Certification tests of a protective device such as ROPS to ensure safe usage of tractors

Irina Troyanovskaya[1,2] , and *Anton* Kalugin[1,*]

[1]South Ural State Agrarian University, Applied Mechanics Department, Chelyabinsk, Russia 454080
[2]South Ural State University, Wheeled and Caterpillar Vehicles Department, Chelyabinsk, Russia 454080

Abstract. According to the safety requirements, all protective devices of tractor units are subject to obligatory certification. One of the main means of protecting the operator during overturning is ROPS system. In accordance with GOST (National State Standard), a performance check of ROPS protective structures is carried out on basis of full-scale tests. The purpose of the presented study is to develop the experimental procedure and to obtain the performance check result of ROPS protective device of the tractor unit's cabin using B10 bulldozer manufactured by the Chelyabinsk Tractor Plant as an example. The tests were carried out at the Ural Test Center NATI. For this purpose, a special bedplate was used, allowing to test the protective cabins of tractors with the total mass of up to 110 tons. The hydraulic system of the bedplate allowed to carry out the process of lateral loading of ROPS step by step, where each step corresponded to the 10 mm structure deformation. The applied load and structure deformation were recorded at each step. The energy accumulated by the structure was calculated as the area under the stress-strain curve. The energy U = 40867 J, which was required according to GOST, was accumulated during lateral deformation □ = 270 mm. The force constituted Fy = 243 kN. After removing the lateral load, the structure was subjected to the vertical static and longitudinal loading. During the whole experiment of ROPS protective device, repairs, deformation corrections and adjustments were not allowed. The test results of ROPS structure of B10 bulldozer cabin showed compliance with the GOST safety requirements. During ROPS deformation, penetration of the protective structure elements into the driver's limited zone was not observed.

1 Applicability

With transition of Russia to a market economy, most of the current standards that determine the requirements for reliability, productivity and efficiency of tractor units were revoked [1]. In accordance with the Federal Law "On Technical Regulation" [2] only safety standards remained obligatory.

After Russia entered the Customs Union with Belarus and Kazakhstan, the technical regulations [3] according to which protective devices of all tractor units were subject to

* Corresponding author: starfruitworks@gmail.com

mandatory certification came into effect. The most important of the protective devices is ROPS (roll over protective structure) for the tractor cabin, designed to reduce the risk of damage to the operator, subject to the use of seat belts [4].

Based on the requirements of GOST, the performance assessment of ROPS protective device should be based on the results of a full-scale experiment [5]. Therefore, the purpose of the study was to test the experimental procedure and compliance with the safety requirements of ROPS protective system of an industrial tractor.

2 Test object and equipment

As a test object the protective device in the form of a two-post ROPS of B10 bulldozer, manufactured by the Chelyabinsk Tractor Plant, was chosen.

The experiment was conducted at the Ural Test Center NATI, which had a special test bedplate, allowing to test protective cabins of tractors with a total mass of up to 110 tons. The bedplate was made in the form of a power frame mounted on a reinforced concrete base (Fig. 1).

Fig. 1. Appearance of the test bedplate.

The test object was mounted inside the bedplate. The loading was carried out by means of a vertical and horizontal hydraulic cylinder. The hydraulic system of the bedplate provided a maximum force of 2200 kN [6].

In the process of testing, constant control of the load and structure deformation was carried out, which made it possible to calculate the energy absorbed during the experiment. The structure deformation was measured directly along the course of the hydraulic cylinder using a measuring linear scale (the scale division was 1 mm, the error was ± 0.5 mm). The load was determined by means of monometers measuring the pressure in both cavities of the hydraulic cylinder (with the error ± 5%).

3 Method of testing

According to GOST, the test object should be mounted on the bedplate so that the rigidity of the structure is equivalent to the rigidity of mounting on the machine frame [5]. Therefore, the protective device was mounted on the steering clutch housing of the bulldozer and fixed in accordance with the real installation on the tractor. Inside the test protective device, a DLV manikin simulating the driver's position was installed.

The lateral load was applied to the top of the main ROPS elements (Fig. 2). The lateral load application speed amounted to 4 mm/s, which allowed the load to be considered static. The protective device was loaded step by step with a scale division of 10 mm deformation.

Fig. 2. Lateral loading of ROPS

The impact of the lateral load continued until the force and energy values reached the levels required by GOST. The minimum values of the lateral force Fy (N) and the required absorbed energy U (J) were determined depending on the mass m (kg) of the tested machine [**Error! The reference source hasn't been found**.]:

$$Fy=70000(m/10000)^{1.2} \quad \text{and} \quad U=13000(m/10000)^{1.25}.$$

ROPS protective device of B10 bulldozer with the mass m = 25000 kg during side overturning of the machine must withstand the force Fy = 210197 N and at the same time absorb energy not less than U = 40867 J.

After removing the lateral load, a static vertical load Fz was applied to the deformable ROPS structure. According to GOST the minimum value of the vertical load is: Fz = 19.6 m = 490250 N.

The load was distributed over the entire width of the upper part of ROPS system using a transition element (LDD) (Fig. 3) and lasted 5 minutes.

Fig. 3. Vertical loading of ROPS

After removing the vertical load, a longitudinal load *Fx* was applied to the top elements of ROPS. The longitudinal load was applied at the back in the place of closest proximity to the driver's position. The load direction was horizontal and parallel to the longitudinal axis of the machine (Fig. 4).

Fig. 4. Longitudinal loading of ROPS

The loading continued until the force value exceeded the minimum required level according to GOST: $Fx=56000(m/1000)^{1,2}=168157$ N.

During the whole experiment of ROPS protective device, repairs, deformation corrections and adjustments of the structure were not allowed [**Error! The reference source hasn't been found**.] The experiment was constantly under observation to ensure that the structural elements did not get into the operator's zone (DLV).

4 Test results

The lateral force developed by the hydraulic cylinder was calculated as $Fy=\rho_n S_n-\rho_{sh}S_{sh}$, where ρ_n, ρ_{sh} – the values of the pressure in the piston and rod cavity of the power hydraulic cylinder, S_n, S_{sh} – the cross-sectional area of the piston and rod of the power hydraulic cylinder. The pressure check every 10 mm made it possible to build a correlation between the lateral force Fy and deflection of the structure Δ. The character of the curve $Fy(\Delta)$ clearly indicates the presence of plastic deformations in the case of lateral loading. The maximum permissible load is 250 kN. To describe the experimental data with the correlation $Fy(\Delta)$ we will use the following curve

$$Fy=Fy_{max}th(\Delta/b), \quad (1)$$

where $Fy_{max}=250$ kN is the maximum value of the load, $th=(e^{\Delta}-e^{-\Delta})/(e^{\Delta}+e^{-\Delta})$ is the hyperbolic tangent, b is an empirical parameter. The proposed curve has only one empirical parameter and when b=150, it describes the experimental points with a certainty R^2 = 0.9944 (Fig. 5).

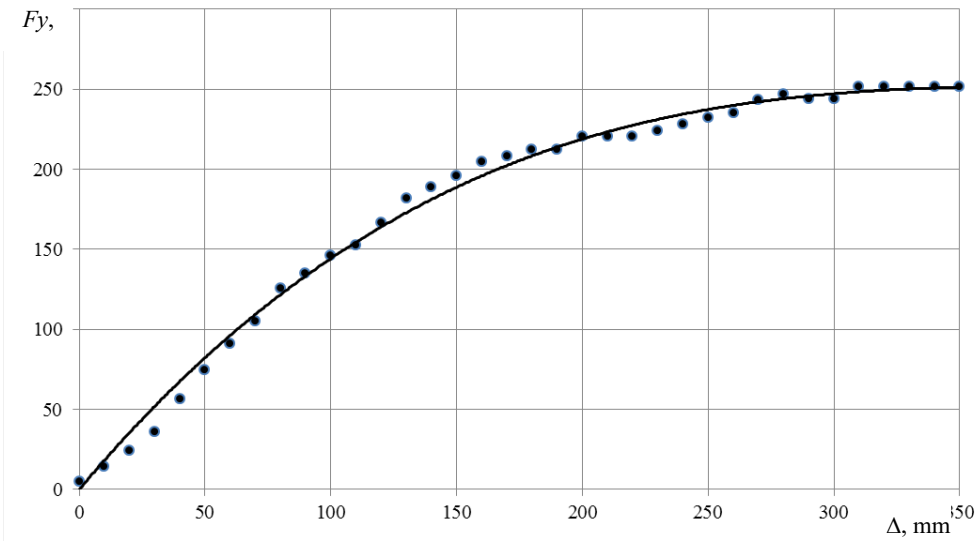

Fig. 5. Correlation between the lateral force Fy and deflection Δ of ROPS structure

The energy absorbed by ROPS system was calculated as the area under the curve $Fy(\Delta)$. The required force $Fy=212,4$ kN in accordance with GOST was achieved by the structure with the deformation of 180 mm. However, the energy accumulated at that particular time reached U=22166 J, instead of the required U=40867 kJ.

The required energy (U=42374 J) was accumulated with lateral deformation Δ=270 mm, and the force constituted Fy=243 kN.

The achieved values of forces and energy without penetration of the ROPS structure elements into the DLV zone during the tests of B10 bulldozer protective cabin are given in the table.

Table 1. Required and reached values of forces and energy of ROPS protective structure of B10 bulldozer.

Parameter	GOST requirement	Test value
Lateral force *Fy* (N)	210197	243157
Energy absorbed by structure with lateral load *U* (J)	40867	42374
Vertical force *Fz* (N)	490250	519900
Longitudinal force *Fx* (N)	168157	17380

5 Conclusion

During testing of ROPS protective device of B10 tractor unit's cabin, the required by GOST force and energy parameters were achieved. The ROPS system withstood all kinds of loading (lateral, vertical and longitudinal). The plastic deformations obtained by the structure did not violate the DLV zone. As a result, a conclusion was made about the compliance of ROPS structure with the requirements of GOST on the B10 bulldozer safety when overturned. According to the results of lateral loading of ROPS protective structure, the maximum mass of the tractor unit cannot be more than 250 tons.

References

1. Khvoin D.A. Efficiency increase of protective devices of forest machines' cabins: dissertation of the candidate of technical sciences. Petrozavodsk, 2011. 125 p.
2. Federal Law No. 184-FZ of December 27, 2002 (as amended on July 29, 2017) "On Technical Regulation", Rossiyskaya Gazeta, December 31, 2002. No. 245.
3. TP TC 010/2011. On safety of machinery and equipment. Technical regulations of the Customs Union. 2011. 66 P.
4. GOST 12.2.019-2005 Occupational safety standards system. Tractors and agricultural machinery. General safety requirements. M.: Standartinform. 2005. 28 p.
5. GOST R ISO 3471-2009. Earth-moving machines. Safety devices for overturning. Technical requirements and laboratory tests. M.: Standartinform. 2009. 30 p.
6. Shatalinskaya E.A. and others. Test bedplate for industrial tractors' protective devices. Tractors and agricultural machinery. 1989. No. 11. P. 23-24.
7. Zuzov V.N., Markin I.V. Evaluation of passive safety of tractor cabins at the design stage. Tractors and agricultural machinery. 2001. No. 4. P. 26-27.