Non-Linear Implicit Analysis of Roll over Protective Structure
OSHA STANDARD (PART 1928.52)

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Abbreviations: ROPS – Roll over protective structure, OSHA – Occupational Safety and Health Standards for Agriculture. L-D curve – Load v/s Deflection curve, SRP – Seat Reference Point, FER - Factor of energy ratio.

Keywords: OSHA standard (Part 1928.52), Non-Linear Implicit Analysis, ROPS, Tractor Safety.

Abstract

The aim was to setup and implement a safety device i.e. Roll over Protective Structure. (ROPS) as per the US Homologation i.e. OSHA standards for OCCUPATIONAL SAFETY AND HEALTH STANDARDS FOR AGRICULTURE (Part 1928.52). Roll over protective structure with a front mounted Foldable ARC type ROPS, intended to absorb energy during the rolling over of the tractor and preventing the invasion of the driver space. This gives rise to do more effective use of material and geometry parts which can reduce the overall weight with enhanced utility.

This paper gives a brief idea about how Non-Linear Implicit (Geometry and Material) technique and Radioss, Hypermesh & Hypergraph are used to achieve and estimate all parameter as per standard. Material non-linearity included to capture the plastic behavior of the parts, Internal energy v/s Time curves plotted for ROPS to check required energy absorbed and area under the load v/s Deflection curves calculated to estimate the strain energy absorbed for longitudinal and lateral loading conditions. Deformed structure is checked for any intrusion with the zone of clearance as per standard.

Introduction

Rollover Protective Structure (ROPS), is a cab or frame that provides a safe environment for the tractor operator in the event of a rollover. A machine with structural members having its primary purpose to protect the operator with marginal protection in the operation of a machine turnover (rollover).

Causes of Rollover:

- Overturning on slopes
- Maneuvering at speeds
- Poor ground conditions
- Working on gradients

ROPS are available, affordable and able to save lives!

The ROPS must meet standards, such as those set forth by the American Society of Agricultural Engineers, which certify they provide adequate protection in a tractor upset.

The purpose is to establish the test and performance requirements for a protective frame designed for wheel-type agricultural tractors to minimize the frequency and severity of operator injury resulting from accidental upsets. General requirements for the protection of operators are specified in 29 CFR 1928.52.
This paper is about the virtual simulation of two poster front mounted foldable arc type ROPS as per OSHA 29CFR 1928.52.

**Testing Requirement:**

All protective frames for wheel-type agricultural tractors shall be of a model that has been tested as follows:

- **Laboratory test:** A laboratory energy-absorption test, either static or dynamic, under repeatable and controlled loading, to permit analysis of the protective frame for compliance with the performance requirements of this standard.
- **Field-upset test:** A field-upset test under controlled conditions, both to the side and rear, to verify the effectiveness of the protective system under actual dynamic conditions. Such testing may be omitted when:
  - The analysis of the protective-frame static-energy absorption test results indicates that both $\text{FER}_s$ and $\text{FER}_r$ (of this section) exceed 1.15;

As per the standard OSHA 29 CFR 1928.52, Rear and side loading need to perform. The test is as described and performed as mentioned. Herein, Laboratory Test is taken care of i.e. Static Test Procedure and trying to correlate with physical testing in future.

The following definitions shall apply:

$W =$ Tractor weight (see 29 CFR 1928.51(a)) in lb (W’ in kg);

$E_s =$ Energy input to be absorbed during side loading in ft-lb ($E_s'$ in J [joules]);

$E_s = 723 + 0.4 W$ ($E_s' = 100 + 0.12 \ W'$);

$E_r =$ Energy input to be absorbed during rear loading in ft-lb ($E_r'$ in J);

$E_r = 0.47 W$ ($E_r' = 0.14 \ W'$);

$L =$ Static load, lbf [pounds force], (N) [Newton];

$D =$ Deflection under L, in. (mm);

$L-D =$ Static load-deflection diagram;

$L_{\text{max}} =$ Maximum observed static load;

Load Limit = Point on a continuous L-D curve where the observed static load is 0.8 $L_{\text{max}}$ on the down slope of the curve;

$E_u =$ Strain energy absorbed by the frame in ft-lb (J); area under the L-D curve;

$\text{FER} =$ Factor of energy ratio;

$\text{FER}_s = \frac{E_u}{E_s'}$;

$\text{FER}_r = \frac{E_u}{E_r'}$;
The test shall be stopped when:

1. The strain energy absorbed by the frame is equal to or greater than the required input energy $E_{is}$; or
2. Deflection of the frame exceeds the allowable deflection; or
3. Frame load limit occurs before the allowable deflection is reached.

Finite Element Analysis has been carried out to simulate the static testing condition and requirement. As per the above formulae’s and equations, the required energy for both the load cases i.e. Rear and Side Tests are as follows in Table 1:

<table>
<thead>
<tr>
<th></th>
<th>Side Loading</th>
<th>$E'_{is} = 723 + 0.4 \text{ W}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Energy Required (J)</td>
<td>2135.23</td>
</tr>
<tr>
<td>2</td>
<td>Rear Loading</td>
<td>$E_{ir} = 0.47 \text{ W}$</td>
</tr>
<tr>
<td></td>
<td>Energy Required (J)</td>
<td>1357.09</td>
</tr>
</tbody>
</table>

Table 1: Required Energy Calculation for Side & Rear Loading.

**SRP – Seat Reference Point:**

The seat-reference point ("SRP") is that point where the vertical line that is tangent to the most forward point at the longitudinal seat centerline of the seat back, and the horizontal line that is tangent to the highest point of the seat cushion, intersect in the longitudinal seat section. The seat-reference point shall be determined with the seat unloaded and adjusted to the highest and most rearward position provided for seated operation of the tractor.
FE Modeling:

- ROPS pipe and all supportive plates for ROPS Assy. are modeled using 2-D quad and tria elements.
- Rigid and beam elements are used to represent bolt & pin.
- Total Number of Elements used is 14289 with having 14617 Nodes.

Materials:

- Stress- strain curve is used to simulate the plastic behavior of used material in ROPS.

Rear or Longitudinal Loading:

Rear-load application shall be distributed uniformly on the frame over an area perpendicular to the direction of load application. Size and location of the plate is as per the OSHA guidelines. Enforced displacement is applied at the plate center and mounting holes of ROPS is constrained in all d.o.f. L-D curve is plotted to calculate the stain energy.
Side or Transverse Loading:

Apply the side-load on the same frame, and record L and D simultaneously. Side-load application is also applied as per the given condition and guidelines of OSHA. Enforced displacement is applied at the plate center and mounting holes of ROPS is constrained in all d.o.f.
Results & Discussions

ROPS simulation is carried out in Radioss. The load cases i.e. side and rear load cases were simulated as per OSHA standard guideline.

Fig. 4 is internal energy plot for both side (transverse) and rear (longitudinal). It has been observed that the required energy is observed by the ROPS in both the load cases.
Rear or Longitudinal Loading:

![Diagram showing rear or longitudinal loading with OSHA images for deflection intrusion and FEM deflection plot.](image)

Figure 5: Rear or Longitudinal Deflection plots

**Required**

- \( e = 30 \text{ in.} \) (762 mm) at the longitudinal centerline;
- \( f = \) Not greater than 4 in. (102 mm) to the rear edge of the crossbar, measured forward of the seat-reference point ("SRP");
- \( m = \) Not greater than 12 in. (305 mm), measured from the seat-reference point to the forward edge of the crossbar.

FER > 1.15

**Observed Value**

- \( m = 269.2 \text{ mm} \)
- \( f = \) Not intruded beyond SRP as displacement is 134.75mm
- FER = 1.30
Figure 6: L-D Curve for Rear or Longitudinal Loading

Side or Transverse Loading:

![Diagram showing deflection intrusion and FEM deflection plot](image)

(a) OSHA Images for deflection intrusion  
(b) FEM deflection plot

Figure 7: Side or Transverse Deflection plots

**Required**

\[
d = 2 \text{ in. (51 mm) inside of the frame upright to the vertical centerline of the seat;}
\]
\[
e = 30 \text{ in. (762 mm) at the longitudinal centerline;}
\]
\[
g = 24 \text{ in. (610 mm) minimum;}
\]
\[
\text{FER} > 1.15
\]
Observed Value

\[ d = 147.03 \text{ mm} \]
\[ g = 640 \text{ mm} \]
\[ \text{FER} = 1.54 \]

Benefits Summary

Hyper works help in simulating stringent requirement of OSHA. Inbuilt feature of area calculation for L-D curve in Hypergraph helped in doing iteration fast. Through virtual simulation we were able to freeze design in very less time.

Challenges

Calculating strain energy by using L-D curve.

Future Plans

To establish correlation between test and FEA result. There is always scope of improvement, and Authors are hoping to enhance the process as much as possible to correlate lab testing.

Conclusions

1. The critical components like ROPS for Tractors can be very accurately simulated using Hyper-Works to describe the standard criteria.
2. The Methodology proves effective in predicting maximum allowable ROPS deflections when considering the standard criteria.
3. The results can be correlated with the actual lab testing, thereby reducing cost and time in the development.
4. The accelerated method of computation proved effective thereby arriving at correct design after several iterations but in much reduced time.

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REFERENCES