Catching Structural Fatigue of **Concrete Mixer Truck at the Design Stage** with Modal Synthesis

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SANY concrete mixer trucks carry heavy loads with complex operating conditions, and as such new models are usually subjected to rigorous road tests with a specified mileage for at least two months before mass production. The intensified test field includes twisted road, a fish scale pit road and washboard road. When subjected to such demanding proving grounds, the vehicles would suffer significant damage to the frame structure that typically occurred under fatigue-torsion conditions.

To reduce the time it took to test vehicles and find the design flaws earlier in the test process, it was necessary to conduct the fatigue simulation analysis of certain structural parts on the mixer truck. In this project, we used MSC software tools to build a multibody dynamics model for the four-axis mixer truck so we could perform the virtual proving ground analysis. We also implemented physical test validation of the stresses and vibrations to further calculate the fatigue results, to provide an early warning of any under-designed components.

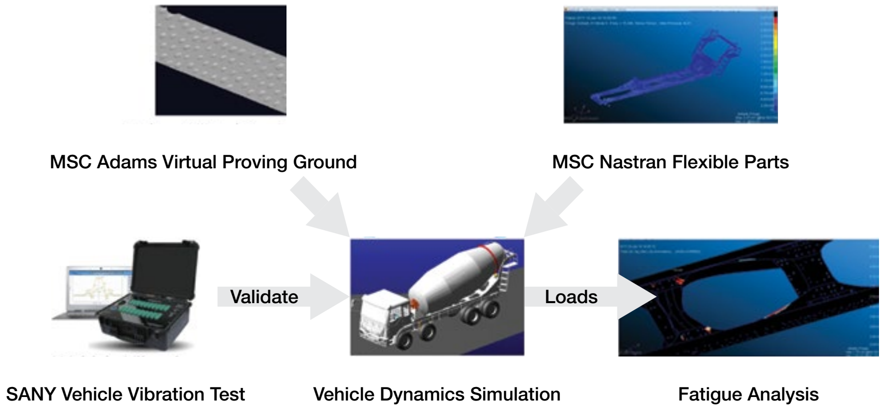

Figure 2

Figure 1: **Physical road testing for the mixer truck**

Full Vehicle Multibody Dynamics Modelling

Structural Components Modal Stress Recovery Theory

The large structural parts of the mixer truck include the main frame, the sub-frame, the front, the back and the escalator. If a conventional finite element method is used to simulate the deformation of the structural parts, it drastically increases the degrees of freedom for the model and thus the computational cost. Since the structural response is controlled by the low-order modes, it is not necessary to solve the high-order dynamic equations of the whole structure for a few low-order modes. Therefore, the modal synthesis method is used to simulate the deformation of the structural components, and one of the most representative methods, the Craig-Bampton method, was used.

In this application, MSC Nastran is used to analyse the free modes of the main frame, sub-frame, front, back and escalator to generate an MNF file. This is imported into the MSC Adams multibody dynamics software to create a flexible frame, as shown in Figure 3.

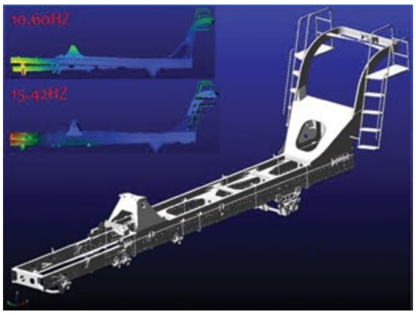

Figure 3: **Flexible truck frame model**

Full Vehicle Modelling

MSC Adams dynamic simulation analysis software was used to build the entire vehicle model. Adams is the most widely used mechanical system dynamics simulation tool, with applications across industries like automotive, aerospace, aerospace, railway, medical and machinery. Adams enables engineers to more effectively evaluate various system dynamic characteristics, improve product performance and reduce expensive and time-consuming physical testing.

Adams provides a dynamic model library for buses and trucks. The truck model library has a sophisticated three-bridge template. This article describes how SANY built a complete vehicle dynamics model for the concrete mixer step by step by starting from this template.

1. **Input the parameters:** This included the vehicle parameters, steering system, front suspension, front leaf spring, rear leaf spring, frame, cab, mixing drum, powertrain and tyre parameters. In general, we extracted the hard points, component mass inertia, bushing characteristics and other parameters, etc.
2. **Built a frame model for the mixer truck:** We created a four-bridge mixer frame model based on the three-bridge template that included the addition of the second bridge and the mixer drum subsystem.
3. **Subsystem modelling:** We modified the existing template subsystem based on input parameters, established a mixer truck steering system, front suspension system, rear suspension system, frame, cab, powertrain system, braking system and tyre system; new front leaf spring system, rear leaf spring model and mixing drum system.
4. **Full vehicle modelling:** Finally, we replaced the subsystems in the previous mixer truck model to generate the full vehicle model, as shown in Figure 4.

Figure 4: **Rigid-flexible coupled full vehicle model**

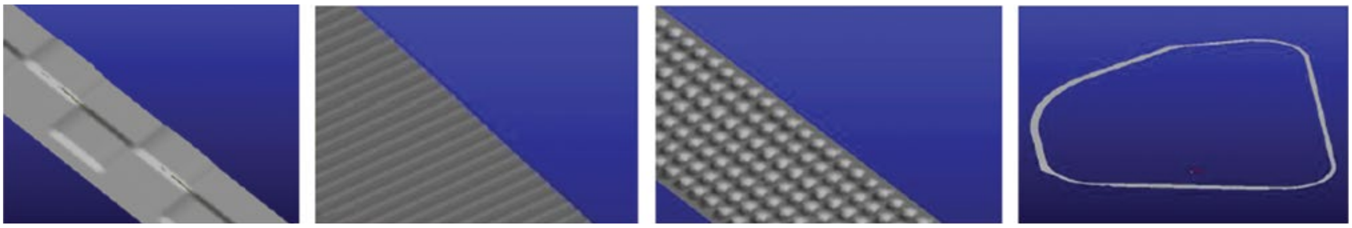

Figure 5: **MSC Adams Virtual Proving Ground**

Virtual Proving Ground Modelling

We used the Adams 3D shell road model to establish three special types of virtual roads and the full-circle proving ground. These special virtual roads were used to verify the dynamic model and to create the virtual proving ground that is used to extract the loads exerted by the roads (Figure 5).

Multibody Dynamics Analysis

Model Tuning

There are 3 pairs of leaf springs in the four-bridge mixer truck. Each piece is modelled by discrete beam elements. The degrees are nearly 800 degrees of freedom for the rigid-flexible coupled full vehicle model. With such a complicated model, the model tuning needs to be completed on both the suspension level, and the full vehicle level.

Virtual Pavement Simulation Analysis

The most important task of full vehicle tuning is to perform sensitivity analysis. We performed the sensitivity study based on the key parameters that have an impact on the stress results. These parameters include the twisted road ramp, tyre pressure, bushing stiffness and so on.

After analysis, the importance for those different parameters are ranked as follows: reducer bushing stiffness > eccentricity > ramp > tyre pressure. The amplitude increases as the damping ratio decreases.

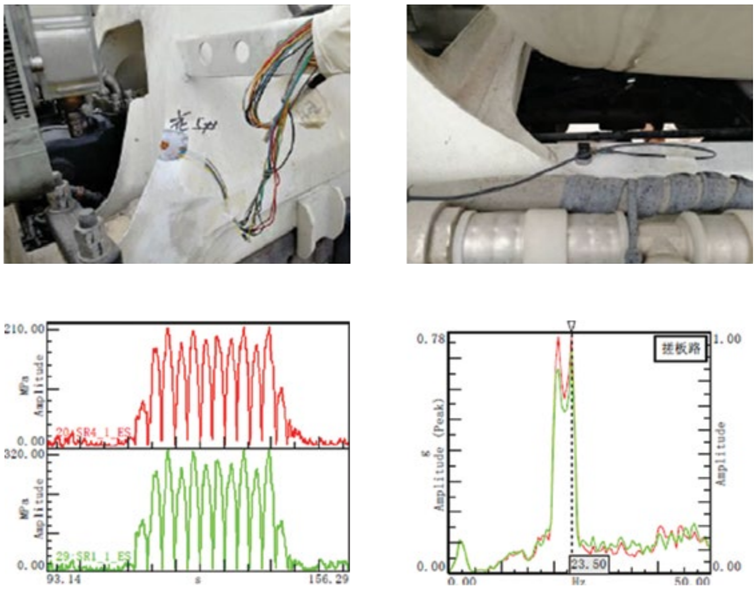

Figure 6: **Stress and Vibration Test Results**

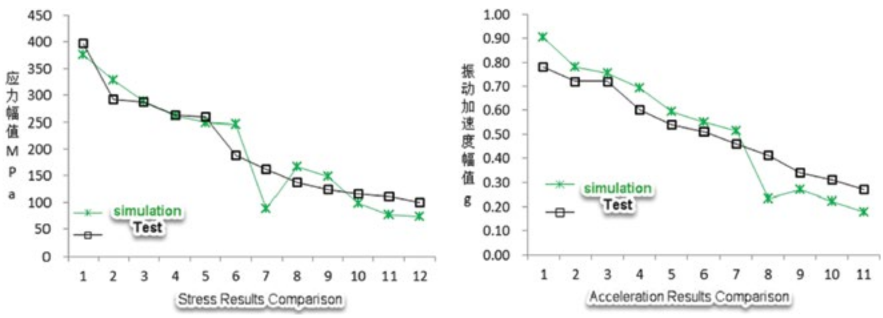

Figure 7: **Correlation between simulation and testing results**

Stress Vibration Experiment Validation

Stress Vibration Experiment

In the testing facility, the vehicle stress and vibration tests were carried out in strict accordance with the test procedures. There were 24 symmetrically-arranged stress monitoring points. Eight of those were dedicated to the principal stress; 16 were related to the Von Misses stress. Overall there are 13 measurement points for vibration, focusing on the accelerations in the vertical direction, as shown in Figure 6.

Simulation-test Correlation

For the twisted road, we correlated the full vehicle simulation results on the stress value. According to the order of importance for various parameters in the sensitivity study, we incorporated the tyre stiffness, vehicle drift & pull and ramp slope parameters with the precise tyre pressures, and we focused on tuning the bushing stiffness. Adams's modal stress recovery feature was used to compare the simulated stress results with testing results. We also compared the results on vertical acceleration between the simulation and testing (Figure 7).

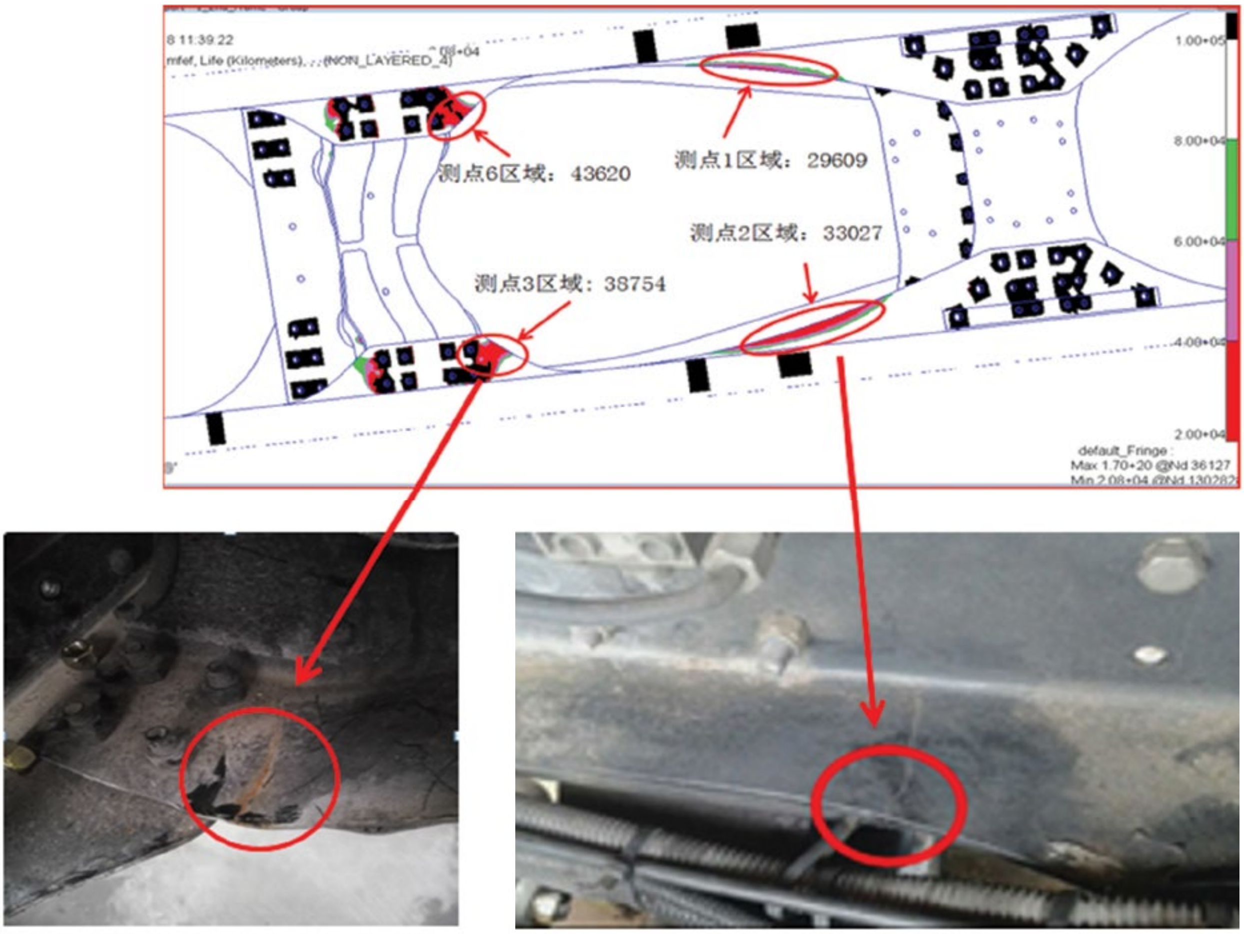

Figure 8: **Fatigue simulation results correlate well with physical test results**

The values of the first five maximum stress points were all greater than 200 MPa, and the maximum error of simulation and test amplitude was 13%. The average stress value was greater than 100 MPa, with an 83% correlation level with the test results. The acceleration results also correlated well between simulation and testing, and the trend simulation error is only 9%.

Fatigue Simulation Analysis

Virtual Proving Ground Simulation Analysis

Adams has a code-driven function that specifies the steering, throttle, brake, gear and clutch signals with pre-programmed events. The test bench controls the vehicle to drive around the virtual proving ground through a pre-built program. Subsequently, the Adams Durability module can directly output load files to the MSC Fatigue tool for fatigue calculation.

Fatigue Calculation Results

The MSC Fatigue calculation has three prerequisites: a finite element model, Adams loads and material information. The finite element model is provided by the BDF file from MSC Nastran. The road loads calculated by Adams are included in a DAC file. The material information includes the main sub-frame SN curve and the escalator SN curve. The calculated life cycle of the frame is shown in Figure 8.

Through fatigue calculation, the minimum life cycle of the frame was shown to be 29,609 km, and the minimum life cycle of the sub-frame was 22,010 km, both of which are far greater than the 10,000 km design requirement. Through the intensified physical tests in the real proving ground, we can prove that there hasn't been any fatigue cracking failure that occurred in the frame structures, as the simulation results had predicted.

Conclusion

In this project, the four-bridge mixer truck is taken as the main research object. Based on the modal stress recovery theory, the fatigue life of the frame is calculated using the MSC durability simulation workflow. The simulated stress vibration had an 83% correlation with the physical testing and the simulation and test results have a trend consistency of over 90%. The proving ground durability results also verified the accuracy and effectiveness of the rigid-flexible coupled simulation methodology and the fatigue life calculation. The entire durability workflow can be used to predict the life cycle of newly developed vehicle models, which has drastically reduced overall testing campaign duration, development costs and the need for physical prototyping.

Reference

"The Component Fatigue Analysis of Concrete Mixer Truck Based on Virtual Road", Xia Xuewen, Wang Chengkai, Lei Xinjun, © Automobile Applied Technology. Article ID: 1671-7988(2018)23-216-04