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Design and Analysis of Pulley Block for Recovery of Damaged Tracked Vehicle

Rashmi S[1], Anil Kumar[2], Srinivas Reddy M[3]
[1,3]CMRIT, Kundanahalli, Bangalore, Karnataka, India
[2]R&D, BEML Ltd, New Thippasandra, Bangalore, Karnataka, India

ABSTRACT

The recovery of damaged vehicle in hostile environment may be challenging under various circumstances. For these operations, Recovery vehicle should be integrated with a heavy duty double capstan winch along with a pulley block. Depending upon the recovery capacity, winch pulling force can be amplified by using different pulley block setups. Since Loads on pulley block changing, so its components would experience different magnitudes of loads. In this paper we have discussed the design and analysis of critical components of pulley block which includes pulley, triangular junction block and Jaw Plate. Here, Design of Pulley block carried out from conceptual level. FE results and Theoretical calculation are shown good agreement between them. For FE analysis, Hyper works and NASTRAN used as pre/post processor and solver respectively.

Keywords: Pulley block, Pulley, Triangular Junction Block, FEM, Theoretical Validation

I. INTRODUCTION

In order to recover the bogged down vehicle, recovery vehicle will be integrated with a heavy duty double capstan Winch, which performs the recovery function with estimated direct pull capacity. But when it is struck in mud or in slope, an additional effort is required to pull the tank, in such cases pulley block is used to reduce effort of winching by multiplying pulling forces, which in turn reduce the reaction forces on the recovery vehicle. Hence pulley block plays an important role in the effort reduction and carry maximum load with combination of pulleys i.e. using the two or more pulley combination desired effort can be achieved. It is important to design the pulley block and its arrangement in order to fulfill the requirements.

Main winch can exert maximum direct pull of 30 ton and with the pulley arrangement it should pull the load of 60 ton in 2:1 rope lay configuration and 90 ton in 3:1 rope lay configuration. So it is required to design the pulley block for 2:1 and 3:1 rope lay configuration.

II. METHODS AND MATERIAL

1. Pulley Block

Pulley Block can be experienced varying loads while recovery operations. Hence its component prone to undergo different magnitudes of loads. Pulley block components are characterized as critical based on load taking capacity and given as

1. Pulley
2. Triangular Junction Block
3. Jaw Plates

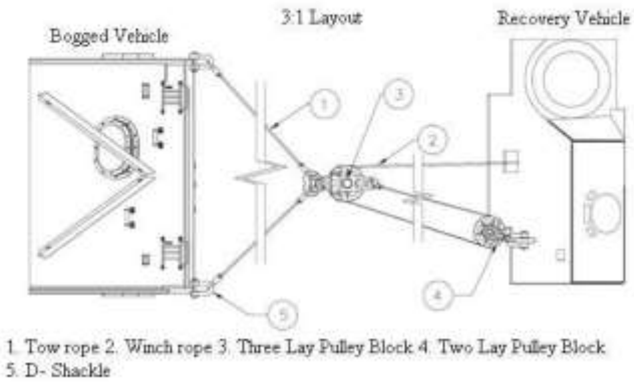


Figure 1a. Pulley block 3:1 Layout configuration

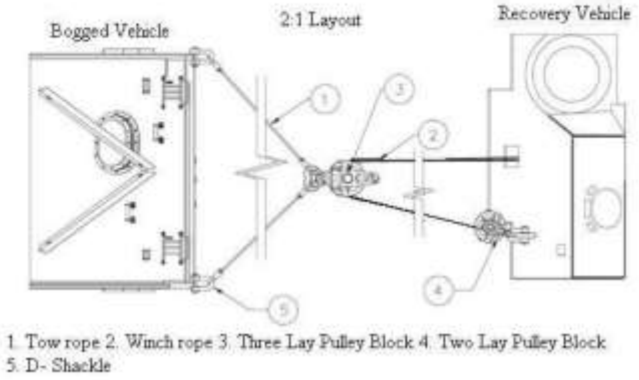


Figure 1b. Pulley block 2:1 Layout configuration

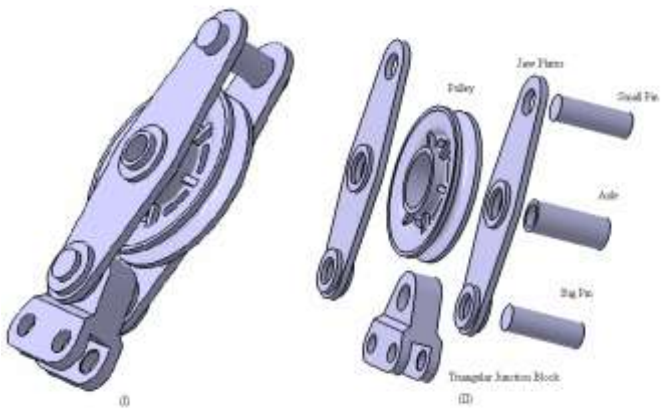


Figure 2. (I) & (II): Pulley block and its exploded View

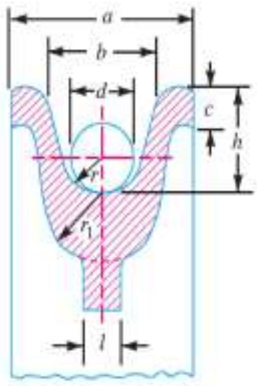
Table 1: Pulley Block members load carrying comparison of

2:1 layout and 3:1 layout

S/N	Components	Load	
		2:1 Layout	3:1 Layout
1	Pulley	60 t	60 t
2	Triangular Junction Block	60 t	90 t
3	Jaw Plates (2 nos.)	30 t (each)	45 t (each)

2.1. Design of Pulley

Pulley is a component used to amplify the force or change the direction of force. In their simplest form, they consist of rope that runs through a grooved wheel. The profile of the pulley is taken from IS standard which depends on the diameter of rope as shown below,



Rope dia, d=28mm
Sheave dia/Rope dia = 12:1
Sheave dia, D = 336mm
r = 0.53d = 15mm
r1 = 1.1d = 31 mm
a = 2.7d = 75.6mm
b = 2.1d = 59mm
c = 0.4d = 11.2mm
h = 1.6d = 45mm
l =0 .75d = 21mm

Figure 3. Sheave profile of Pulley Block

Since the diameter of the pulley in present design is between 280-500 mm we have chosen 6 numbers of ribs. Hub design is usually expressed in terms of diameter of shaft and may be fixed by the following relationship. The diameter of the hub should not be greater than $2D_s$, where 'D_s' is the diameter of shaft.

$D_h = 1.5\ D_s + 25 = 160$mm

Where, D_h = diameter of hub

Length of hub is given by, Lb = 2/3 * B

Where, B= width of pulley and is given by
B = 2.7 * d = 75.6 mm

Lb = 2/3 * B= 50.4 mm

But the length of the hub, sometimes offset to suit the conditions**.** By taking reference of design data, Pulley is modeled in CATIA V5.

Figure 4. 3D model of Pulley

2.1.1. FE Analysis of Pulley

By taking IGES format model of Pulley, Finite element modeling has been carried out by Hyper mesh 9.0. Pulley's mathematical model has discretized with 2nd order Tetrahedron elements. It is constrained at axle location and profile load of 60 ton (refer Table 1) is applied at rope contact area as shown in Fig. 5.

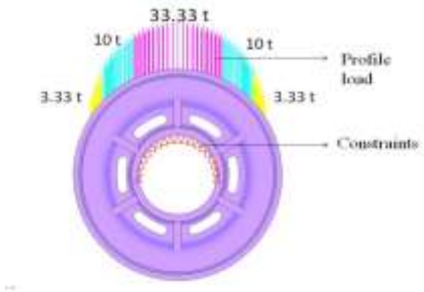


Figure 5: Loads and BC of Pulley

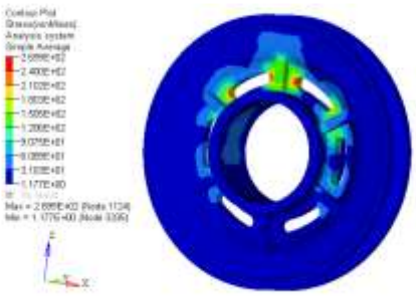


Figure 6. Stress plot of Pulley

2.1.2. Theoretical Validation

Total load on pulley = 60 ton
Load on main rib = 326967.3 N
Area by considering main rib = 1429.07mm^2
Normal stress on pulley rib,

$$Stress\ on\ Rib = \left(\frac{Force\ on\ Rib}{Area\ of\ Rib}\right)$$

Stress on Ribs = 228.79 MPa

2.2. Design of Triangular Junction Block

For present application, conventionally Hook is preferred for its integrity against too heavy loads and well defined design concept. But due to some limitation, a new concept of Triangular junction block has been introduced to serve similar purpose.

By taking reference of Table3 for the material yield
Dia of Big pin hole (90 ton) DH_{BP90t} = 75 mm
Dia of Small pin hole (45 ton) DH_{SP45t} = 55 mm
Radius of Eye end for Big pin hole
$R_{BP90t} = 1.5 * DH_{BP90t} = 75$ mm
Radius of Eye end for Small pin hole
$R_{BP45t} = 1.5 * DH_{BP45t} = 55$ mm

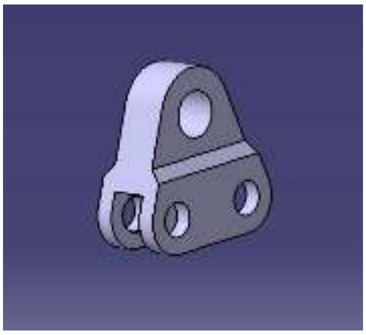


Figure 7. 3D model of Junction Block

2.2.1. FE Analysis of Triangular Junction Block

By taking Iges format model of Triangular junction block, Finite element modeling has been carried out by Hypermesh 9.0. Junction Block has discretized with Hexahedron elements. It is constrained at 45 ton Shear Pin locations and Load of 90 ton (refer Table 1) is applied at 90 ton Big Pin location as shown in Fig. 8.

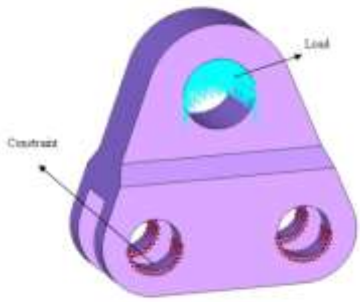


Figure 8. Loads and BC of Junction Block

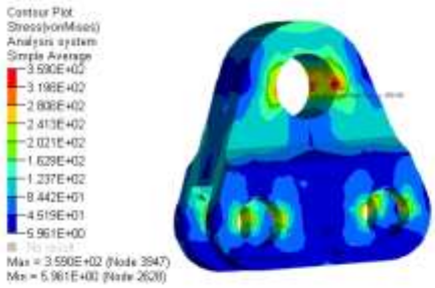


Figure 9. Stress plot of Junction Block

2.2.2. Theoretical Validation

Load P_1 = 90 ton = 882900 N
Dia of Big pin hole (90 ton) DH_{BP90t} = 75 mm
Assumed width W_{TJB} = 150 mm
Thickness of junction block (T_{TJB}) = 80 mm

Stress concentration factor
K_σ = 2.2 (Refer Data handbook [1])
$\sigma_{max} = K_\sigma * \sigma_{nom} = 323.73\ mpa$

2.3. Design of Jaw plate

Jaw plates transfers load from Pulley to Triangular junction block through axle and shear pins. Due to heavy loads, it is prone to fail because of high stress concentration. To compensate this stress, Jaw plates are reinforced with bosses.

Dia of Shear Pin's hole DH_{sp} = 75 mm
Dia of Axle's hole DH_{Axle} = 90 mm
Radius of Eye ends, $R_{sp} = 1.5 * DH_{sp}$ = 75 mm

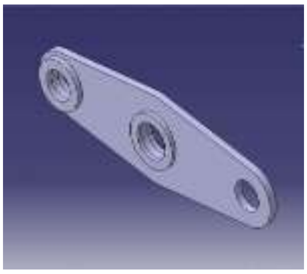


Figure 10. 3D model of Junction Block

2.3.1. FE Analysis of Jaw Plate

By taking Iges format model of Jaw Plate, Finite element modeling has been carried out by Hypermesh 9.0. Jaw plate's model has been discretized with Hexahedron elements. It is constrained at Axle and small Shear Pin locations and Load of 45 ton (refer Table 1) is applied at Junction block shear Pin location as in Fig. 11.

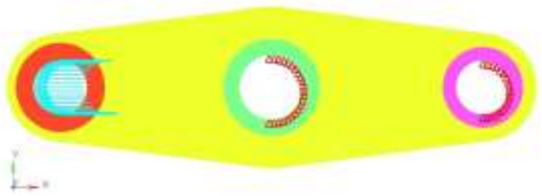


Figure 11. Loads and BC of Jaw Plate

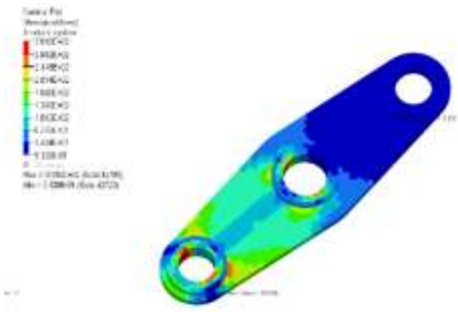


Figure 12. Stress plot of Jaw Plate

2.3.2. Theoretical Validation

Load P_2 = 441450 N
Each boss thickness = 15 mm
Area of boss 1& 2 = 750 mm^2
Area of cover plate = (37.5*20) = 1350 mm^2
Sum of area = 1500 mm^2
$\sigma_{nom} = \frac{P}{(w-d)*t} = 147.15MPa$
Stress conc. factor K_σ = 2.2 (refer [1])
σ_{max} = 323.73 MPa

III. RESULTS AND CONCLUSION

In the present work, Design of Pulley Block for the recovery of 90 ton bogged heavy vehicle has been carried out. FE Analysis results and theoretical calculations are shown good agreement between them.

Table 2

S/N	Component	FEA (Mpa)	Theoretical (Mpa)	Per. Err (%)
1	Pulley	269.9	228.79	15.23
2	Junction Block	359.0	323.73	9.82
3	Jaw Plate	301.6	323.73	6.8

The percentage errors are within the acceptable limit of industry standard. It may be influenced by lot factors such as approximation of load and boundary condition, assumptions for theoretical calculations, quality of meshing etc.

As per MIL standard, materials for pulley block components are given below,

Table 3 : Materials of Pulley Block Critical components

S/N	Component	Material	Yield (MPa)	FEA (MPa)	FOS
1	Pulley	IS:5517-1993-37c15	700	269.9	2.6
2	Junction Block	IS:2062-201-E650	650	359.0	~2
3	Jaw Plate	IS:2062-201-E650	650	301.0	2.16

In the present design, Triangular junction block has been introduced over conventional Ramshorn hook. Junction Block has advantage of less initial manufacturing cost, simple design, less weight compared to Ramshorn hook.

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