Fatigue Life Analysis of Frame Based on Measured Load Spectrum

Jiyao Wang, Jianan Liu, Yu Sun, Lianxu Shan, Jianhua Li, and Ning Yu

Abstract In view of the transverse crack of the longitudinal beam near the upper bracket of the front axle shock absorber of a dump truck frame, the improvement scheme is proposed. According to the actual road conditions of the dump truck, the strain test of the longitudinal beam, the displacement test of the shock absorber and the strain test of the piston rod of the shock absorber before and after improvement are completed. The calibration of the force of the piston rod of the shock absorber is completed in the bench test. The load spectrum of the frame fatigue simulation analysis is obtained by using the strain test results of the piston rod of the shock absorber. A section of frame model is intercepted, the finite element model of frame is established by shell element, and the finite element stress analysis of frame is carried out with HyperMesh software. At the same time, according to the time series load excitation spectrum and the fatigue characteristic parameters of frame material, the fatigue life of frame before and after improvement is obtained by using FEMFAT software. The results of the cloud chart of the frame fatigue life show that the position of the frame easily damaged before improvement is consistent with the actual position of the crack, and the fatigue life of the frame after improvement is significantly improved compared with that before improvement, which verifies the correctness of the fatigue life analysis method, and provides a reference for the fatigue life prediction and structural improvement of the frame.

Keywords Frame · Measured load spectrum · Fatigue life · FEMFAT

1 Introduction

Dump truck frame is mostly “side beam” frame, as the base of chassis, it bears the mass and bending moment of each assembly, and the torsion angle produced by uneven road surface. Almost all assembly parts of the automobile are installed on the

J. Wang (✉) · J. Liu · Y. Sun · L. Shan · J. Li · N. Yu
FAW JIEFANG Automotive Company Commercial Vehicle Development Institute, Changchun, China
e-mail: wangjiyao@rdc.faw.com.cn

China Society of Automotive Engineers (eds.), *Proceedings of China SAE Congress 2020: Selected Papers*, Lecture Notes in Electrical Engineering 769,
https://doi.org/10.1007/978-981-16-2090-4_42

frame through bracket. For some structural parts with uneven force, under random excitation of road surface, it is easy to cause fatigue damage of frame, and then affect the safety performance of the whole vehicle [1].

In this paper, aiming at the transverse cracks in the longitudinal beam near the bracket of the front axle shock absorber of a dump truck frame, the measured load spectrum before and after improvement is collected on the frame longitudinal beam and shock absorber, the force calibration test of the piston rod of the shock absorber is completed, and the load spectrum of the frame fatigue simulation analysis is obtained. Based on the finite element analysis software HyperMesh and FEMFAT, the fatigue life of the frame before and after improvement is calculated [2, 3]. The results of fatigue life nephogram show that the vulnerable position of the frame before improvement is consistent with the actual crack location, and the fatigue life after improvement is significantly increased, and it is verified by the actual road test successfully, which shows that the fatigue analysis method has certain value, and provides reference for the fatigue life prediction and structural improvement of the vehicle frame [4, 5].

2 Load Spectrum Test of Frame and Shock Absorber

Aiming at the crack failure of the longitudinal beam near the upper bracket of the front axle shock absorber of a dump truck frame, the improvement scheme is proposed. In order to prevent the failure from happening again, it is necessary to carry out load test on the frame before and after improvement to clarify the improvement effect.

2.1 Crack Location and Improvement Scheme of Frame

A service station feedbacks that when the dump truck runs 71,192 km, transverse cracks appear on the longitudinal beam near the upper bracket of the front axle shock absorber of the frame. The actual location of the crack is shown in Fig. 1.

For the cracked vehicle, L-type plate is added inside the longitudinal beam near the upper bracket of the frame shock absorber to improve the local strength of the frame and the production of the L-type plate is completed. Figures 2 and 3 are the schematic diagrams of longitudinal beams scheme before and after improvement, and Fig. 4 is the actual display of the L-type plate.

2.2 Load Spectrum Test Process

The road condition of the dump truck frame load spectrum test is the user's actual road, which is composed of general highway and expressway. The road condition

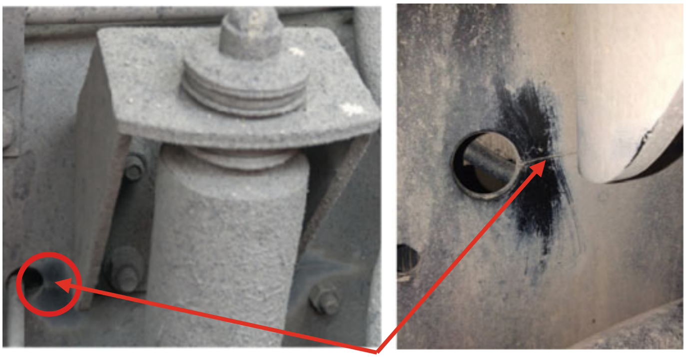


Fig. 1 Transverse crack location of frame longitudinal beam

Fig. 2 Diagram before improvement

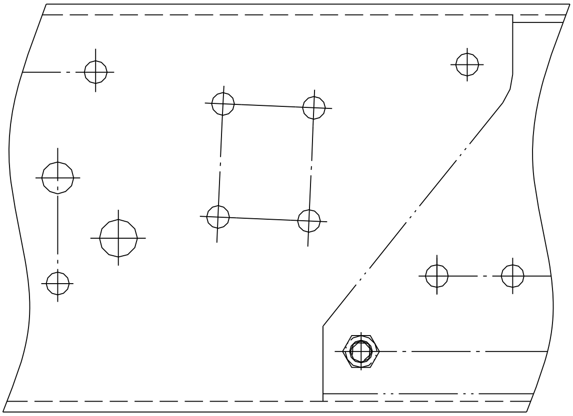


Fig. 3 Diagram after improvement

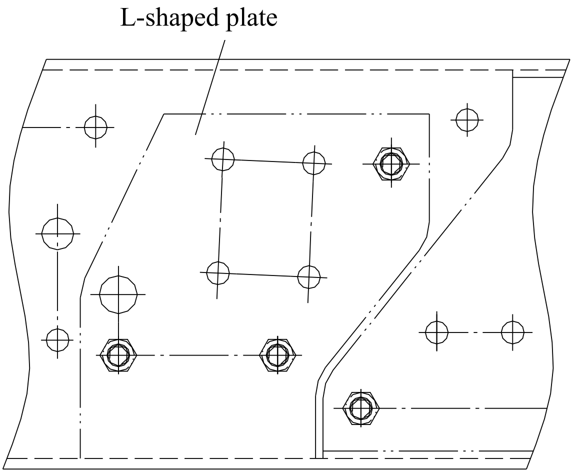


Fig. 4 Actual display of L-type plate

is good, the full load gross weight is 31 tons, the no-load driving proportion is low, and the overload and superelevation detection is strict. The average driving speed of the vehicle tested by GPS sensor is 58 km/h, and the maximum driving speed is not more than 80 km/h. In order to keep the vehicle condition consistent, the load test is carried out in two states of the same vehicle with or without L-shaped plate, and the total driving mileage is 209.8 km. Among them, the collection mileage before improvement (without L-type plate) is 67.6 km, and after improvement (with L-type plate) is 142.2 km, with a total duration of 4.4 h.

A total of 6 sensors are arranged in the load test, including 4 strain sensors on the frame longitudinal beam, 1 strain sensor and 1 displacement sensor on the shock absorber. The sensor measuring point information is shown in Table 1, the schematic diagrams of sensors layout is shown in Fig. 5, and the real status of sensors layout is shown in Fig. 6.

Table 1 Sensor measuring point information

Ordinal	Sensor type	Location of measuring points	Channel name	Channel code
1	Strain	Near the connection between frame longitudinal beam and shock absorber	Strain at upper left	Ch0
2			Strain at lower left	Ch1
3			Strain at upper right	Ch2
4			Strain at lower right	Ch3
5		Shock absorber piston rod	Strain at piston rod	Ch13
6	Displacement	Shock absorber	Axial displacement	Ch4

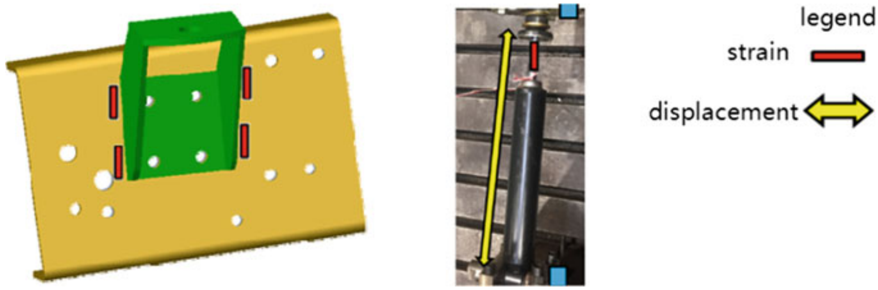
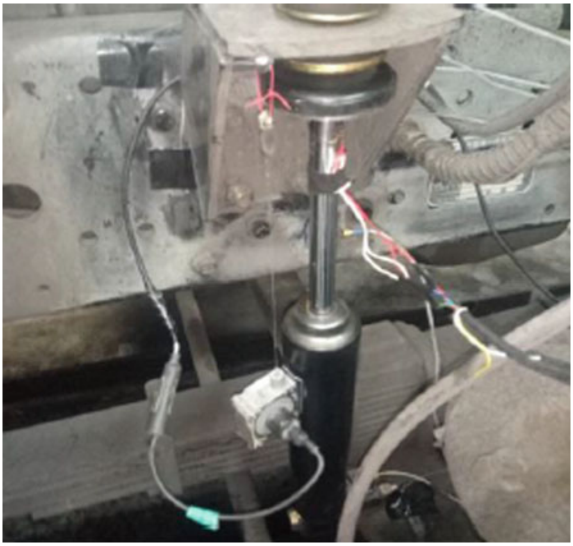


Fig. 5 Schematic diagrams of sensors layout

Fig. 6 Real status of sensors layout



3 Load Spectrum Analysis of Frame and Shock Absorber

By processing the abnormal signal data such as zero point and burr in the load test data, the strain test data of the frame longitudinal beam, the strain test data of the piston rod of the shock absorber and the displacement test data of the shock absorber before and after improvement are obtained [6].

3.1 Load Spectrum Analysis of Frame Longitudinal Beam

Taking the full load test data on some general highways as an example, the strain test data of Ch0 (upper left), Ch1 (lower left), Ch2 (upper right) and Ch3 (lower right) of the frame longitudinal beam before and after improvement are shown in Figs. 7 and 8.

The stress data of frame longitudinal beam can be obtained by the following formula:

$$\sigma = E\varepsilon \quad (1)$$

In the formula, ε is the strain test data, μm/m; E is the elastic modulus, MPa.

According to formula (1), the stress test data of the longitudinal beams before and after improvement can be calculated. The comparison of stress peak values is shown in Table 2. It is easy to know that the stress at the measuring point of the frame longitudinal beam changes repeatedly. The peak stress at the upper position is less than that at the lower position, and the peak stress value after improvement is less than that before improvement; the maximum stress peak value before improvement is 263 MPa, and the maximum stress peak value after improvement is 158 MPa, which are all less than the yield strength of frame longitudinal beam material. The static strength of the frame longitudinal beam is safe and reliable.

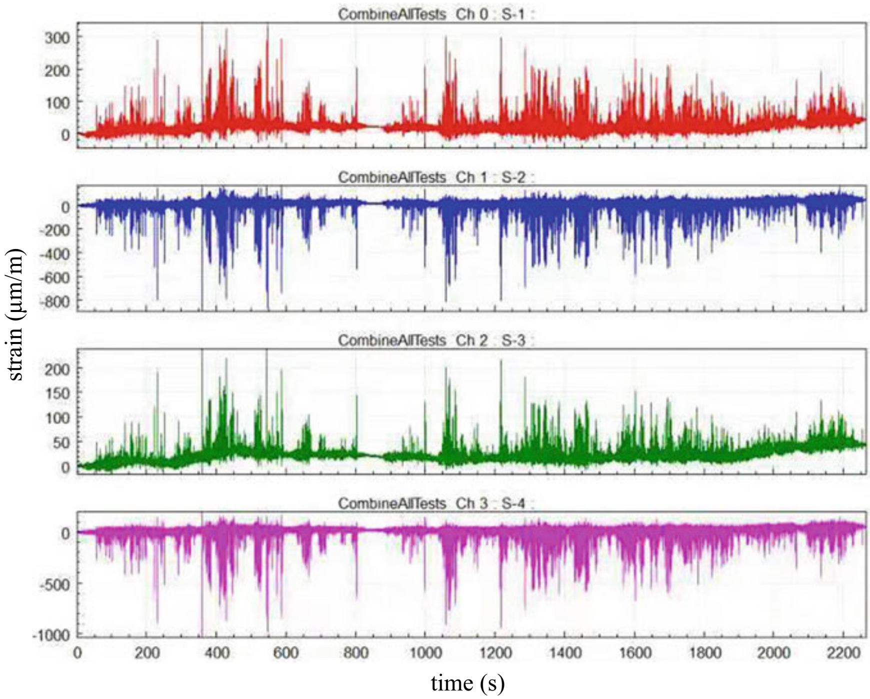


Fig. 7 Strain test data of the frame longitudinal beam before improvement

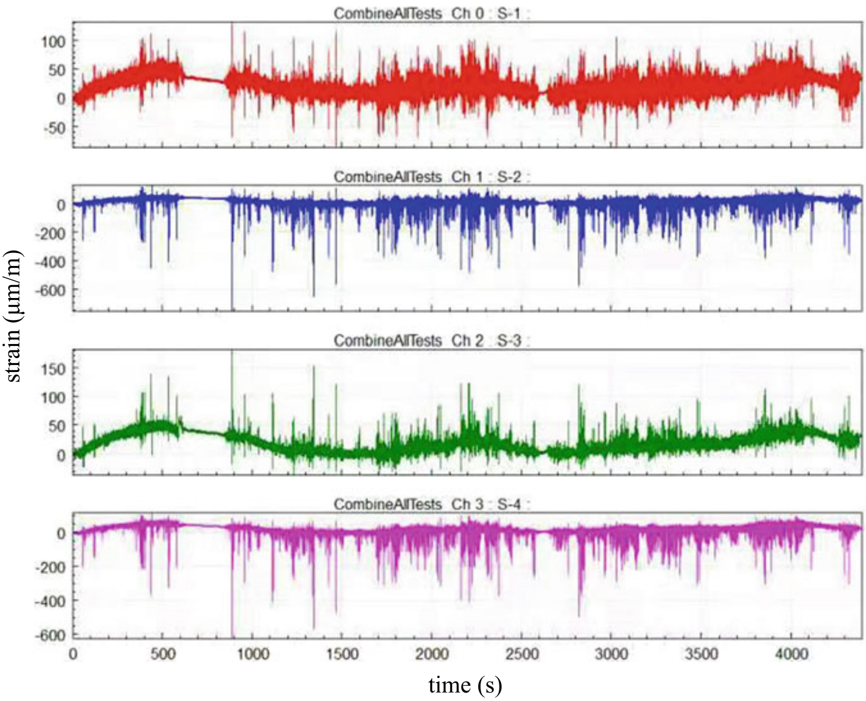


Fig. 8 Strain test data of the frame longitudinal beam after improvement

Table 2 Stress peak values of frame longitudinal beam before and after improvement

	Stress peak values			
	Ch0 (upper left)	Ch1 (lower left)	Ch2 (upper right)	Ch3 (lower right)
Results before improvement/MPa	84	231	63	263
Results after improvement/MPa	27	158	38	137

3.2 Load Spectrum Analysis of Shock Absorber

Taking the full load test data of some general highways as an example, Fig. 9 shows the displacement test data of the shock absorber and the strain test data of the piston rod of the shock absorber before improvement, and Fig. 10 shows the displacement test data of the shock absorber and the strain test data of the piston rod of the shock absorber after improvement. According to the displacement test data of the shock absorber, most of the displacement values of the shock absorber before and after improvement fluctuate between −20 and 20 mm. The upper limit of displacement is 60 mm, the lower limit is 48 mm, and the initial length of the shock absorber is 580 mm, which does not exceed the stroke limit of the shock absorber (the length

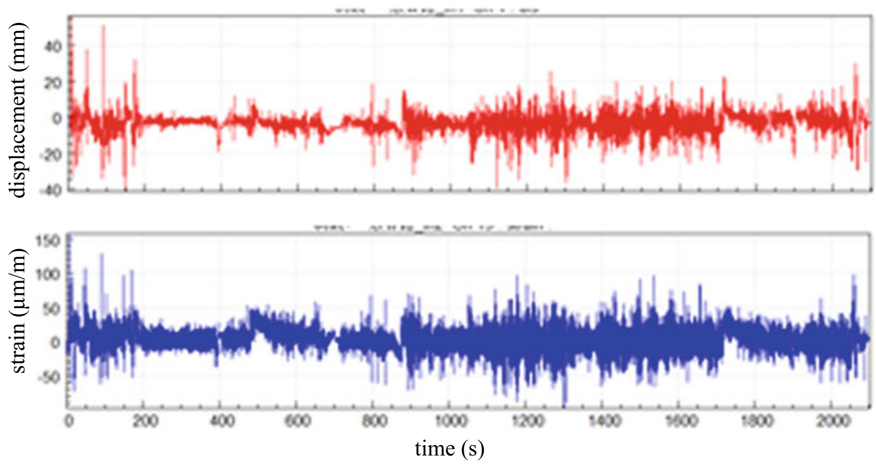


Fig. 9 Displacement and strain test data before improvement

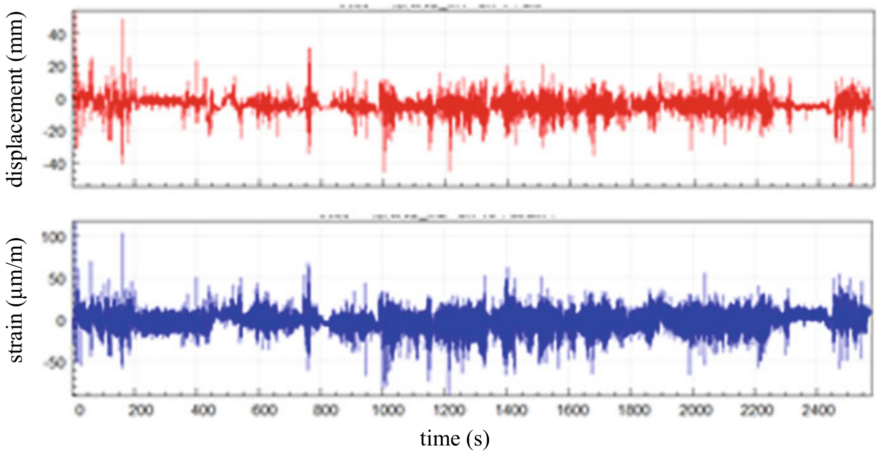


Fig. 10 Displacement and strain test data after improvement

range of the shock absorber given by the manufacturer is 425–705 mm), and the shock absorber works normally, The positive and negative changes of the strain value of the piston rod before and after improvement are consistent with the continuous stretching and contraction state of the shock absorber in the actual work.

3.3 Load Spectrum of Frame Fatigue Simulation Analysis

The load spectrum of frame fatigue simulation analysis is the force test data of the piston rod of the shock absorber. In order to obtain the force data of the piston rod of the shock absorber, it is necessary to calibrate the piston rod to determine the linear relationship between force and strain.

Figure 11 shows the bench test calibration diagram of the piston rod of the shock absorber. The shock absorber is fixed on the actuator and stretched to the limit state. The strain gauge is pasted on the piston rod of the shock absorber and the detection system is set up. When the actuator applies 2, 4, 6, 8 and 10 kN forces successively, four strain values of the piston rod are detected, which are 3.914×10^{-5}, 7.527×10^{-5}, 1.004×10^{-4}, and 1.334×10^{-4}. The force and strain curve of the piston rod shown in Fig. 12 is obtained by using linear fit. The functional relationship is shown in the following formula:

$$F = 0.606\varepsilon \tag{2}$$

In the formula, F is the force of the piston rod of the shock absorber, kN; ε is the strain of the piston rod of the shock absorber, μm/m.

According to the function relationship of Eq. (2), based on the strain test data of the piston rod before and after improvement in Figs. 9 and 10, the force test data of the piston rod before and after improvement as shown in Figs. 13 and 14 can be obtained. It can be seen from Figs. 13 and 14 that the force of the piston rod of the shock absorber changes with time, and most of them fluctuate between −4 and 4 kN.

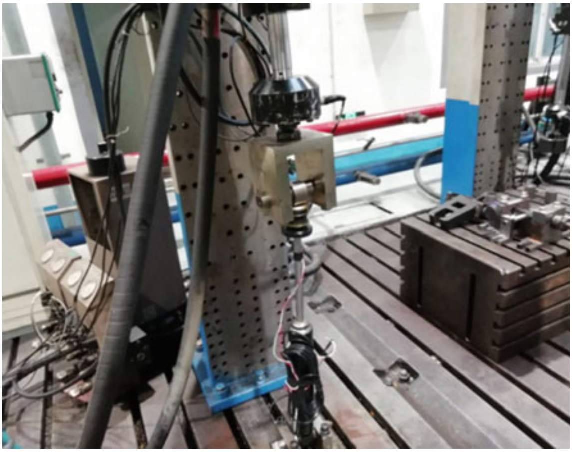


Fig. 11 Calibration diagram of piston rod of shock absorber

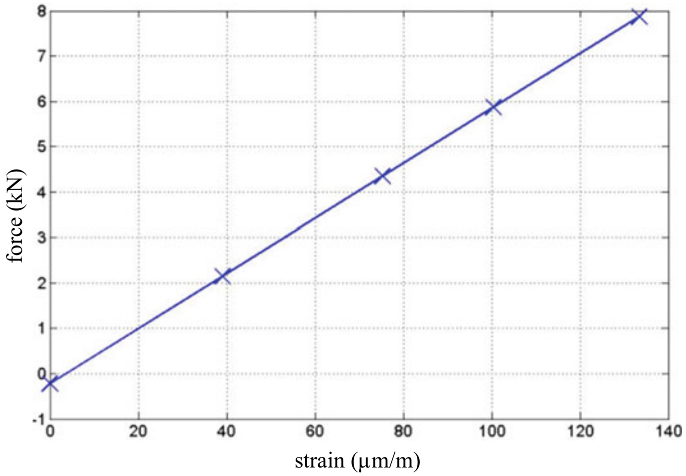


Fig. 12 Force and strain curve of piston rod

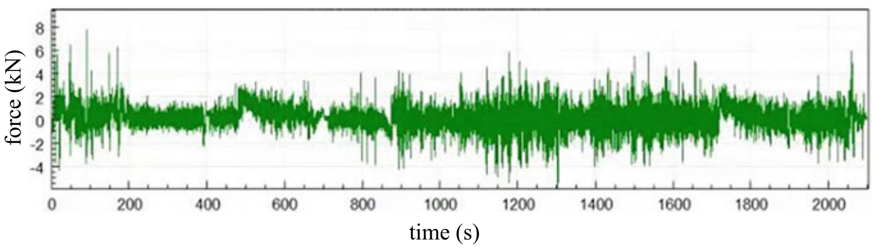


Fig. 13 Force test data of piston rod before improvement

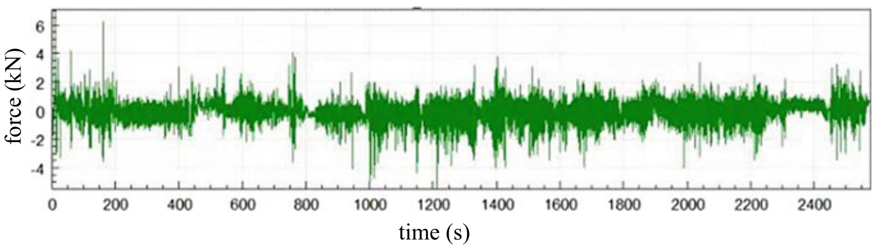


Fig. 14 Force test data of piston rod after improvement

4 Fatigue Life Analysis of FEMFAT

FEMFAT (finite element method and fatigue) is a set of fatigue analysis software which can load static and dynamic loads based on the results of finite element analysis.

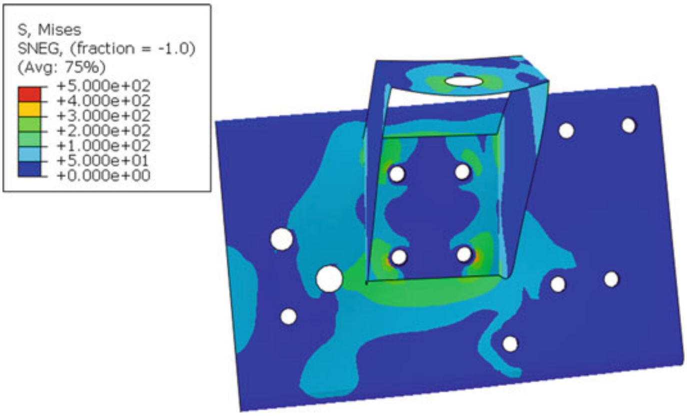


Fig. 15 Stress distribution nephogram of analysis results before improvement

When using the fatigue analysis software FEMFAT, it is necessary to accept the stress and displacement results of the finite element static analysis, set up the specific material information and load characteristics, and then analyze and calculate the life, safety factor or component damage [7, 8].

4.1 Static Analysis of HyperMesh

In order to save computing resources, this paper takes part of the frame model as the research object, uses ProE software to draw the frame longitudinal beam, L-type plate and shock absorber bracket, and imports the assembled frame model before and after improvement into HyperMesh for pretreatment. The shell element is used to simulate the parts of the frame model, and the rigid unit is used to simulate the bolt connection. In this paper, the finite element model of the frame before and after improvement is completed by setting the boundary conditions and applying the unit load excitation (taking 1 kN as an example). The finite element model of the frame is imported into ABAQUS post-processing software for calculation, and the result file of stress distribution is obtained. The stress distribution nephogram before and after improvement is shown in Figs. 15 and 16 respectively.

4.2 Fatigue Characteristic Parameters of Materials

The fatigue characteristic parameters of the frame material have a decisive influence on the fatigue life of the frame. In this paper, the material of all parts of the frame model is A610L steel, the elastic modulus is 210,000 MPa, the Poisson's ratio is 0.3,

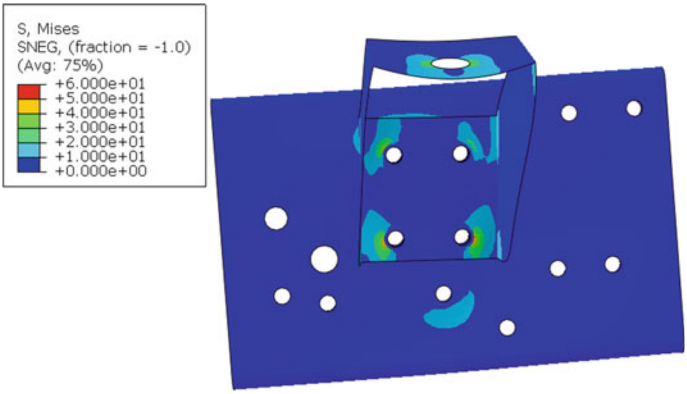


Fig. 16 Stress distribution nephogram of analysis results after improvement

the elongation is 8%, and the yield strength is 500 MPa. When the stress value is lower than 80% of the material yield limit, the S–N curve is used for the whole life analysis; when the stress value exceeds 80% of the material yield limit, the local stress–strain life analysis is performed by using the ε–N curve. According to the results of the peak stress of the frame longitudinal beams before and after improvement in Table 2, the maximum stress of the frame is 263 MPa, which is lower than 80% of the material yield limit. Therefore, the whole life analysis of the frame model is carried out according to the fatigue theory S–N curve [9].

The finite element models of HyperMesh static analysis before and after improvement are imported into the ChannelMAX module of FEMFAT. The S–N curve and fatigue limit diagram for calculation are obtained by inputting material parameters and modifying material properties by using the special material empirical synthesis technology of FEMFAT software, as shown in Fig. 17.

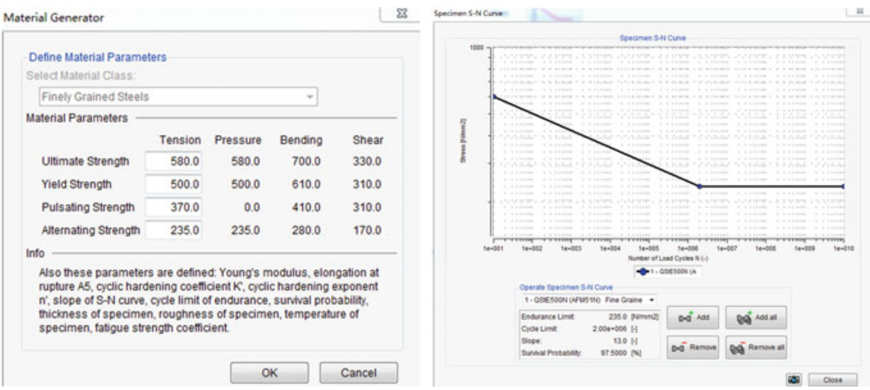


Fig. 17 Definition of material fatigue characteristic parameters

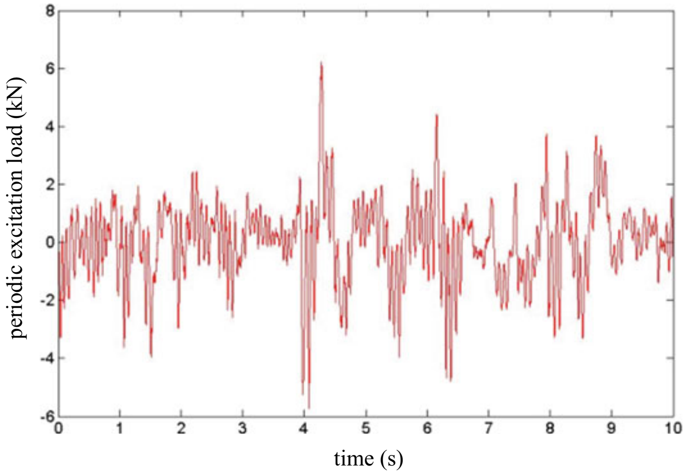


Fig. 18 Time series load excitation spectrum

4.3 Time Series Load Excitation Spectrum

Based on the force test data of the piston rod of the shock absorber before and after improvement as shown in Figs. 13 and 14, the load excitation spectrum of frame fatigue simulation analysis is obtained by a periodic time series of 10 s, as shown in Fig. 18. After the definition of material fatigue characteristic parameters is completed, entering the channel definition interface of ChannelMAX Module shown in Fig. 19, linking the stress distribution result file of Figs. 15 or 16 and the time series load excitation spectrum file of Fig. 18 to the corresponding channels, and setting the output path and file, then fatigue analysis can be carried out.

4.4 Fatigue Life Analysis of Frame

The fatigue life nephogram of the frame before and after improvement is shown in Figs. 20 and 21 respectively. The red area is the part with serious damage. Before improvement, the serious damage area occurs near the lower row connecting hole of the frame longitudinal beam and the shock absorber bracket. The minimum life (average value) is 4.5×10^5. According to the load spectrum cycle of 10 s, the minimum fatigue life time can be calculated as 1250 h, and the corresponding driving mileage is 72,500 km The size and location of the minimum value are consistent with the actual situation.

The fatigue life of the frame longitudinal beam with large damage before and after improvement is shown in Table 3. From Table 3, the minimum life of crack position is increased from 4.516×10^5 to 3.882×10^{14} times, and the minimum fatigue life

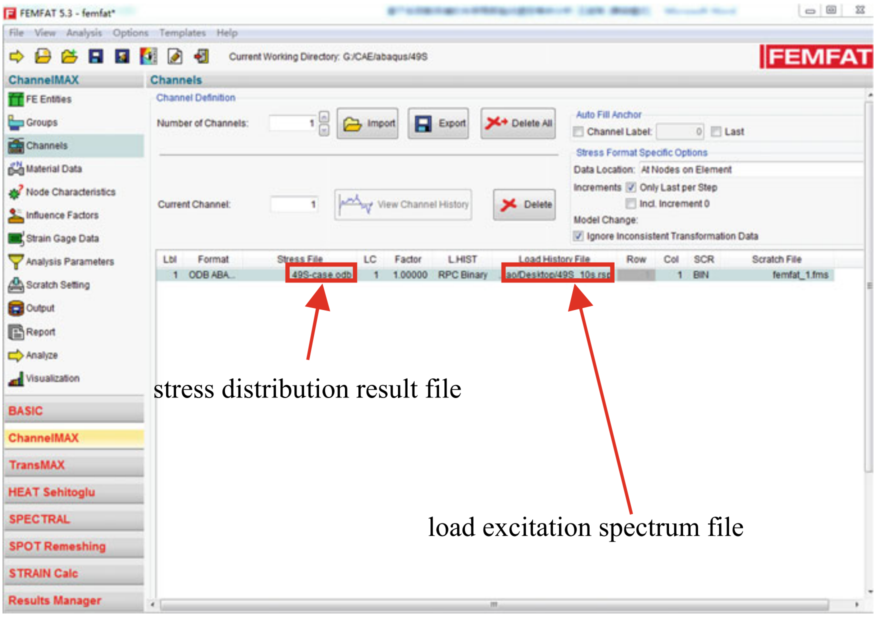


Fig. 19 Channel definition interface of ChannelMAX module

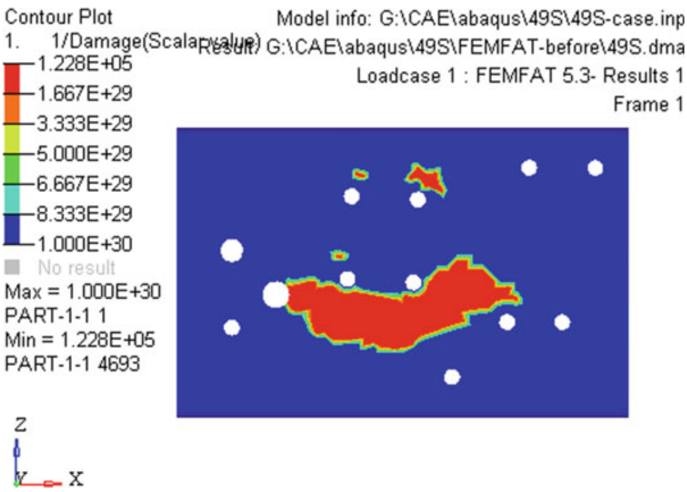


Fig. 20 Fatigue life nephogram of frame before improvement

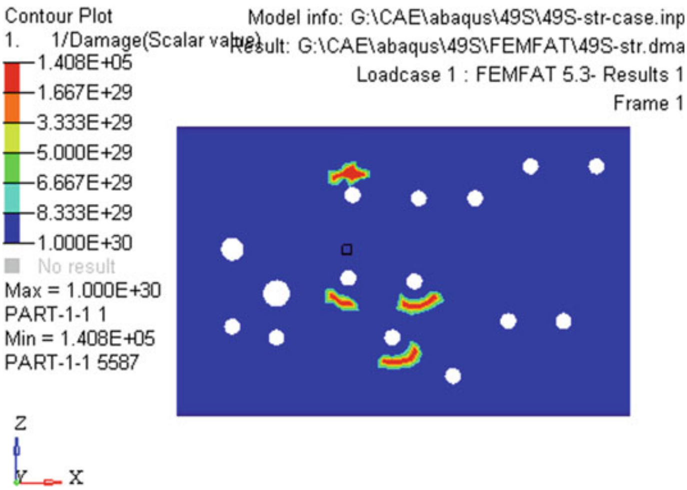


Fig. 21 Fatigue life nephogram of frame after improvement

Table 3 Fatigue life of frame longitudinal beam with large damage

Node number	Life before improvement/times	Life after improvement/times
4404 (lower left)	4.516×10^5	3.882×10^{14}
4641 (lower right)	4.867×10^5	5.489×10^{12}
4883 (upper left)	8.34×10^{11}	8.499×10^{12}
5098 (upper right)	2.507×10^{11}	9.999×10^{20}

is increased by 8.596×10^8 times. Moreover, the fatigue life of dangerous points after improvement is mostly in the order of 10^{12}, and the corresponding fatigue life time is 3.3×10^9 h. The frame after improvement does not crack after 800,000 km of actual road conditions, which further verifies the correctness of the fatigue life analysis method and provides reference for the fatigue life prediction and structural improvement of the frame.

5 Conclusions

(1) In order to solve the quality problem of transverse crack in the longitudinal beam of frame, the improvement measures are put forward, and the load spectrum test process of frame and shock absorber is introduced.

(2) Through the analysis of the stress peak value of the frame longitudinal beam before and after improvement, the results show that the stress peak value of the frame longitudinal beam after improvement is significantly reduced compared

with that before improvement, and the peak stress value of the frame longitudinal beam before and after improvement is not more than the material yield strength, and the static strength of the frame longitudinal beam is safe and reliable.

(3) Through the analysis of the displacement test data of the shock absorber before and after improvement, the working state of the shock absorber is judged to be normal. Based on the strain test data of the piston rod of the shock absorber before and after improvement, the force calibration test of of the piston rod of the shock absorber is completed, and the load spectrum of the frame fatigue simulation analysis is obtained.

(4) According to the S–N curve of fatigue theory, the whole life analysis was carried out by using FEMFAT software. The results show that the damage location of the frame is consistent with the actual crack location, and the fatigue life of the frame after improvement is significantly improved. The frame after improvement does not crack after 800,000 km of actual road conditions, which meets the user's requirements. It proves the correctness of the fatigue life analysis method and provides reference for the fatigue life prediction and structural improvement of the frame.

References

1. Yang Q, Gu Z, Mi C, Tao J, Liang X, Peng G (2012) An analysis on the fatigue life of frame in SF33900 mining dump truck. Automot Eng 34(220) (11):1015–1019
2. Li C, Han Z, Huo J, Song S (2013) Fatigue life analysis of semi-trailer frame based on FEM. J Eng Des 20(05):414–418+426
3. Huang Y, Dong G, Zhong M, Li Z, Wang J (2017) Vehicle fatigue performance design based on dynamic road load spectra measured. Automot Eng 39(280) (11):1281–1285+1293
4. Yao W (2004) Structural fatigue life analysis. National Defense Industry Press, Beijing
5. Gao H (2016) Fatigue analysis and optimization of a heavy truck frame. Beijing University of Technology
6. Li G, Yang Z, Shen C, Jia J, Wang L (2018) Study on fatigue of lock bracket on measured load spectrum. In: Proceedings of 2018 annual meeting of Chinese society of automotive engineers. China Society of Automotive Engineers, p 4
7. Sun Y, Zeng F (2016) Study on simulation of commercial vehicle frame fatigue life. J Chongqing Univ Technol (Nat Sci) 30(02):29–36
8. Zhang W (2016) Simulation and research on fatigue durability of a heavy truck rearview mirror bracket based on FEMFAT. In: Proceedings of the 12th China CAE engineering analysis technology annual meeting. China Mechanical Industry Automation Branch of Mechanical Engineering Society, Industry University Research Working Committee of China Mechanical Society, High Performance Computing Professional Committee of Chinese Computer Society, Shanxi National Defense Science and Technology Industry Informatization Association. Industry University Research Working Committee of China Mechanical Society, pp 83–85
9. Lotsberg I, Wastberg S, Ulle H (2010) Fatigue testing and S-N data for fatigue analysis of piles. J Offshore Mech Arctic Eng 132:1–7