finite unit by selecting the function based on node displacement.
Step 4: According to displacement function of node displacement, this study determines the stress state in the inner of unit, this strain and the relationship of primary strain and material.
Step 5: Determine various forces include force which focus on node, uniform boundary stress and discretionary distributing load.

The generation algorithm of hexahedron mesh

According to the shape and physical characteristic of the model, we cut the solved area into some interlinkage units and analyze the stress and deformation of the unit, and then solve form algebra equation.

Since the surfaces of vehicle body are curved normally, we divide the area into mesh before and after deforming. This study converts tetrahedron unit of ten nodes into hexahedron mesh (Figure 1). The steps of the meshing algorithm are as follows:
Step 1: Convert the analysis field into tetrahedron unit of ten nodes (TET 10 for short). This study extracts characteristic point from vehicle deformation area using laser scanner, then the tetrahedron meshes are generated.
Step 2: Judge that the border of every TEN10 unit is curving or not. It need to judge that the middle coordinate (M) of the line AB and the middle coordinate (E) of unit border are equal or not (Figure 2). If the coordinates are equal, AB is a straight border. Otherwise, AB is a curve.



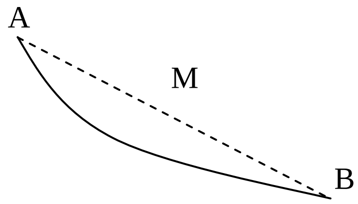


Figure 1 Tetrahedron unit of ten nodes   Figure 2 Judging that borders are curving

Step 3: Calculate the center of the four triangles in every TET 10 unit, the centers are P_{ABC} , P_{ABD} , P_{BCD} , P_{ACD} .

Step 4: Judge that every surface of TEN10 units have curving border or not. If curving border exists, the surface is curving face. This study mapped the center of the four triangles in the unit surface into the curving face using shape function of triangle which has and 6 nodes and curving border. The mapped method is as follows:

$$x_{new} = N_1 x_A + N_2 x_B + N_3 x_D + N_4 x_E + N_5 x_I + N_6 x_H \quad (1)$$

$$y_{new} = N_1 y_A + N_2 y_B + N_3 y_D + N_4 y_E + N_5 y_I + N_6 y_H \quad (2)$$

$$z_{new} = N_1 z_A + N_2 z_B + N_3 z_D + N_4 z_E + N_5 z_I + N_6 z_H \quad (3)$$

The definition the shape function N_i (i = 1，···，6) is:

$$N_i = L_i (2L_i - 1)\text{，} \quad i = 1\text{，}2\text{，}3 \quad (4)$$

$$N_4 = 4L_1 L_2 \quad (5)$$

$$N_5 = 4L_2 L_3 \quad (6)$$

$$N_6 = 4L_1 L_3 \quad (7)$$

Step 5: Calculate the center of tetrahedron unit which has straight border, the O point is gotten.

Step 6: Judge that every surface of TEN10 units have curving border or not. If curving border exists, this study mapped the point O into a new position using shape function of tetrahedron unit of ten nodes which has curving border. The mapping method is similar to the mapping of curving face, because the warping of hexahedron unit is smallest through connecting the mapping point to other relevant point.

Step 7: Divide every TEN10 unit into four hexahedron units through connecting point O to other relevant point.

Step 8: Eliminate repeated nodes and number the units and nodes renewedly.

CALCULATION MODEL OF IMPACT FORCE AND INSTANTANEOUS SPEED

Calculation Model of Impact Force

According to the basic theory of finite element method, the process of finite element analysis which deals with the continuum is as follows:

（1）Divide the continuum into finite units, which can be described by finite variables.

（2）According to the rule of standard discrete system, these units are combined, then the solution of the whole system can be achieved.

Suppose that the numbers of the nodes is the typical unit 1. According to the node displacement, distributing loads and primary strain, we can get the force which brings pressure to bear on the node uniquely. Suppose that the behavior of unit is linear elasticity, the force is equation (8) where f_p^1 is the node force which balances the distributing loads, $f_{\varepsilon_0}^1$ is the node force which balances the primary strain, $a^1 = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$, $a_1 = \begin{bmatrix} u_1 \\ v_1 \end{bmatrix}$ are node displacement. K^1 is rigidity matrix.

$$q^1 = K^1 a^1 + f_p^1 + f_{\varepsilon_0}^1 \quad (8)$$

In order to get a whole solution, it must be satisfied with the harmony of the displacement and the balance of force, so the force which brings pressure to bear on node i is equation (9).

$$r_i = \sum_{e=1}^{m} q_i^e = (\sum_{e=1}^{m} K_{i1}^e) a_1 + (\sum_{e=1}^{m} K_{i2}^e) a_2 + \ldots \sum_{e=1}^{m} f_i^e \quad (9)$$

Equation (9) only aims at the node which is conjoint to node i. If we combine all the equations, the system equation can be gotten, such as equation (10), where K and f are equation (11)..

$$Ka = r - f \quad (10)$$

$$\begin{cases} K_{ij} = \sum_{e=1}^{m} K_{ij}^e \\ f_i = \sum_{i=1}^{m} f_i^e \end{cases} \quad (11)$$

According to the process of finite element analysis of continuum, this study calculates the impact force before body deforming of accident vehicle relying on the characteristic data of deformation.

Calculation Model of Instantaneous Speed

Based on the mesh chart of collision deformation energy of the finite element theory, this study quantitatively analyzes the relationship between vehicle collision speed and body deformation. The mesh chart of collision deformation energy divides the body into many areas, and the absorbed energy value of every deformation area is calculated after the crash.

When comparing the actual deformation of a crash vehicle with the values in the mesh chart, the value of the area between the deformation curve and vehicle contour line is the absorbed energy because of vehicle crushing shrinkage.

Initially, hypotheses are as follows:
1.The deformation degrees of all areas are same in the entire width in vertical direction;
2.The friction between cars and ground is neglected in the process of collision;
3.The elasticity restore is neglected after crashing.
The calculation formula of conclusion deformation is equation (12) where f is collision force of body width, c is deformation depth, w is the body width, E_n is the absorbed energy. This

equation shows the energy when the deformation width is from w_{n-1} to w_n, and the deformation depth is from c_{n-1} to c_n.

$$E_n = \int_{w_{n-1}}^{w_n} \int_{c_{n-1}}^{c_n} fdcdw (n = 1, 2...) \tag{12}$$

Combined with the linear relationship between collision speed and residual body deformation, the equivalent speed loss is obtained when the amplitude of body deformation is from w_{n-1} and c_{n-1} to w_n and c_n, where a and b are rigidity coefficients.

$$v_n^2 = \left(\frac{w_n - w_{n-1}}{w} \right) \left[ac_n + b \right]^2 - \left[ac_{n-1} + b \right]^2 \; (n = 1, 2...) \tag{13}$$

Through equation (12) and equation (13), the calculation model of instant displacements can be established. Combined with vehicle dynamics model which includes tire model theory, this study constructs the refined calculation and simulation reconstruction of the vehicle-fixity crash accident.

This study builds the databases of accident vehicle deformation using the method of extracting and analyzing the data. Through combining with the refined calculation and simulation reconstruction of the vehicle-fixity crash accident, this study develops the analysis and reconstruction system of vehicle-fixity crash accidents on the Visual C++6.0 development platform.

APPLICATION CASE OF THE SYSTEM

If we would use analysis and reconstruction system of vehicle-fixity crash accidents, some parameters should be gotten from accident spot, such as the species and shapes of fixity、collision position and final stop collision、collision trace position、ground brake imprinting and main structural parameters. Then, the collision speed in ground coordinate system、the speed before accidents happen and movement condition in the process of accident can be calculated.

In examination of a vehicle-fixity crash accident that occurred on Xianning Western Road in Xi'an, this study analyses the actual case using the analysis and reconstruction system of vehicle-fixity crash accidents. In this accident, a Jetta FV7160CIX/CNG car collided with lampposts and trees. Accordingly, this accident is a typical vehicle-fixity crash accident. Using the system, the relevant data and accident process before and after the crash can be obtained through analysis, the results of which will identify the reason for and process of the vehicle-fixity crash.

The data gathered in the spot was input into the analysis and reconstruction system of vehicle-fixity crash accidents. The data include the species and shapes of fixity, collision position and final stop collision, collision trace position, ground brake imprinting and the main structural parameters. As displayed in Figure 3, the speed before the vehicle-fixity crash and the speed when the driver begins to brake were read. Then, the brief introduction of accident process(Figure 4) can be gotten.

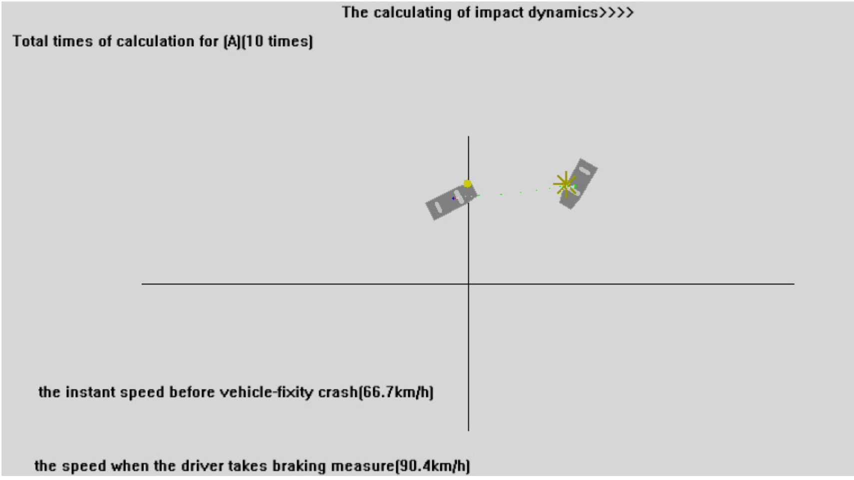


Figure 3 Calculation process and result

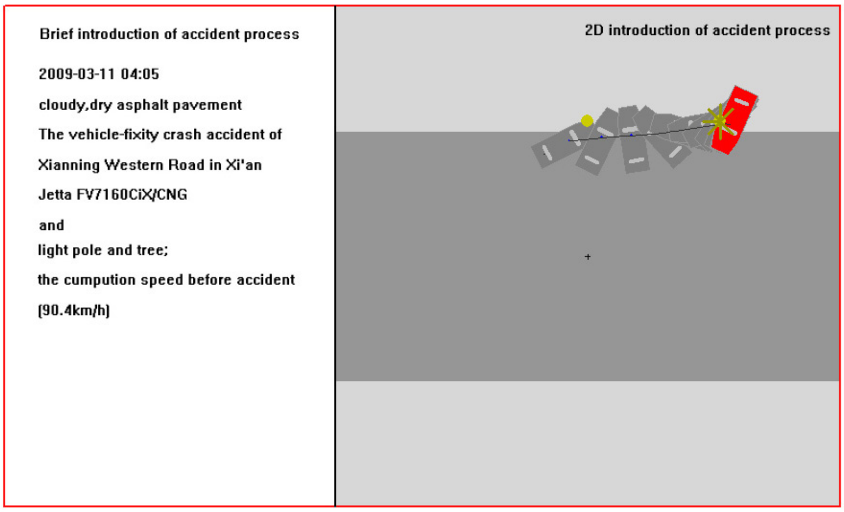


Figure 4 Brief introduction of accident process

According to the spot diagram and database, the reason, process and result of the accident can be described, so that the accident can be accurately identified. A similar accident can be calculated and reconstructed using the analysis and reconstruction system of vehicle-fixity crash accidents.

CONCLUSIONS

At first, this study researched on the extracting method of structure characteristic of collision position before accident happened and the deformation characteristic after crash.Through the finite-element analysis process of deformation area, this study meshed the deformation area, using the generation algorithm of hexahedron mesh. According to the basic theory of finite element method, this study built calculation model of impact force and instantaneous speed. Therefore, this study constructed the refined calculation and simulation reconstruction of the vehicle-fixity crash accident. This study developed the analysis and reconstruction system of vehicle-fixity crash accidents on the Visual C++6.0 development platform. Through analysis of the actual case, this study obtains data and the spot diagram of the accident, achieving a successful application of the system

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