Research on the Updating Method of Vehicle Frame Finite Element Model

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\textbf{Abstract:} First, the strain gauges were pasted on the front and back tie rods of the vehicle for the sake of calibration. Under the designated working conditions, the strain data of the tie rods were collected via a data acquisition unit (DEWESoft). Meanwhile, the pressure of suspension cylinder was measured, the force distribution ratio of front axle and back axle was respectively calculated through the strain data and cylinder pressure data, and the calculation formula of the distribution ratio was obtained. The calculation results were verified through a traction test of the complete vehicle. In the end, the finite element model was updated according to the test data, followed by the analysis of the structural stiffness and strength. The method proposed in this paper will considerably contribute to the improvement of finite element analysis accuracy of the complete vehicle, and moreover, it can be promoted in the design of other similar structures, with a certain reference significance.

1. Introduction

There are more and more product categories in the machinery industry, and their upgrading speed is fast, along with the fierce market competition. The product R & D is featured by tight schedule and heavy task, so the R & D remains to be shortened urgently, and the digital simulation analysis provides an idea to solve this problem, but the simulation precision has been perplexing analysis engineers. Zhang H \cite{1} et al. expounded the updating of a finite element model from the linearity to nonlinearity. Zhou C W \cite{2}, Yang Y \cite{3} and Nie Y G \cite{4} et al. conducted the related studies from different angles, but their studies were based on theories without the close combination of test. Therefore, the tensile force of tie rods was tested in this study, the traction was calculated, the force distribution ratio of front axle and back axle was solved, and the finite element model was updated and analyzed finally, thus laying a foundation for the subsequent analysis.

2. Test and Test Data

2.1. Full-axle principle of tie rod strain gauge group \cite{5}

The resistance strain measurement method is a most commonly used method among the experimental stress analysis methods. This method is used to measure the surface strain of a member using the strain sensitive element—resistance strain gauge, obtain the its surface stress state according to the strain-stress relation, and then conduct the stress analysis. The strain gauges were uniformly distributed in the middle of the tie rods, one longitudinal gauge and one transverse gauge were pasted...
at each position, thus forming a full axle. The longitudinal strain gauges were denoted as \( R_1 \) and \( R_4 \), and transverse strain gauges as \( R_2 \) and \( R_3 \). Assume that the change in the sectional area of the tie rods is neglected, then the pressure \( P \) presents a linear relation with the measured strain.

![Wiring diagram of strain gauge of full bridge](image)

Figure 1 Wiring diagram of strain gauge of full bridge

2.2. Calibration of tie rods

The tie rods pasted with the strain gauges were calibrated using the three-point calibration method. First, the tie rods were linearly loaded and then lowered, this process was repeated for several times, the tensile force of the actuator was increased from zero to \( F_d \), the reading \( \varepsilon_d \) of each strain gauge was recorded, the actuator pressure was reduced to \( F'_d \) and then the reading \( \varepsilon'_d \) was recorded. If \( \varepsilon'_d \) was a half of \( \varepsilon_d \), the slope \( k_d \) of linear change was recorded.

\[
k_d = \frac{\varepsilon_d - \varepsilon'_d}{\varepsilon_d - \varepsilon'_d}
\]

![Actuators for calibration](image)

Figure 2 Actuators for calibration

The final calibration results are seen in the following table:

| Tie rod | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|
| Slope   | 50.01 | 51.21 | 49.86 | 52.01 | 45.21 | 41.22 | 40.56 | 41.22 |

2.3. Complete vehicle test

2.3.1. Operation test

The calibrated tie rods were installed on the complete vehicle to carry out a test under the designated
working conditions. Before the test, the vehicle should meet the stipulated service conditions. In order to ensure the consistency of repeated tests, the operation should be standardized. In this complete vehicle test, the T-shaped operation route was adopted, the site pavement was trimmed without obvious unevenness, the vehicle attitude was divided into three segments—spading, transportation and unloading, and two modes—four-wheel drive and two-wheel drive, the loading machine was rightly against the stockpile and it stopped at about 10 m away from the stockpile, the loading machine kept the bucket horizontal and slowly moving forward until it could not operate any longer. After the bucket was filled with the materials, the loading machine retreated and made a turning travel by 90° and unloaded the materials when arriving at the stockpile, therefore, one spading and loading process was completed, and this was repeated twice under each of the two modes. Table 2 displays the force borne by the tie rods when the materials in the bucket of loading machine stayed still in the spading segment, if the force was positive, the tie rod was compressed, and if it was negative, the tie rod was tensioned.

![Figure 3 Job route](image)

**Table 2: Forces Borne by Tie Rods (Unit: kN)**

| Tie rod       | Front upper left | Front upper right | Front lower left | Front lower right | Back upper left | Back upper right | Back lower left | Back lower right |
|---------------|------------------|-------------------|------------------|-------------------|-----------------|------------------|-----------------|------------------|
| Test value    | 65.71            | 42.91             | -87.2            | -71.78            | -97.42          | -66.53           | 80.56           | 79.50            |

If the member beneath the spring was regarded as a whole, in the horizontal direction, it bore the force $F_{tension}$ given by the tie rod and ground frictional force $f_{friction}$, which were equal with the opposite directions. The complete vehicle was regarded as a whole, and then the traction $F_{traction}$ was equal to the ground frictional force $f_{friction}$:

$$F_{tension} = f_{friction} = F_{traction}$$

Through the test values of tie rods, it could be known that $F_{traction} = 64.46$ kN, the force borne by the front axle was $F_{front axle} = -50.35$ kN, and $F_{back axle} = 14.11$ kN. During the test, the force distribution ratio of front axle and back axle was $γ = \frac{50.35}{14.11} = 3.557$; in the meantime, the pressures in the large and small chambers of oil cylinder were tested as shown in the following Table 3. According to the pressure values of large and small chambers as well as the inner diameter D of suspension cylinder and rod diameter d, the force borne by the suspension cylinder could be calculated as $F_{suspension \ cylinder}$.

$$F_{suspension \ cylinder} = \frac{\pi D^2}{4} \cdot P_{large \ chamber} - \frac{\pi D^2}{4} \cdot P_{small \ chamber}$$

**Table 3: Pressures of Large and Small Chambers in Suspension Cylinder (Unit: MPa)**

| Suspension cylinder | Front left | Front right | Back left | Back right |
|---------------------|------------|-------------|-----------|------------|
| $P_{large \ chamber}$ | 11.99      | 13.94       | 5.90      | 6.91       |
| $P_{small \ chamber}$ | 13.94      | 11.98       | 6.91      | 5.89       |

The weight data of the vehicle are seen in the following table:
Table 4 Weight (Unit: kg)

| Item               | Left wheel | Axle weight | Right wheel |
|--------------------|------------|-------------|-------------|
| Front axle         | 10,481     | 20,963      | 10,482      |
| Back axle          | 6,131      | 12,261      | 6,130       |
| Total vehicle weight | 33,197     |             |             |

Through the data in the above table and the distance $L_0$ from front axle to back axle, the center-of-gravity position $G$ of the complete vehicle could be calculated. If the horizontal distance from the center of front wheel to the center of gravity was $L_{\text{front}}$, and that from the center of back wheel to the center of gravity was $L_{\text{back}}$, and then:

$$N_{\text{front}} \cdot L_{\text{front}} - N_{\text{back}} \cdot L_{\text{back}} = 0$$

$$L_{\text{front}} + L_{\text{back}} = L_0$$

When the bucket spaded the materials until the vehicle presented a slipping trend, the front axle weight was $N'_{\text{front}}$, the back axle weight was $N'_{\text{back}}$, and the weight beneath the suspension cylinder of the complete vehicle was $G_{\text{below spring}}$.

$$N'_{\text{front}} = F_{\text{front left of suspension cylinder}} + F_{\text{front right of suspension cylinder}} + G_{\text{lower front of spring}}$$

$$N'_{\text{back}} = F_{\text{back left of suspension cylinder}} + F_{\text{back right of suspension cylinder}} + G_{\text{lower back of spring}}$$

According to the above equations, when the friction coefficients of the four wheels were approximately consistent, the force distribution ratio of front axle and back axle was as follows:

$$\gamma = F_{\text{front left of suspension cylinder}} + F_{\text{front right of suspension cylinder}} + G_{\text{lower front of spring}} / F_{\text{back left of suspension cylinder}} + F_{\text{back right of suspension cylinder}} + G_{\text{lower back of spring}}$$

If the bucket bore the force $F_{\text{bucket}}$ in the vertical direction, assume that the direction was downward, the horizontal distance from the center of gravity of bucket filled with the materials to the center of front wheel was $L_{\text{bucket}}$, and then:

$$F_{\text{bucket}} (L_{\text{front}} + L_{\text{bucket}}) + N'_{\text{front}} L_{\text{front}} - N'_{\text{back}} L_{\text{back}} = 0$$

The force borne by the bucket was $F_{\text{bucket}} = N'_{\text{front}} L_{\text{front}} - N'_{\text{back}} L_{\text{back}} / L_{\text{front}} + L_{\text{bucket}}$, which could be taken for the reference in the force value input during the simulation.

After the data substitution, the followings could be obtained: $N'_{\text{front}} = 12,012.21$ N, and $N'_{\text{back}} = 3,363.42$ N.

Therefore, the force distribution ratio of front axle and back axle is $\gamma_1 = 12,012.21 / 3,363.42 = 1/0.28$.

On the above basis, the force distribution ratio of front axle and back axle was related to the pressure of suspension cylinder, and the results calculated by the two means were consistent, indicating that the test is successful.

2.3.2. Traction test of complete vehicle

The traction test of the complete vehicle was carried out on the cement floor at the test site. The test vehicle was at the front, driving the standard load—a trailer—behind it through the steel wire ropes, the back vehicle kept the neural position, while the test vehicle slowly moved under four wheel-drive and two-wheel drive modes (twice under each mode) until it slipped in situ, and the tensile force borne by the steel wire rope was recorded. As shown in Figure 4, the maximum traction was 64.11 kN, the traction value calculated previously was 64.46 kN, the deviation value between the two was within 5%, and the significance of the traction test lied in verifying the reliability of the above test data.
Figure 4: Test Value of Traction

3. Updating of Finite Element Model

As the complete vehicle was of complex structure and there were many uncertain actors in the analysis, such as the model simplification, boundary conditions, material parameters and contact between members, the finite element model might be different from the practical situation. The finite element model was updated through the test data, and a novel idea of combining the simulation test was proposed. The acting forces of front axle and back axle under the four-wheel drive mode could be obtained according to the test data. By adjusting the parameters of front and back tie rods in the finite element model, the calculation results of acting forces of front axle and back axle in the model were consistent with the test results, so the load-carrying route of the vehicle frame was closer to the reality, and in the end, the correctness of the force transfer route in the finite element model was verified through the force calculation results and test results of the suspension cylinder.

Figure 5: Post-Updating Stress Nephogram

Under the same attitude as the test, the nephogram results are shown in Figure 5, the maximum value was 453.20 MPa, the material was Q690, satisfying the safety factor of 1.5, the forces borne by the four suspension cylinders were extracted as seen in the following Table 5, and compared with the test data, the result deviations were all below 5%.
### Table 5: Pressure of Suspension Cylinder (Unit: N)

|                       | Front left | Front right | Back left | Back right |
|-----------------------|------------|-------------|-----------|------------|
| Finite element        | 15,034.32  | 24,150.26   | 248.68    | 54,291.05  |
| calculated value      |            |             |           |            |

### 4. Conclusion

The force distribution ratios of front axle and back axle calculated by the two means were consistent, and thanks to this, when different materials were spaded, a calculation formula that could obtain the distribution ratio fast was proposed in this study. Moreover, a new method which integrated the simulation with the test was proposed. In the finite element analysis, the force transfer route was basically consistent with the practical operation, the error between the test value and simulation value of the force borne by the suspension cylinder was within 5%, so the model precision was greatly improved, laying a solid foundation for the follow-up analysis.

### References

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