Redesign of Fall Over Protective Structure (FOPS) for Operator Cabin Roof as Per EU Norms

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Abstract: The safety of the operator during machining operation is ensured by the safe design of the safety frames of the working machine in any of the working condition. When the heavy object such as rocks, heavy concrete blocks, overhead demolitions falls on the roof of the protective structure the working space of the machine operator is evaluated by the ability of FOPS to protect the operator. The cabin must provide a safe work space under various odd working conditions. Hence it is necessary to have a safe cabin for operator as per EU norms.

In case of mining machine safety is required for much high impact energies. This paper represents the method of conducting strength tests for the protecting roof. The strength tests are done using finite element analysis program. During loading and impact testing DLV (Deflection Limiting Volume- protected space between cabin roof and operator head) is considered.

Keywords*: FEA, Protective roof, DLV, safety.*

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1. INTRODUCTION

ISO 3449:2008 defines the reliability test for operator cabin for safety of the operator. It defines two acceptance level for FOPS. Level II acceptance is generally intended for protection from falling trees, rocks, overhead demolition. In this testing dropping mass of 227 kg is dropped from a height of 5.22m on a FOPS structure to produce 11,600J energy. Level II acceptance criteria are meeting by doing FEA analysis. Skill and resources are required by the designer to model the structure computationally. This requirement may be satisfied with a finite element program that features elastic-plastic material behavior and change of geometry after each load increment. The hardest part of designing a frame on heavy working machine is that the stain should not exceed the material’s minimum guaranteed strain. To determine the type of protection required, the risk present on the site must be identified. FOPS roof should have the ability to absorb the kinetic energy of the falling object as the test object is dropped from a sufficient height over the operator roof. After the impact neither the frame nor the object should enter the DLV. The frame must have the ability to absorb the kinetic energy of the falling object. By changing the material of current cabin structure a rigid FOPS can be designed.

2. DESIGN METHODOLOGY

2.1 Material Selection

The ability of the frame to deform is critical. It is also important that the design of the frame allows the deformation to occur as intended.

Materials with low Charpy values and low ductility should be avoided. Materials must have a minimum Charpy V-notch impact strength at -30°C of or not less than:

- 11 J if the specimen is 10 mm x 10 mm
- 9.5 J if the specimen is 10 mm x 7.5 mm
- 7.5 J if the specimen is 10 mm x 5 mm
- 5.5 J if the specimen is 10 mm x 2.5 mm.

The Charpy V-notch strength of high strength materials should be verified.[4]

Grade	Yield strength MPa	Tensile strength MPa	Elongation
SALIMA 410	410 MIN	540-660	20
S420MC	420 MIN	480-620	16-19

Table no 2.1-Material properties

2.2 Theoretical Calculation:

- According to law of conservation of energy, potential energy (PE) gets converted to kinetic energy (KE):

Potential Energy = Kinetic Energy
Mass * acceleration due to gravity (g) * height =
½ * Mass * (velocity)2

$$\text{Velocity} = (2 \cdot g \cdot \text{height})^{0.5} = (2 \cdot 9.807 \cdot 5.218)^{0.5} = 10.1166 \text{ m/s}$$

- Impact force calculation:

If an object of mass m=227kg is dropped from height h=5.22m, then the velocity just before impact is v=10.114939m/s. The kinetic energy just before impact is equal to
K.E.=11612411J.

If the distance travelled after impact is,

ISSN: 2321-8169
4842 - 4844

d=0.1m, then the impact force may be calculated using the work energy principle to be,

Average impact force= F=116124.11N

Average impact force = 116124.11N on top grill of protective structure.
Surface area available by design to restrict above impact force on protective structure is = (approx.) 130 mm^2
Stress = Average impact force/ surface area Stress = 116124.11/125
Calculated stress = 928.9Mpa

Now calculation for maximum deflection after impact on protective structure

Consider protective structure grill are simply supported.
Formula for simply supported beam to calculate deflection under point load is given as:

$$\delta_{max} = \frac{Pl^3}{48EI}$$

$I = BH^3 / 12$
$I = 22X(63)^3 /12$
$I = 458419.5\ mm^4$
$I = 0.000000396000\ mm^4$

δ=1161124.11$(1)^3$/48(200X10^9) (0.0000004584195)
δ = 264.84mm
Total deflection calculated by analytical method is 263.84mm

2.3 Cabin Material:

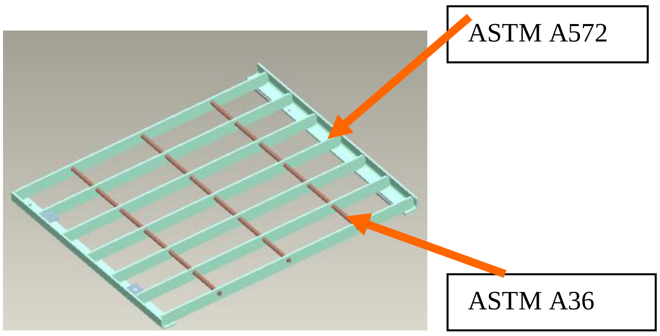

Figure. 2.3.1 Cabin Roof material earlier

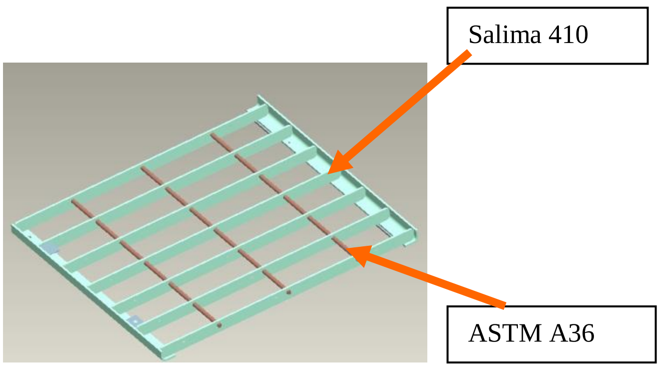

Figure. 2.3.2 Cabin Roof material revised

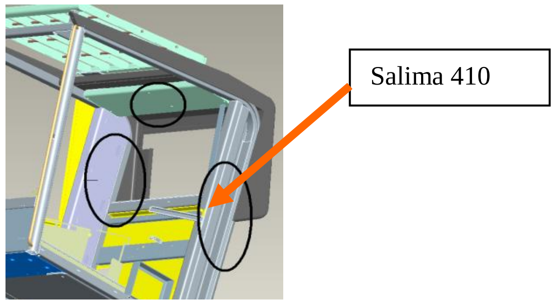

Figure. 2.3.3 Cabin material revised

2.4 FE Analysis of Protective Structure:

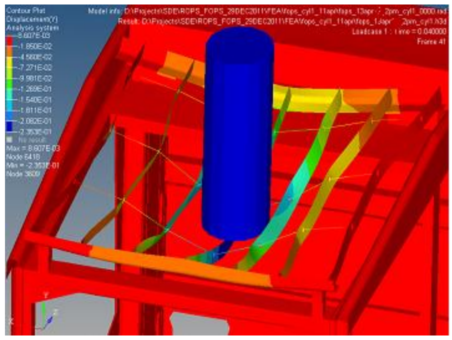

Figure 2.4.1 Displacement in Y-direction: location 1

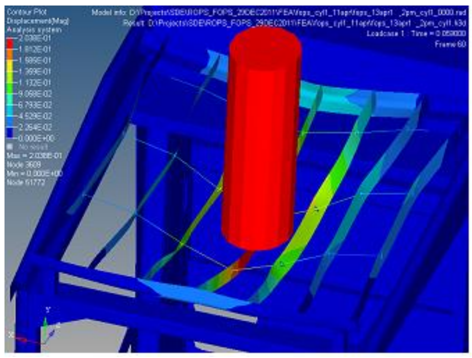

Figure 2.4.2 Displacement in Y-direction: location 2

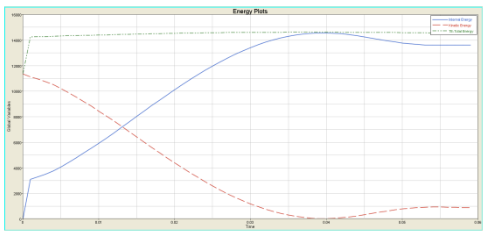

Figure 2.4.3 Dropping location 1 energy plot

Max allowable Vertical deflection
328.68 mm

Result conclusion from displacement FEA analysis:-

Max displacement in Y-direction = 235.3mm at t=0.05 sec

Clearance b/w cabin top and DLV = 93.38mm

3. CONCLUSION:

Sr. No	Theoretical calculation Result	FEA Analysis Result	Experimental Test Result
	Displacement of Test Specimen after impact on Protective Structure In mm	Displacement of Test Specimen after impact on Protective Structure	Displacement of Test Specimen after impact on Protective Structure
1	265mm	235mm	238mm

1. It was observed that after impact loading the displacement values found by experimental method and by FE analysis are less against the required value of 328.68mm. This indicate that the energy of the drop mass was completely absorbed by the operator cabin roof structure
2. As no part of the cabin roof entered the DLV, this indicates that current operator cabin is safe under ISO 3449:2008 FOPS test loading condition.

4. REFERENCES

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