Experiment and simulation research of forklift roof guard dynamic load test based on LS-DYNA

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Abstract. In order to solve the problems that the driver is threatened by accidental falling objects during forklift operation, according to the requirements of international standard ISO 6055:2004 for dynamic load test of forklift roof guard, the explicit dynamic calculation model of dynamic load simulation test was established based on LS-DYNA, and the dynamic load test was carried out at the same time. The maximum permanent deformation of roof guard is 13.5mm and 11.8mm, respectively, in the simulation and test results of dynamic load. The simulation analysis and test results show that this forklift roof guard has good deformation resistance and safety performance. And the data consistency is good, both of which meet the requirements of test standards. The results provide more design schemes and references for the structure of forklift roof guard.

1. Introduction
In the process of transportation and stacking of forklift truck, falling objects will pose a major safety hazard to the driver. The main function of the roof guard is to prevent the possible damage caused by falling objects to drivers. Therefore, the safety design of forklift roof guard frame is particularly important[1-3]. The international standard ISO 6055:2004 “Industrial trucks-overhead guards—specification and testing” specifies the technical requirements and test methods for the safety performance test of forklift roof guards[4]. Among them, the dynamic loading test is to measure the ability of the roof guard above the driver to resist permanent deformation. However, the dynamic loading test is a kind of destructive test, and the repetitive tests are time-consuming and difficult to operate, with high cost. Therefore, the safety performance of forklift roof guard was studied by simulation analysis. Scholars at home and abroad have done a lot of research on the roof guard[5-8]. Aiming at a new type of forklift roof guard designed in this paper, the safety performance test is carried out in accordance with international standards. The explicit dynamic calculation model of dynamic loading test simulation is established based on LS-DYNA. The finite element simulation and real test are done for the dynamic loading test of the roof guard. The research results provide more research ideas for the structural design of the forklift roof guard.

2. Test requirements and evaluation methods
2.1. Test requirements
According to the international standard ISO 6055:2004 for the safety performance of forklift roof guard, the falling object should have a square impact surface with a side length of 300mm and a mass of 45kg in the dynamic loading test. The square impact surface is made of oak or other materials of the
same density, its thickness is not less than 50mm, and the edges and corners should have rounded corners of \(10_6\) mm.

The falling object shall fall freely for 10 times from a height of 1.5m above the top of the roof guard. The center of the falling object shall be directly above the driver’s position for the first time, and nine other placements should be along the center of the falling object average distribution in clockwise 600mm diameter circle. The midpoint of the circle is above the driver’s seat above the point or the driver standing position. The first point of the nine falling points is in front of the roof guard, as shown in Figure 1.

![Figure 1. Dynamic test method of roof guard.](image)

2.2. **Evaluation methods**

After the dynamic load test of the roof guard, if there are no cracks or separation of the components of the roof guard and its accessories, or the permanent deformation in the vertical direction does not exceed 20mm, it shall be deemed as qualified. The measurement shall be carried out in a circle with the diameter of 600mm under the roof guard centered on the vertical line of the driver’s seat.

3. **Dynamic load simulation of roof guard**

3.1. **Finite element model**

The structure size of the roof guard designed in this paper is 1500mm×825mm×150mm, which is mainly composed of round tubes and strengthened rib plates. The section size of each tube is 45mm in diameter and 4mm in thickness. The width of strengthened rib plate is 45mm and the thickness is 6mm. Q345d was selected as the material, and spray painting was carried out after welding. The finite element model used in this paper is composed of falling object and roof guard. Based on LS-DYNA, it was established of the dynamic calculation mode on the roof guard. The three-dimensional solid model of dynamic load is meshed by ANSYS pre-processing. The falling object is divided into hexahedral mesh with the mesh size of 2mm. Tetrahedral mesh is adopted for the whole roof guard and the mesh size is 1mm, as shown in Figure 2.
Considering the influence of friction, the static and dynamic friction coefficients between the falling object and the roof guard are 0.53 and 0.37 respectively[9]. In order to prevent the hourglass problem from invalidating the calculation results, this paper uses the Flanagan-Belytschko formula based on viscosity to control the hourglass.

### 3.2. Constitutive model

Considering that there is almost no deformation of the falling object, in order to save calculation time, it was regarded as rigid bodies in this study. The plastic deformation is the main energy absorption mode of the roof guard during the falling impact of the test object, and the strain rate effect is relatively obvious. Therefore, the multi-segment linear elastic-plastic model was selected in this study to define the constitutive relation of the roof guard material. The yield stress can be expressed as follows:

\[
\sigma = \left[ 1 + \left( \frac{\dot{\varepsilon}_{\text{eff}}^p}{C} \right)^\frac{1}{p} \right] \left( \sigma_0 + f_p(\varepsilon_{\text{eff}}^p) \right)
\]

Where, \(\dot{\varepsilon}_{\text{eff}}^p\) - effective strain rate, \(C\), \(p\)-strain rate parameter, \(\sigma_0\)-yield stress at constant strain rate, \(f_p(\varepsilon_{\text{eff}}^p)\)-hardening function based on effective plastic strain.

The Q345d material parameters of the roof guard are as follows: density is 7850kg/m\(^3\), elastic modulus is 210GPa, Poisson’s ratio is 0.3, yield strength is 345MPa.

### 3.3. Results and analysis

In order to improve the calculation efficiency, the free-falling process of the object can be ignored. The falling object impacts the roof guard at an initial velocity of 5.42m/s at an altitude of infinite close to zero above the top of the roof guard. Meanwhile, the effect of gravity field should be considered. In this paper, the impact calculation time is 0.5s, and the correctness of the simulation results is reflected by the energy balance curve. Figure 3 shows the variation curve of energy with time during the dynamic loading test of roof guard.

As shown in Figure 3, the trough and the peak appeared on the curves of internal energy and kinetic energy around 70ms, indicating that the falling object has the maximum contact with the roof guard at this time. Maximum elastic-plastic deformation of the roof guard was produced. The whole falling process mainly occurred within 100ms. The kinetic energy of the falling object was rapidly reduced and converted into the internal energy of the roof guard. The overall trend of energy variation conforms to the conservation of energy, and the ratio of hourglass energy to internal energy is calculated as 2.07%. Therefore, the calculated results are reliable. Without considering the impact
effect[10], the dynamic load simulation of the roof guard was carried out according to the drop point mentioned above for 10 times.

By analysing the results in Figure 4 and Figure 5, it can be concluded that the maximum deformation of the roof guard is 3.38mm during the first impact process, and the main deformation was concentrated near the impact part of the falling object. The strengthened rib plate was twisted. The maximum equivalent stress value is 440.7MPa. The larger stress area was distributed in the welding position between the strengthened rib plate and the frame. The maximum stress value does not exceed the fracture stress of material Q345d, which meets the strength requirements.

4. Dynamic load test of roof guard
The dynamic load test of the roof guard is carried out, as shown in Figure 6. The falling points and measuring points were marked on the roof guard in advance. And ten drop points and ten measuring points were selected as the simulation. After the completion of the dynamic load test, it was observed that there were no cracks and component separation in the roof guard and its accessories, as shown in Figure 7. Since it is easier to measure the undersurface of the strengthened rib plate, it is chosen as the measured position. The maximum deformation is defined as the difference between the distance from the undersurface of the strengthened rib plate to the ground and the original value. Figure 8 shows the maximum deformation of simulation analysis and real test.

It can be concluded from Figure 8 that the deformation of the roof guard is consistent with the trend of the test results. And the deformation of most of the simulated measuring points is greater than the corresponding test results, which is due to the simplification of the model and the impact effect. From
the quantitative point of view, the maximum relative error between the simulation results and the
dynamic load test results is less than 15%. Therefore, the simulation results in this paper have high
reliability.

According to the data in Figure 8, the deformation values of all measuring points are less than
20mm, meeting the requirements of ISO 6055:2004 standard. Therefore, the roof guard has good
safety performance of resisting permanent deformation under dynamic load.

5. Conclusion
In this paper, based on the international standard ISO 6055:2004, the dynamic load simulation analysis
of a forklift roof guard is carried out by using the LS-DYNA software, and the real test is carried out.
The following conclusions are as follows:
1) The simulation of dynamic load test accords with the law of conservation of energy, and the
hourglass energy is less than 5% of the total energy. So, it is considered that the simulation model is
correct in modelling and accurate in calculation.
2) The maximum equivalent stress value caused by dynamic load test is 440.7MPa, which does not
exceed the fracture stress of material Q345d. At the same time, no cracks and component separation
phenomenon were found in the roof protection frame and its accessories during the test. Therefore,
this roof guard meets the strength design requirements.
3) The maximum relative error between the simulation results and the dynamic load test results is
less than 15%. Therefore, the simulation results in this paper have high reliability, and it is confirmed
that the roof guard has good safety performance against the permanent deformation under dynamic load.

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