ICIC Express Letters
Part B: Applications
Volume **7**, Number **6**, June **2016**

ICIC International ©2016 ISSN 2185-2766
pp. 1305–1311

EXTRACTION AND EQUIVALENT TECHNOLOGY OF BODY DEFORMATION FOR ACCIDENT VEHICLE

Wangfang Yuan[1], Runxiu Hu[2], Lang Wei[1] and Weifeng Zhang[1]

[1]School of Automobile
Chang'an University
Middle-Section of Nan'er Huan Road, Xi'an 710064, P. R. China
autoyuanzi@163.com; { qch_1; zhangwf711 }@chd.edu.cn

[2]Quality Test Station of Vehicle in Shaanxi
Xi'an 710061, P. R. China
44076682@qq.com

Received November 2015; accepted February 2016

Abstract. *The present paper aims to identify the cause of vehicle crash. The object of study is deformation area of accident vehicle. Through impacting test of actual vehicle, this study researches the extraction and equivalent technology of accident vehicle for body deformation. Based on the 3D laser scanner and reversal designing software, this paper studies investigation method of deformed region and extraction method of body deformation for accident vehicle. Through designing and carrying out the deformation test of actual vehicle, the relation curve between force and displacement is gotten. Through building the model of deformed region based on finite element method, this paper develops the extraction and equivalent systems for road traffic accident vehicle body deformation on VC++ platform, and then calculates the deformation of deformed region of test vehicle. This system can contribute to the analysis and reconstruction system of road traffic accidents and provide the basis for road traffic accidents.*
Keywords: Test, Deformation, Finite element, Extraction, Equivalent

1. **Introduction.** As the rapid development of automobile industry in China, the traffic problems are highlighted increasingly. The analysis methods of road traffic accidents based on computer technology are used very well. According to equivalence principle of deformation amount, normalizing the complex and irregular deformation can input the parameter into computer and analyze the road traffic accident, and also study the relation between force and deformation of typical vehicle crash. At present, the measuring methods of body deformation of accident vehicle include equivalent plastic method and photogrammetry method. The equivalent plastic methods in China for the deformation of traffic vehicle include the empirical approach and improved equivalent plastic method. The 3D reconstruction model of accident vehicle had been built based on normal camera by Beihang University [1]. Shanghai Jiao Tong University had researched on photogrammetric model based on direct method of linear transformation, and extracted vehicle deformation using 2D and 3D models [2]. At present, the common measurement method of body deformation for accident vehicle has some deficiencies. The postulated conditions of empirical approach are too many, and the test data points are limited and have low accuracy. The equivalent plastic method divided the deformed region of vehicle into several minizones, and summed up deformation along the width direction. This method has a certain application value, but the accuracy is low [3]. In addition, the method above-motioned cannot reflect complex and irregular deformation, and the result cannot be input into the computer to analyze traffic accident [4-6].

Based on the 3D laser scanning technology and three-dimension testing software, this paper studies investigation method of deformed region and extraction method of body deformation for accident vehicle on the VC++ and OpenGL platform, designs the extraction and equivalent systems for road traffic accident vehicle body deformation, and applies the system to the actual deformation.

2. **Study on the Deflection and Feature of Vehicle Deformation.** This study surveys the curved face of vehicle deformation and gets the deformation data using handheld positioning 3D laser scanner named Handyscan EXAscan which is produced by Creaform company. The vehicle impacting test is shown as Figure 1. Through the investigation of deformation of the test vehicle using Handyscan EXAscan, the scanning data and chart are gotten using the software Geomagic Qualify. The scanned charts of left side B-pillar of the test vehicle before and after loading are shown as Figure 2 and Figure 3, whose formats are STL. Then, the vehicle deformation is extracted using the software Geomagic Qualify. This study does orientation deviation analysis for left side B-pillar of the test vehicle and gets the result, as Figure 4. The maximum of positive deviation of deformed region is 10.564 mm, the maximum of negative deviation of deformed region is −124.107 mm. The average of positive deviation of deformed region is 1.850 mm, and the average of negative deviation of deformed region is −55.677 mm. The standard deviation of all the deformed region is 31.272 mm. On the left of Figure 4, there are 19 sections of the deviation of chromatography, which are convenient to observe deformation.

Figure 1. Test of vehicle impacting

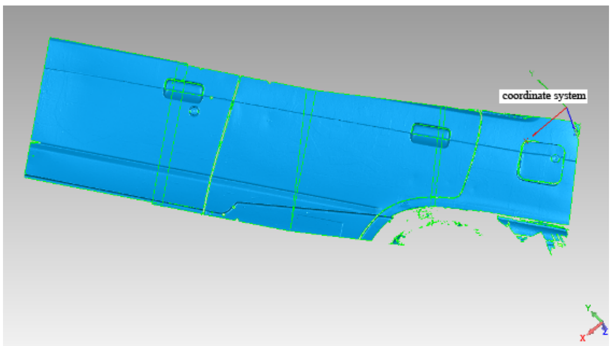

Figure 2. Scanned charts before loading

3. **Analysis of Force and Deformation for Vehicle Body.** In the vehicle environmental simulation of laboratory, the mechanics and deformation characteristics of car body are tested. The test instruments in the laboratory include dynamic electro-hydraulic servo test system and SYNERGY5173 data acquisition instrument. In the laboratory, the common vibration and impacting of vehicle can be simulated, as Figure 1. The data of deformation and force can be gotten in the process of loading in the road traffic accident.

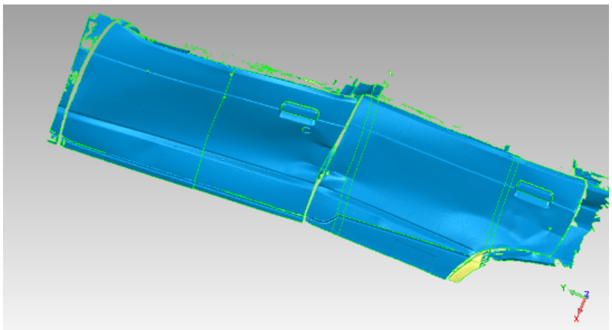

Figure 3. Scanned charts after loading

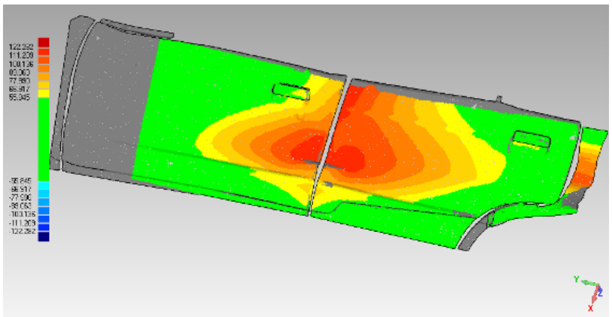

Figure 4. Extraction of deformation

Table 1. Partial data of displacements and loads on B-pillar

Time (s)	Displacement (mm)	Load (KN)	Time (s)	Displacement (mm)	Load (KN)
0.00	0.00	0.012	4.00	1.57	0.079
1.00	0.37	0.037	5.00	1.98	0.098
2.00	0.78	0.049	6.00	2.38	0.128
3.00	1.18	0.067	7.00	2.78	0.195

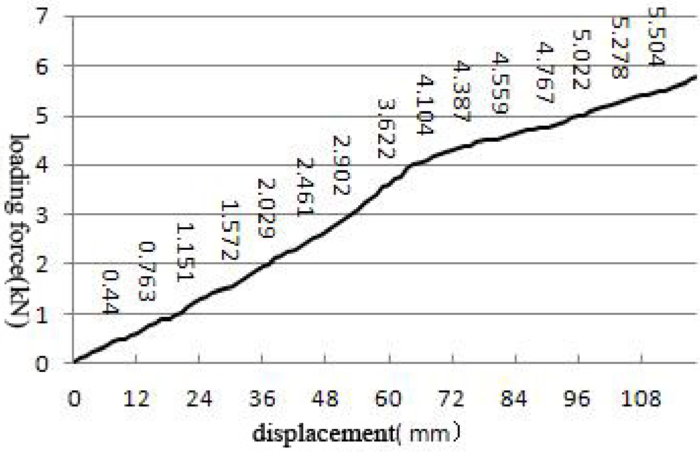

Figure 5. Chart between displacements and loads

Then, this study analyzes the data of the test as Table 1 and draws the curves between displacement and load as Figure 5. Through analyzing the test data, the relation between displacements and loads loaded on the B-pillar is linear. In addition, this study also does the loading tests on the A-pillar, C-pillar, engine cover and door of the test vehicle, and processes the test data. The results are that all of the relations between displacements and loads on the A-pillar, C-pillar, engine cover and door of the test vehicle are linear.

4. **Study on Equivalent Plastic of Deformation Based on Finite Element Method.** Based on deformation test of loading on vehicle, this paper has compiled the program using VC++ and OpenGL, which can read the data of variance analysis and the STL data of scanning. Now, this paper will put forward a calculation model of total deformation for vehicle deformed region, which will divide the total deformation into many triangular-prisms and get the coordinate formulas of the triangular-prisms volume. Furthermore, this study will analyze the deformation shape of accident vehicle, and build cone and ball equivalent plastic deformation model respectively.

4.1. **Building of total deformation model.** First, this paper reads the variance analysis data when extracting the displacement of vehicle deformation. The curved face after deforming is test surface, and the curved face before deforming is reference surface. In the process of variance analysis, this paper sets X, Y, Z coordinates. The coordinates before and after deforming are fixed, which can be used for searching the displacements of triangular patch vertex which compose the curved face after deforming. At last, this paper matches the data of variance analysis with the order of STL data of scanning after deforming and gets the coordinates and the displacements of triangular patch vertex which compose the curved face. The total deformation of deformed region can be converted into total volumes of certain numbers' triangular-prisms.

According to the definition of the variance analysis, this paper divides the curved face into many triangular-prisms, whose element is shown as Figure 6. In Figure 6, the triangle ABC locates reference surface, and the triangle $A_1B_1C_1$ locates test surface. n_0 is the direction of deviation axis. The lengths of segments AA_1, BB_1 and CC_1 are displacements of three vertexes along the direction of deviation axis, and the segments AA_1, BB_1 and CC_1 are parallel each other.

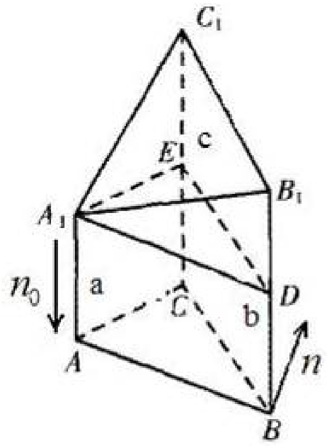

FIGURE 6. Triangular-prism

Suppose the coordinates of triangular-prisms' vertex are $A(x_1, y_1, z_1)$, $B(x_2, y_2, z_2)$, $C(x_3, y_3, z_3)$, $A_1(x_4, y_4, z_4)$, $B_1(x_5, y_5, z_5)$, $C_1(x_6, y_6, z_6)$. The lengths of segments are $AA_1 = a$, $BB_1 = b$, $CC_1 = c$. The distance from segment AA_1 to plane BCC_1B_1 is h. The distance between segments BB_1 and CC_1 is h_1. The volume is Equation (1):

$$V_i = \frac{1}{6}(a + b + c)h_1 h \tag{1}$$

In Equation (1), $\left\{\begin{array}{l} a = \sqrt{(x_4 - x_1)^2 + (y_4 - y_1)^2 + (z_4 - z_1)^2} \\ b = \sqrt{(x_5 - x_2)^2 + (y_5 - y_2)^2 + (z_5 - z_2)^2} \\ c = \sqrt{(x_6 - x_3)^2 + (y_6 - y_3)^2 + (z_6 - z_3)^2} \end{array}\right.$.

After determining the volume of every triangular-prism, this paper sums up the volumes and gets total deformation of deformer region as Equation (2).

$$V = \sum_{i=1}^{n} V_i \tag{2}$$

4.2. **Cone equivalent plastic deformation model of deformed region based on finite element method.** Through analyzing the deformation of a large number of vehicle bodies, this study finds that a part of deformations of impacting points on the front and side are maximum. The collision point is the center and makes the related assemble deform. When the intersecting line between the plane which includes the impact point with boundary point of deformation and curved face is straight line, or the deformation shape is similar to cone, this study can select cone equivalent plastic deformation model. The input parameter of the model is basal diameter of cone D_{yz}, and the averages include horizontal and vertical distances of deformed region's boundary as the basal diameters of cone named d_1 and d_2. D_{yz} is shown as Equation (3):

$$D_{yz} = \frac{d_1 + d_2}{2} \tag{3}$$

The output parameters are the height of cone H_{yz} and the area of deformed area S_i. According to the total volume of deformed region V. H_{yz} is shown as Equation (4):

$$H_{yz} = \frac{12V}{\pi D_{yz}^2} \tag{4}$$

According to physical significance of variance analysis based on Geomagic Qualify, the body deformation in this paper tests the distance between the points of the test surface (after deforming) and the projection points of reference surface (before deforming). These projection points divide the reference surface into many triangular-prisms together and the vertex coordinates of every triangular-prism are known. Suppose that there are N triangular-prisms, which have deformed in the reference surface. The coordinates of the three vertexes i are $A(x_{1i}, y_{1i}, z_{1i})$, $B(x_{2i}, y_{2i}, z_{2i})$, $C(x_{3i}, y_{3i}, z_{3i})$. The area of triangular-prism is shown as Equation (5):

$$S_i = \frac{1}{2}\left|\overrightarrow{A_iB_i} \times \overrightarrow{A_iC_i}\right| \tag{5}$$

The area of total deformation is shown as Equation (6):

$$S = \sum_{i=1}^{N} S_i \tag{6}$$

4.3. **Ball equivalent plastic deformation model of deformed region based on finite element method.** Through analyzing the deformation of a large number of vehicle bodies, this study finds that a part of deformations of impacting points on the front, side and rear-end collision are similar to ball. This study can select ball equivalent plastic deformation model. The input parameter of the model is plane diameter of ball D_{qq}, the average includes horizontal and vertical distances of deformed region's boundary as the basal diameters of cone named d_1 and d_2. D_{yz} is shown as Equation (3). The output parameters are the height of ball H_{qq} and the area of deformed area.

This model defines the spheriform center of spherical segment as the origin of coordinates, the spherical segment is the space segment using full line. X axis is parallel to spherical segment and Y axis is perpendicular to spherical segment. The coordinate system is shown as Figure 7. Suppose that the depth of spherical segment is H_{qq}, the radius

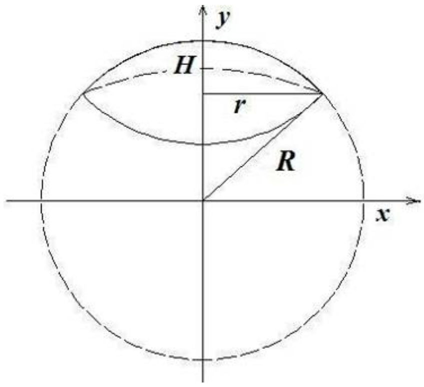

FIGURE 7. Ball element

of cross section is r, and the spheriform radius is R. The volume of spherical segment is shown as Equation (7):

$$V = \int_{R-h}^{R} \pi x^2 dy = \pi \int_{R-h}^{R} (R^2 - y^2) dy = \pi R {H_{qq}}^2 - \frac{1}{3}\pi {H_{qq}}^3 \tag{7}$$

The total deformation of vehicle body is V, and r and R are known:

$$r = \frac{1}{2} D_{qq}, \quad R = \frac{{H_{qq}}^2 + r^2}{2H_{qq}} \tag{8}$$

According to equivalence principle of total deformation, Equation (9) can be gotten:

$${H_{qq}}^3 - \frac{3}{4}{D_{qq}}^2 H_{qq} - \frac{6}{\pi} V = 0 \tag{9}$$

Then solving Equation (9) using Cardano's Formula method, the depth of spherical segment can be gotten. In addition, the area of body deformation refers to Equation (6).

5. **Implementation of Equivalent Systems of Deformation for Road Traffic Accident Vehicle.** Based on the 3D laser scanning technology and geomagic three-dimension testing software, this paper studies investigation method of deformed region and extraction method of body deformation for accident vehicle on the VC++ and OpenGL platform, and designs the extraction and equivalent systems for road traffic accident vehicle body deformation. The STL data of B-pillar is shown as Figure 8. Aiming to B-pillar deformation of test vehicle, this paper calculates the equivalent plastic deformation, and inputs the basal diameter of cone or plane diameter of ball. After clicking the button of each model, the height of cone and the depth of spherical segment can be gotten. The calculation result of B-pillar of test vehicle after loading using the system is shown as Figure 9. Through testing, the transverse distance of B-pillar of test vehicle after loading is 1654.054 mm, the vertical distance is 495.952 mm, so the basal diameter of cone or plane diameter of ball is 1075 mm. The calculated depths are 109.152 mm and 70.8684 mm, and the area of deformation is 7280892 mm.

6. **Conclusions.** This paper designs and carries out the loading test of common collision position. Through researching the key technology of deformation extraction, reading and matching technique of scanning data after deforming, this study builds calculation model of total deformation based on finite element method. Combined with the deformation characteristic of different position, this paper builds cone equivalent plastic deformation model and ball equivalent plastic deformation model respectively using the equivalence principle of total deformation, and develops the extraction and equivalent systems of body deformation for accident vehicle by means of actual deformation.

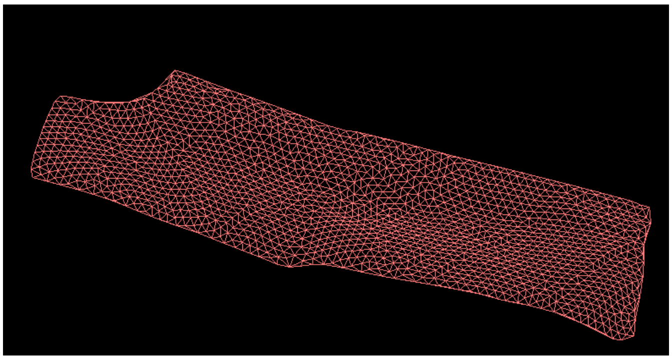

Figure 8. STL data of B-pillar

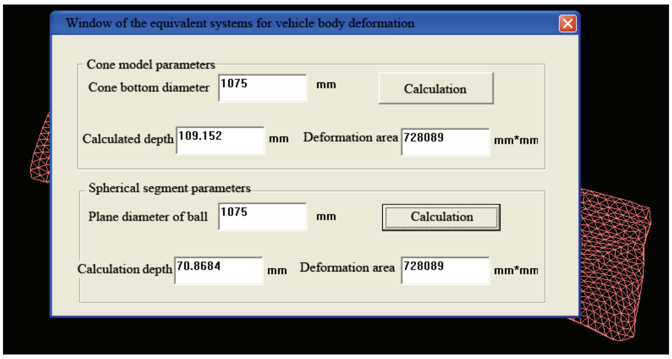

Figure 9. Calculated results of B-pillar

Acknowledgments. The project was supported by the special fund for basic scientific research of central colleges, Chang'an University (ID: CHD2012JC006). The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

REFERENCES

[1] G. Q. Lu, H. G. Xu, S. Q. Ma and Y. B. Li, Self-calibration three-dimension reconstruction model of traffic accident photographs, *Journal of Traffic and Transportation Engineeting*, vol.6, no.3, pp.109-113, 2006.
[2] X. G. Du, X. L. Jin, X. Y. Zhang, Z. J. Zhao and J. Shen, Geometry feature extracting for traffic accident reconstruction based on photogrammetry, *Journal of Shanghai Jiao Tong University*, vol.42, no.6, pp.861-864, 2008.
[3] D. Vangi, Energy loss in vehicle to vehicle oblique impact, *International Journal of Impact Engineering*, vol.36, no.3, pp.512-521, 2009.
[4] L. Wei, T. Chen and Q. Yu, Three-dimensional vehicle dynamics model for road traffic accident simulation and reconstruction, *Journal of Traffic and Transportation Engineering*, vol.3, no.3, pp.89-92, 2003.
[5] L. Wei, An analysis of vehicle dynamic simulating tire model used in collisions accidents, *Journal of Xi'an Highway University*, vol.19, no.1, pp.73-76, 1999.
[6] L. Wei, Y. S. Chen, H. Ishikawa and K. Yamazhaki, A study on simulation model for car-to-car crash and their second impact in traffic accidents, *Automotive Engineering*, vol.22, no.1, pp.38-41, 2000.