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DESIGN AND CONSTRUCTION OF TANK-CHASSIS AND LIFTING STRUCTURE FOR CENTRIFUGAL PUMP HL260 M POWERED BY A DIESEL ENGINE

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ABSTRACT

This article deals with the design, simulation and construction of a fuel storage tank-chassis and a lifting system coupled as a single unit to a Cummins QSK19 engine driven HL260m pump that can guarantee an operating autonomy of up to 12 continuous hours and can be transported to different locations by means of lifting systems. For the mechanical design the recommendations of the American Institute of Steel Construction (AISC) and the application of the failure criteria for Von Mises ductile materials or Maximum Energy Distortion were used. For the dimensioning of the storage tank, the average consumption stipulated by the manufacturer was used and the simulations were performed with SolidWorks®. A functional and safe system that can be used in on-site applications was achieved.

Keywords: simulation, mechanical design, construction, chassis, centrifugal pump.

1. INTRODUCTION

There are industrial, mining and emergency applications in which high pressure water pumps driven by diesel engines must be used and in which a greater autonomy must be guaranteed for an operation shift and which can be transported to the places where it is required [1]. Therefore, the fuel feed system plays a key role.

The systems of transfer are widely used at industrial level for the transport of fluids, between the applications of these systems we have the extraction of waters in quarries and in the deposits of the mines. The purpose of this article is to show the design and manufacturing phases of a chassis that serves as structural support for a high power transfer system, focusing on the design and manufacture of the support structure as well as the fuel tank which must support the dynamic and static loads produced by the fluid and have the capacity to store fuel in order to give the engine an independence of 12 continuous hours.

2. DESIGN PROCESS

2.1 Forces on Chassis

One of the main functions of any structure is to serve as a support for mobile and static elements. It must support the dead load resulting from the weight of the elements. In this case, these are generated by the combination of the forces produced by the components of the water transfer system (engine, pump and non-return valve) as well as the fuel in the tank.

In order to carry out the structural design of the chassis, the recommendations of the ANSI/AISC 360-10 specification for Steel Constructions [2] were taken into consideration. Higher loads should be used. These are the result of nominal loads multiplied by a load factor.

To drive the pump a Cummins QSK19 diesel engine is used, with configuration D193098CX03 which has a mass equal to 2057 kg without accessories [3] and approximately 3 tons once assembled with the same, exerting a force of 29430 N; The pump has a mass of 700 kg and the anti-return valve that complements the transfer system has a mass equal to 300 kg according to measurements made on-site.

Considering the parameters given for the design of the chassis, the structure must have an integrated fuel tank with a capacity of 1.3 $m^{3.}$

$$W_{diesel} = \mathrm{V}.\rho.\mathrm{g} \tag{1}$$

Solving Eq. 1 with the corresponding values, we obtain:

$$W_{diesel} = 1.3\mathrm{m}^3.\frac{1000\mathrm{kg}}{m^3}.9.81\frac{\mathrm{m}}{s^2} = 11028.794\mathrm{N}$$

The chassis must be designed to support also the reactive torque of the motor and pump, in addition to the reaction due to water movement.

Therefore, 4 states must be considered.

- Starting the system.
- Normal operation of the system
- Lifting maneuvers by forklift
- Lifting maneuvers by crane

In Table-1 a summary of the different forces acting on the chassis is shown. From this table the necessary information is extracted to proceed with the structural calculations of the elements that make up the chassis and hoisting structure.

Table-1. Active forces on the chassis.

ENGINE WEIGHT			35316 N
TORQUE			2040 Nm
WEIGHT OF PUMP			6925 N
WIND FORCE			1506 N
REACTIVE FORCE OF THE MOTOR BASE			
R_{Ay1}	7559,30 N	R_{By1}	100987,00 N
R_{Ay2}	7559,30 N	R_{By2}	100987,00 N
M_{Ax1}	2404,70 Nm	M_{Bx1}	2404,70 Nm
M_{Ax2}	2404,70 Nm	M_{Bx2}	2404,70 Nm
M_{Az1}	1615,80 Nm	M_{Bz1}	1615,80 Nm
M_{Az2}	1612,80 Nm	M_{Bz2}	1612,80 Nm
REACTIVE FORCE OF THE PUMP BASE			
R_{Bx3}	-1574,90 N	R_{Cx3}	-1574,90 N
R_{By3}	-88430,30 N	R_{Cy3}	102164,30 N
R_{Bz3}	36124,80 N	R_{Cz3}	36124,80 N
M_{Bz3}	-820,40 Nm	M_{Cz3}	820,40 Nm

2.2 Structural Design

The selection of the type of structural profile is fundamental. These elements must not only withstand the loads to which they will be subjected but must also have the lowest possible weight. For this selection, the principles of material mechanics and mechanical design are applied to quantify the state of stress to which they would be subjected and to ensure that the profiles have enough strength to withstand the load conditions in a reliable manner.

First the design of the chassis base will be carried out, then the lifting structure will be designed, the weight of the equipment must be known as well as the weight corresponding to the structure that conforms the base of the chassis. The base of the chassis is the part of the structure that directly supports the weight of the transfer system and the loads that are generated during its operation; the base of the chassis will be formed by the EF and CD beams that directly support the loads generated by the engine, the GH beam supports the loads generated by the HL260M pump and the lateral beams IJ and KL support the engine and pump beams and is in contact with the ground. Figure-1 shows the distribution of main beams.

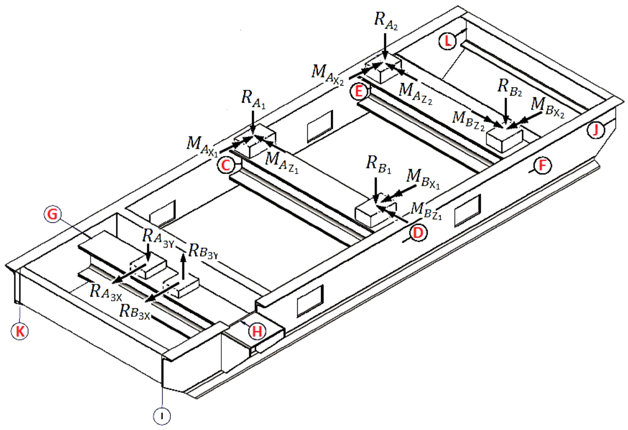

Figure-1. Main beams forming the base of the chassis.

Due to technical requirements given by the manufacturer, the maximum deflection must be less than 0.1 mm. Deflection will be the design criteria for the selection of pump and motor support beams, which we can express as:

$$|\delta_{máx}| \leq 10x10^{-5}\ m \qquad (2)$$

The profile whose maximum deflection is less than the allowed will be selected.

Due to the fact that the chassis is supported directly on the ground, it will be assumed that the beam is supported on the ends with a skid and a pin, performing equilibrium of moments and forces, the deflection curves produced by each individual load with the equations previously developed and the principle of superposition will be used in order to obtain the total deflection curve [4-5], the aim is to find the inertia required to select a profile and material in such a way that the maximum deformation established is not exceeded. Figure-2. Shows the general case of a concentrated load on a beam.

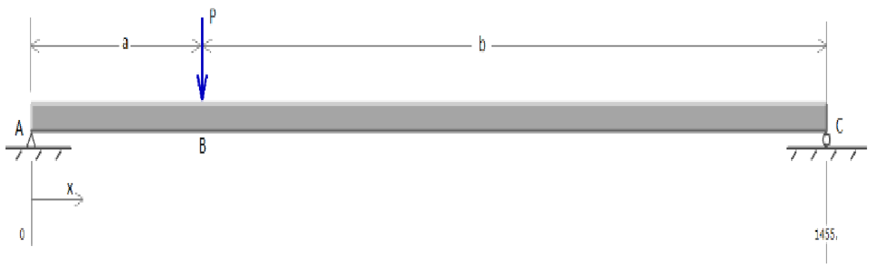

Figure-2. Concentrated load on beam.

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The deflection for this type of load is determined by the following expressions:

$$EI \cdot \delta_{AB} = \frac{Pbx}{6L}(x^2 + b^2 - L^2) \quad (3)$$

$$EI \cdot \delta_{BC} = \frac{Pa(L-x)}{6L}(x^2 + a^2 - 2Lx) \quad (4)$$

Figure-3 shows the deflection curves for concentrated loads R_{A1} y R_{B1}, and Figure-4 shows the moments on the beam:

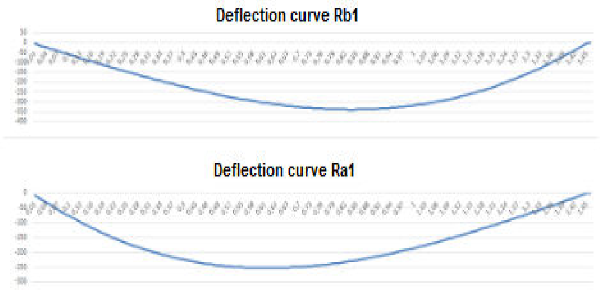

Figure-3. Deflection curves produced by an applied point load.
Source: The authors

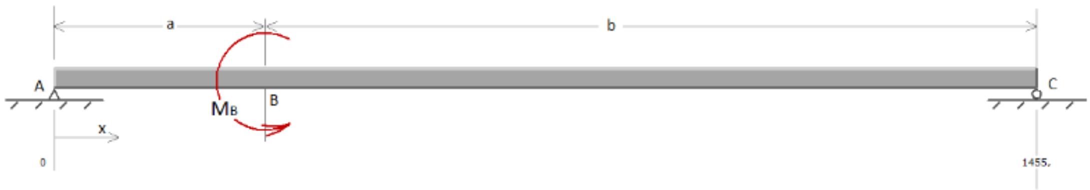

Figure-4. Moment on a beam
Source: Modified image, obtained in MD Solids 3.5 Software

By superimposing the deflection curves, the total deflection curve of the motor beam is obtained. The highest point in the deflection curve of the motor beam is determined and the maximum deflection is obtained $\delta_{máx}$ =0.0001 m (0.1mm). A transverse beam HEB 240 [6] is selected and it was verified that the real deformation that the beam will suffer under load conditions considering its weight is less than the permissible value.

To select the support beam for the pump, the load distribution across its length, the deflection curve of the beam and the inertia required to avoid deformation greater than 0.0001 m (0.1mm) will be determined. For the selection of the lateral beams it must be known that these are the ones that dissipate all the energy of the structure towards earth or seen in another way it is the one that supports all the loads that are generated in the beams of motor and beam of pump.

Distributed loads are normal loads, it is assumed that the load is distributed constant in each section of the beam. In order to identify the loads in each section, the principle of superposition of forces will be applied [7]. The design will be based fundamentally on selecting a channel section that supports the loads to which the beam is subjected, guaranteeing a safety factor to fatigue greater than 2.

The lifting structure of the HL260M chassis must be designed to safely lift the base of the chassis and the equipment that make it up. The design guidelines already described will be used to select the required profiles. The structure must be designed to have a single anchorage point where a sling will be applied that is between 2" and 4" wide and 4 connections to attach it to the base of the chassis.

The design of the lifting structure will be carried out considering that the profiles have the mechanical resistance to do it safely, according to technical requirements, the selected profiles must obtain a fatigue safety factor greater than 2. $(n_f > 2)$ In order to begin with the design of the lifting structure, the loads to be lifted must be known, among which are the engine, the pump, the anti-return valve, the base of the chassis and the weight of the fuel, the centroid of the base assembly and equipment is shown. This information will be necessary to place the lifting point in the same coordinates (X, Z) and in this way avoid the rotation of the structure. A finite element analysis of the entire structure can be performed to observe the behavior of the assembled structure when it is hoisted and transported with the forklift.

2.3 Fuel Tank Design

One of the most important parts of the transfer system is the fuel tank, as it stores the energy source of the system. It must give enough independence to the engine to run at maximum load during a continuous working day of 8 hours, the tank should reduce the movement that occurs in the fluid when the structure accelerates and decelerates during maneuvers. The kinetic energy caused by the uncontrolled wave movement of the fuel in the tank can cause the entire structure to become unbalanced during its hoisting, increasing the danger during these maneuvers. This phenomenon is known as sloshing [8-9]. This phenomenon causes sudden failures in the fuel tank, since

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it exposes the vulnerable parts of the tank to heavy dynamic loads, and its prediction by means of analytical models is complicated since it is a highly non-linear phenomenon. [10].

Bearing in mind that Cummins QSK19 consumes an average of 116 kg of fuel per hour (0.13 m^3/h) a fuel volume of 1.04 m^3 is required, highlighting that the maximum normal fill level of a tank is 80%. Due to this, the tank must have a capacity of 1.3 m^3 in order to give the system the necessary autonomy for its operation. Due to customer requirements, this tank must be integrated to the chassis structure. In Figure-5. The cross section is shown:

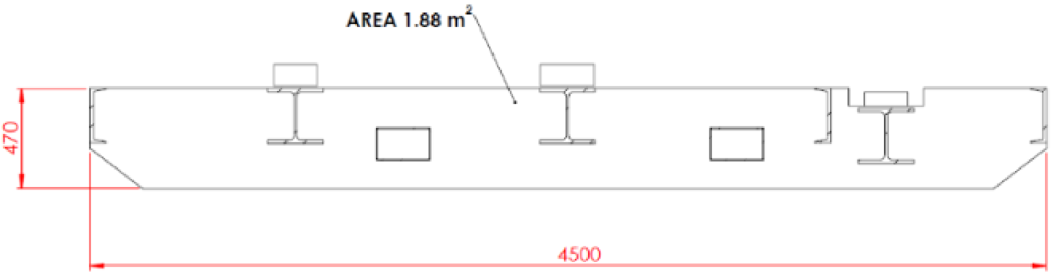

Figure-5. Cross section
Source: The authors

In order to correctly calculate the volume of the fuel tank it is necessary to consider the volume of the profiles that pass through the internal structure of the tank. Since the profiles are across the chassis, the tank can be designed using their cross-sectional area, rather than the volume they displace. In order to find a suitable geometry, the design begins by assuming a rectangular section tank with the following dimensions l by h.

Considering that one of the restrictions is the height of the chassis (457.2 mm as shown in Figure-6) then a height h of 368.5 mm (14.5 inches) is assumed. In such a way that there is a separation between the tank and the ground of 88.9 mm (3.5 inches).

$$1.45\ m^2 = h * l \tag{5}$$

$$l = \frac{1.014\ m^2}{0.368\ m} = 2.76m$$

It was verified that the proposed geometry meets the volume requirements and integrates correctly into the tank structure. However, in order to facilitate the drainage and cleaning of the tank, the design of a rectangular tank was changed to a trapezoidal one as shown in Figure-6 and the slope was calculated according to the length of the tank and the increase in its height.

$$tan\ tan\ \emptyset\ = h_p \tag{6}$$

For an increase of 25 centimeters at the back, a slope of 0.66° is
obtained.

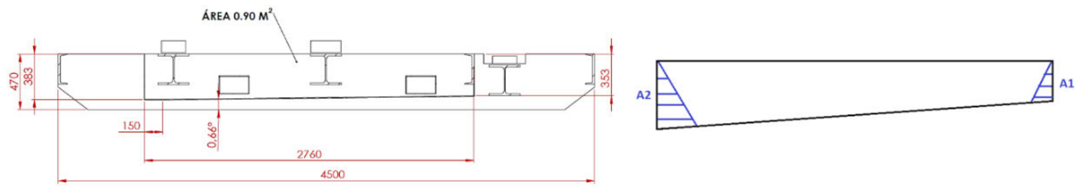

Figure-6. Trapezoidal Section Tank
Source: The authors

Once the geometry of the tank has been defined, a design is made to support the loads in the tank. These loads are of 2 types. A static load due to the weight and pressure that the fluid exerts on the walls of the tank and another dynamic that comes to appear on the chassis during transport of the same, either in vehicles or through lifting maneuvers.

The dynamic load inside the tank is generated during the movement of the chassis from one point to another producing waves in the tank. The kinetic energy of these waves generates dynamic forces on the tank walls, as well as destabilizing the chassis during transport. [11-12].

Generally, the hydrodynamic pressure of liquids in moving containers has two components, one directly proportional to the acceleration of the tank and the second is known as convective pressure. The second is associated with the movement of the free surface and is represented by the mass-spring-shock model [13]. In this work we will only consider the hydrodynamic pressure distribution. The chassis will be subjected to accelerations when being

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transported from one place to another with a forklift. In order to calculate the deceleration and acceleration during starting or braking, it was considered that in heavy trucks, the coefficient of adhesion to the ground is approximately 0.68. Therefore, the maximum deceleration that can be obtained is 3 m/s2 [11].

Figure-7 shows the shape of the fuel surface in the tank as a function of the fuel filling percentage.

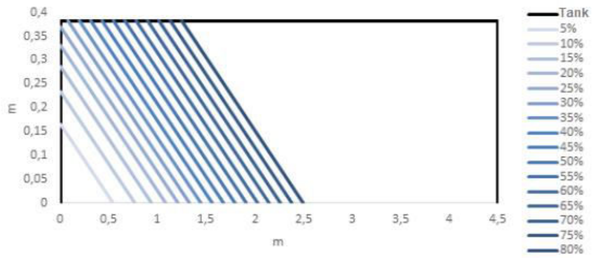

Figure-7. Free Surface of Tank
Source: The Authors

Figure-8 shows the behavior of the hydrodynamic force as a function of the filling percentage of the tank. Although the force component due to acceleration (red line) increases directly proportional to the filling percentage, the greatest hydrodynamic force occurs when the tank is at 25% of its capacity. This is because the convective component is influenced by the filling percentage.

Bearing in mind that the mass in the tank starts from rest, ($V_1 = 0$) it follows that:

$$V_2 = \sqrt{2a\Delta x} \tag{7}$$

If the centroid moves along the "x" and "y" axis, then it can be deduced that:

$$V_{x_2} = \sqrt{2a_x\Delta x};\, V_{y_2} = \sqrt{2a_y\Delta y} \tag{8}$$

Therefore, to calculate the hydrodynamic force due to convective pressure, the equations of linear momentum in the fluid [14-15] are used:

$$\sum F_x = V_{x_2}(V \cdot \rho \cdot A) \tag{9}$$

$$\sum F_y = V_{y_2}(V \cdot \rho \cdot A) \tag{10}$$

In solving the equations, the reactions were determined:

$$R_x = V_{x_2}(V \cdot \rho \cdot A) + F_{pa}$$

$$R_y = V_{y_2}(V \cdot \rho \cdot A)$$

$$F_x = -R_x\,;\; F_y = -R_y \tag{11}$$

Where F_{pa} is the component of hydrodynamic force due to acceleration. By finding the resultant of the force Fy and Fx the hydrodynamic force on the A2 face is obtained. Results are shown in Figure-8.

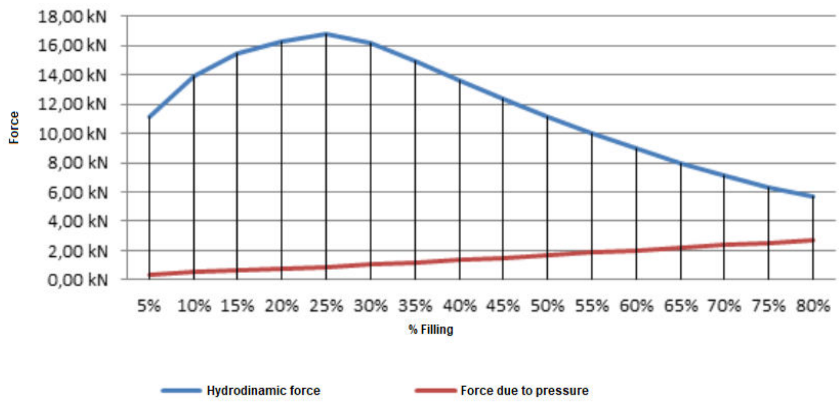

Figure-8. Forces
Source: The Authors

In order to reduce the amplitude and frequency of waves generated during the movement of partially filled tanks, several strategies have been found in the literature, such as the use of foam [16] and different baffle geometries [17-18]. These baffles can have different geometries which vary depending on the use and shape of the tank. In this case, perforated breakwaters will be used because they are more effective in reducing the kinetic energy of the fluid and therefore the hydrodynamic forces [11].

Each breakwater to be used has a configuration of 18 holes of 2 inches representing 10% of the breakwater area, as shown in Figure-9:

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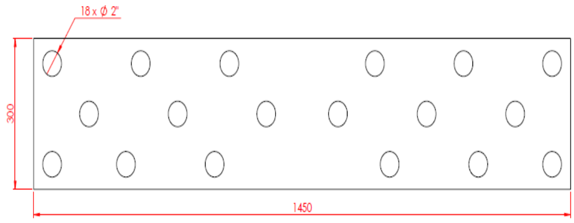

Figure-9. Breakwater
Source: The Authors

Once the finite element analysis has been carried out, it can be observed that the tank has a sufficiently high safety factor to provide the required resistance and safety.

2.4 Manufacture of Chassis and Hoisting Structure Profile Cutting, Structure Assembly, Welding

The first step is to cut the structural profiles according to the indications given. Once the elements have been cut, the structure and the bottom of the fuel tank are assembled. During this process, the comparison of the physical dimensions with the measurements given in the drawings must be carried out. If the dimensions are within the established tolerance, the base of the chassis and the fuel tank must be welded together, otherwise the necessary corrective actions must be established to guarantee that the measurements are within the indicated parameters.

The tank will be slowly filled as shown in Figure-10, with water at room temperature up to 100% of its capacity and will be left for at least 24 hours once it has been completely filled, there will be periodic revisions to observe some type of leak, if found the pertinent correctives must be made and the test must be carried out again [19].

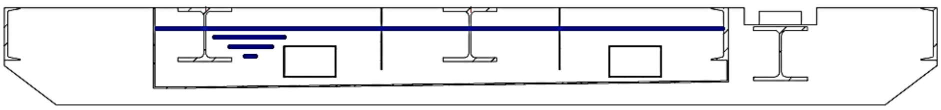

Figure-10. Leak test
Source: The Authors

We proceed to assemble the breakwaters of the tank, the engine support blocks and close the top cover of the tank as shown in Figure-11:

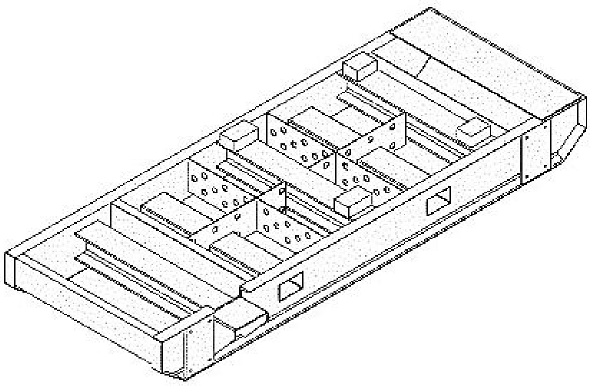

Figure-11. Fuel tank with breakwater
Source: The Authors

For the fabrication of the lifting structure, the structural profiles were cut, and the upper contour was assembled. After this, the joints were welded and the columns and coupling plates were installed at the base of the chassis as shown in Figure-12:

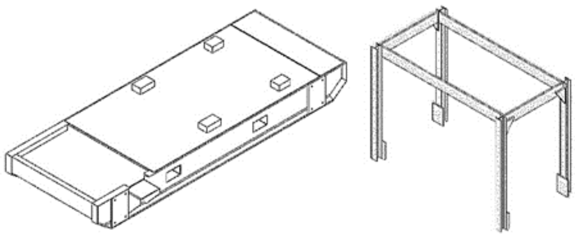

Figure-12. Lifting Structure Arming
Source: The Authors

The assembly of this components was one of the most critical parts of the execution of the project, since they require movements of heavy components and all the protocols of security must be implemented in order to avoid some type of accident. The diesel engine is initially installed on the base of the chassis, then the pump is installed in order to establish the height required for the pump blocks.

The pump support blocks are machined to the required head to ensure alignment between the motor shaft and the pump shaft. After making the assembly of all, proceed to apply a cleaning scheme SSPC-SP3, all components are assembled and proceed to locate the lifting point, for this must be found the center of gravity of the structure. By means of the use of slings a temporary lifting point is located in the center of mass suggested in the plans, the system is lifted and the stability is verified, if the structure tends to turn towards some end the lifting

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point is relocated in such a way that there is no rotation with respect to this point, a procedure and achievement of activities is established that derive in a work schedule for the manufacture of the chassis for pump HL260M driven with diesel engine.

3. DISCUSSIONS

Theoretical calculations to design the structure and fuel tank were validated using Simulation SolidWorks finite element analysis software.

Table-2 shows the comparison between the results of the FEM analysis and the theoretically found values.

Table-2. Validation of results.

Element	Parameter	Calculated	Simulated	% Error
Pump beam gh	Deflection (mm)	0.098	0.0934	4.7
Channel kl	N	4.9	4.3	12.2
Lift pin o	N	2.1	1.9	9.5
Lifting ear 0	N	2.0	2.1	5.2
Central beam mn	N	2.1	2.0	4.7
Lateral beam pq	N	1.7	1.8	5.5
Column qw	N	2.2	2.0	9.1

Figure-13 shows the distribution of the safety factor in the structure when it is lifted. This analysis shows that the critical point is in the lifting ears. Figure-13 shows the detailed behavior of this point, and Figure-4 shows the analysis of lifting ears.

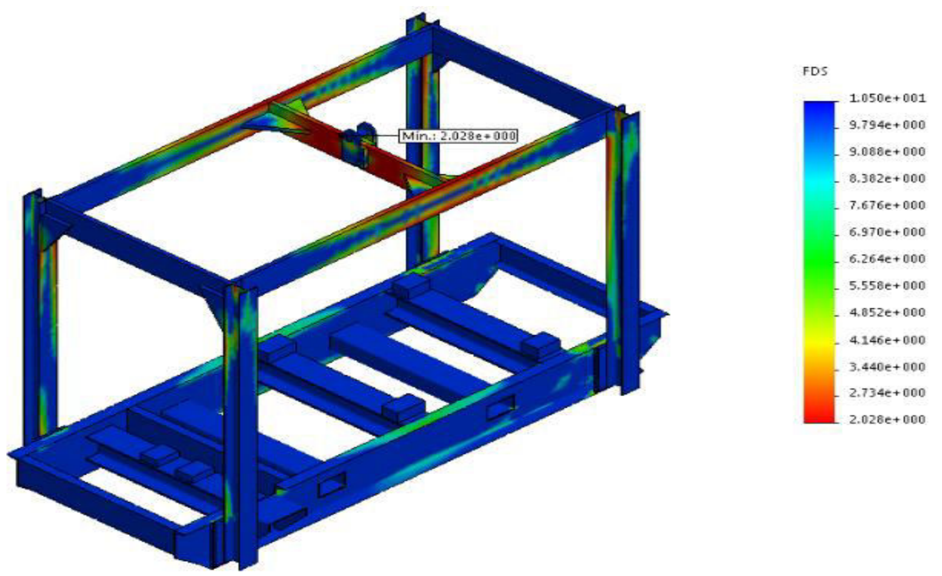

Figure-13. Analysis of the assembly at lifting point O.
Source: The authors, simulated in SolidWorks Simulation.

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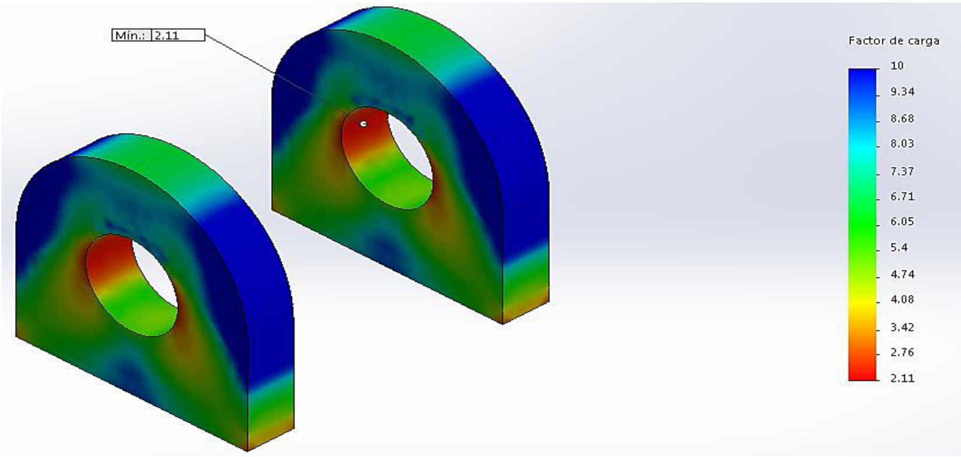

Figure-14. Analysis of lifting ears
Source: The authors, simulated in SolidWorks Simulation.

In the same way was simulated the behavior of the fluid in tank with and without breakwaters, demonstrating a reduction in the kinetic energy of the fluid as shown in Figure-15.

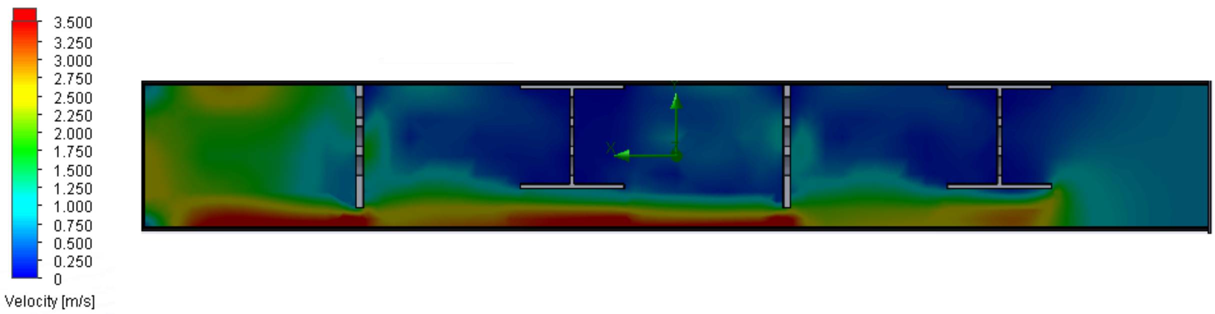

Figure-15. Fluid velocity inside the tank.
Source: The Authors

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