Design and Simulation of a Lamella Clarifier

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Abstract

The front-end design of the Additional Mining Vessel 3 (AMV3) is based on the current mv Mafuta (MFT) design, comprising of a crawler that is used to recover material from the seabed. This material is then pumped through a 700NB riser pipe to a four-way splitter, whose discharge reports to the static drain panels. The main focus of this study is to use experimental methods to explore the feasibility of an alternative Dewatering Bin concept (Lamella Clarifier) that can successfully operate in the unique mining environment, with the increase in operating capacity without jeopardizing the dewatering bins operational efficiency. Using the existing Mafuta mining vessel which uses four dewatering as a baseline. A CFD study was conducted to determine the effect of using lamella plates on the existing dewatering bin prior developing a new concept. Based on the findings from the study, +0.5, -1.4 mm sized particles interjected, which indicated diamonds could escape. An alternative concept was developed and on a 7th scale Lamella Clarifier test rig to establish a fundamental understanding of the alternative dewatering bin concept. This document defines the scope of work for test work to be conducted at Paarden Eiland for the Dewatering Bin concept development.

Keywords
Front-End, Additional Mining Vessel 3(AMV3), mv Mafuta (MFT), and Lamella Clarifier

1. Introduction

Lamella clarifier development study is highlighted. The study looks at the marine mining activities conducted at De Beers Marine (DBM) along the coast of Namibia. It refers to the mining equipment used and how technological improvements of this nature can improve efficiency with respect to production rate. The study focuses on the theoretical concept of the existing dewatering device and the introduction of a lamella clarifier as an alternative dewatering unit that can successfully operate in the unique mining environment for case study 1 and case study 2 explores dimensioning of a steel structure of rectangular tank. Theories and principles behind the different techniques used for separation of particles have a major role in society. More specifically as the need for ocean resources increases. The current dewatering bin was found to lose +1.4mm diamonds as the feed rate increases, which potentially affects the diamond recovered. Further dewatering bin concepts have been explored by means of CFD analysis by the DBM R&D department, to further develop the existing dewatering design for the deployment of production vessels. A need existed to develop, design and manufacture a scale model that will demonstrate the performance of the concept based on a lamella clarifier which is originally used in wastewater industries. The objectives of the was to;

- Review a case study and study methods of simulation
- Develop a 1:7 scale detailed design model of the alternative de-watering bin concept.
- Fabricate a test rig that will allow for quantitative and qualitative test work.
- Test the throughput potential of the lamella clarifier.

2. Literatre Review

2.1. Company Background

With regards to DBM mining operations off the coast of Namibia Africa, production of diamonds has become a commodity of high demand. The supply of diamonds heavily depends on the discovery of new deposits as older deposits become exhausted and expensive. Namibia has the richest known marine diamond deposits in the world, estimated at more than 80 million carats. They represent around 65 per cent of Namdeb Holdings' total diamond production and 90 per cent of its diamond resources. Marine diamond recovery now produces more in annual volumes than the country’s land-based diamond mining (Marine, n.d.).

DBM recover diamonds around 120 to 140m below sea level in the Atlantic Ocean off the Namibian coast. The company operates a fleet of six motor vessels (mv) capable of retrieving and exploring diamond bearing materials from the seabed and processing them to rich diamond concentrate (Richardson, 2007). They are mv Debmar Atlantic, mv Debmar Pacific, mv! Gariep, mv Grand Banks, mv mafuta and SS Nujoma. DBM is one of the leading companies involved with offshore commercialised mining. The company specialises in the extraction of diamonds and has been exploring off the continental shelf of Namibia since 1983 (Richardson, 2013). The company runs a sizeable mining operation that requires a high annual production rate of diamonds to achieve a profitable undertaking. Over the years the level of production has been maintained through investments into sectors such as research and engineering, by developing advanced prototypes or optimising certain aspects of the system.

DBM is capable of optimizing the existing systems through a number of different methods. The two-mining system currently operational as shown in Figure 1 in the fleet include a seabed crawler and a large diameter drill bit. The systems are used extensively and require a high level of maintenance and innovation to ensure optimum performance.

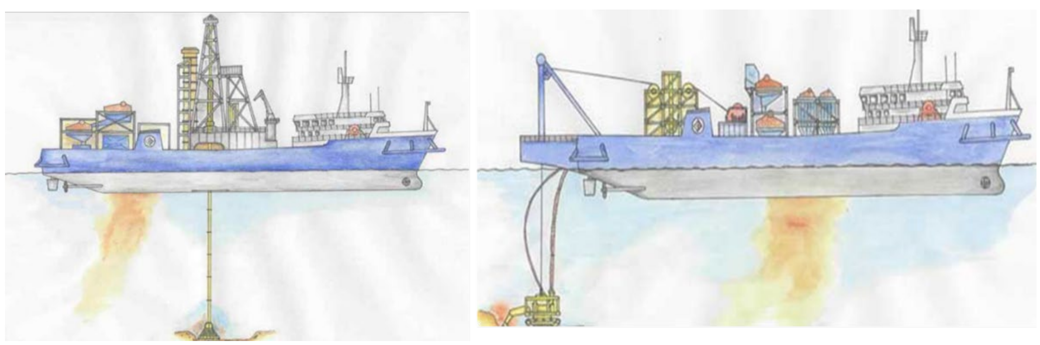

Figure 1. Large diameter drill (Left), Seabed crawler (Right) (G.Raubenheimer, 2019).

2.2. Specialized Dewatering Bin

The main focus of this activity is to use experimental methods to explore the feasibility of the alternative Dewatering Bin concept that can successfully operate in the unique mining environment, using the existing Mafuta mining vessel which uses four dewatering as a baseline. De Beers Marine has manufactured a test rig that will be used to carry out test work to establish a fundamental understanding of the alternative dewatering bin concept. This section defines the scope of work for test work to be conducted at Paarden Eiland, Cape Town for the Dewatering Bin concept development.

2.3. Background

Over the past decade, De Beers marine has made major technological advances in the offshore mining industry, that has saved their mining business (Qiu, 2017). Out of the two different mining systems stated in Figure 1, the seabed crawler was of greater relevance, largely due to the mechanical interaction between the system and the seabed.

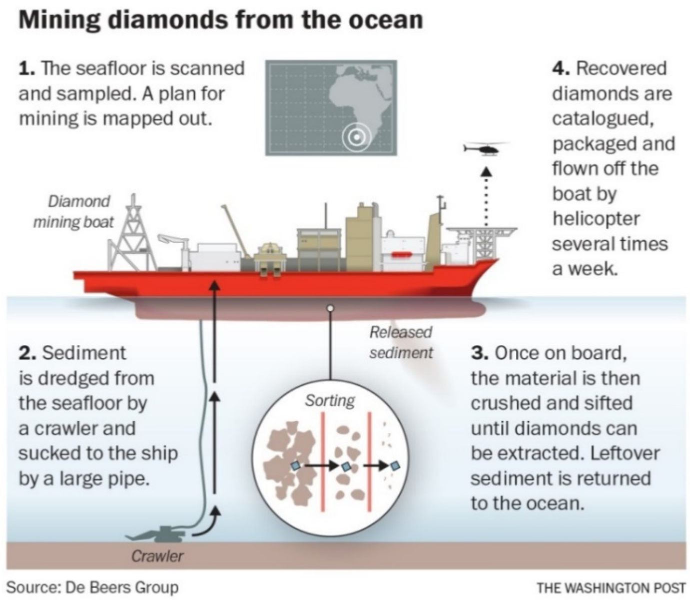

Figure 2. Crawler mining vessel operation process (Siedd, 2017).

Figure 2 depicts an overview of the crawler mining vessel. The seabed is firstly scanned and sampled, the 260 Tone crawler then extracts material off the seabed to the ship where the on-board operation begins, where gravel is screened and separated using a variety of methods. The recovered diamonds are then air lifted from the ship to a sort house. The main focus of this section closely looks at the dewatering bin device. The dewatering bin device that is found within the sorting process. A dewatering bin (in this case an Elutriator is used) is a device that separates particles based on their size, density and shape. The dewatering bin concept was aimed at removing increased volumes of water, removing of ultra-fines and reducing the current footprint (weight and size) that incorporates best marine practices. Elutriators have been successfully used as de-watering devices. Figure 3 indicates a cross-sectional view model of the existing dewatering bin (Elutriator).

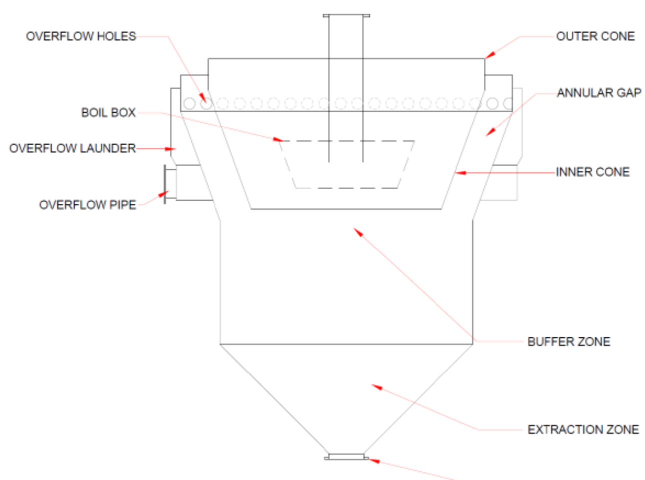

Figure 3. Simplified Cross-Sectional View of Dewatering Bin (Pietersen, 2013).

The incoming material reporting to the primary screen includes materials from the sea bed which include; mud, silt, shells, sand, fine gravel, coarse gravel and diamonds. The dewatering bin is used to efficiently separate the coarse material from the water and fine material. The Material is fed from the screen under-pan into a feed-pipe directing flow into a boil-box, where energy of the incoming flow is dissipated. Material is then directed downwards due to the inner cone structure. The slurry then continues downwards into the **buffer zone** with the intention of forming a homogenous flow pattern that will improve settling at the bottom of the tank. Larger particles continue flowing downwards to the **buffer zone** where a fluidiser is used for the extraction and delivery to the downstream process. Coarser material is expected to report to the under-flow through the outlet and some material rises in the **Annular gap** (or **separation zone**) and final sizing occurs within this region. The average upwards flow velocity at the entrance of the annular gap is referred to as a rise rate. The design is meant to ensure 100% recovery of +1.4mm diamonds, whilst -1.4mm materials report to the over-flow (**Outer cone**) through the overflow holes. The water and under-size solids enter into an overflow pipe prior to being discharged overboard back to the sea.

2.4. Case Study of Dimensioning a Steel Structure of Rectangular Tank.

The subject of this case study is dimensioning steel tank which does not have a standard, cylindrical or spherical shape. Since these forms of tanks commonly appear in practice, dimensioning of these reservoirs is routine. However, depending on the investor's request (dimensions required for the tank, maximum use of space), there is a need for constructions with atypical forms. Such atypical structure, rectangular in shape with three compartments, is dimensioned in this case study. With a few exceptions in which is available number of examples by national standards with silo and tank cells (Anon., 1997). As the first stage of analysis, dimensioning is performed according to the Eurocode, and as the most interesting problem, dimensioning of flat steel plates subjected to bending is analysed. The second stage is the analysis of the model in the software package ABAQUS. Dimensioning of stiffened or unstiffened steel plates of tanks, according to the Eurocode, is performed according to EN 1993-1-7 (Part, 2007) which refers to plates subjected to out of plane loading.

2.5. Basis of Design of Rectangular Tanks According to The Eurocode.

Eurocode 3 presents the part of the Eurocode which refers to the dimensioning of steel structures. It is based on the semi-probabilistic concept of design, or on limit states. In order to select the method of structural analysis, it is necessary to define a structure type, or to define a consequence class to which a structure belongs. Therefore EN 1993-4-2 (JUS.MZ, 1981) defines a consequence class, according to which it classifies a type of construction in a particular class which defines the level of reliability of the construction. According to (JUS.MZ, 1981) ,the level of reliability of tank construction is defined according to following three consequence classes Table 1.

Table 1: Consequence classes for tank constructions **(Miroslav T. Bešević, 2015)**.

Consequence class 3	Tanks storing liquids or liquefied gases with toxic or explosive potential and large size with flammable liquids or water – polluting liquids in urban areas. Emergency loadings should be taken into account for these structures where necessary.
Consequence class 2	Medium size tanks with flammable liquids or water – polluting liquids in urban areas
Consequence class 1	Agricultural tanks or tanks containing water

2.6. Liquid Induced Loads

The liquid which is intended to be stored in the tank analysed is wine. According to (Anon., 1997) a characteristic value of pressure p is;

$$\boldsymbol{p(z) = \gamma z} \qquad (1)$$

Where:
z - is depth of the liquid and
γ- is density of the liquid.
Densities of liquids are given in EN 1991-1-1 (Anon., 2009), which contains tables of nominal values of densities for construction materials, among which is the specified value of density of wine, which is; $\gamma = 10$ KN/m^3.

2.7. Modelling of the Box Structure of The Rectangular Tank.

During dimensioning stiffeners, it is necessary to determine the effective plate width (Maqina et al, 2020). The effective plate width on each side of the stiffener should not be higher than newt, where t is the local plate thickness and new the effective width. The recommended value for new is 15ε (Miroslav T. Bešević, 2015). The most common tank wall configurations i.e, unstiffened and stiffened are discussed herein (Maqina and Kallon, 2020).

Unstiffened Tanks

Represent a construction that is designed with flat unstiffened steel (Figure 4), the tank wall is subjected to a varying distributed load which varies from top to bottom. This internal pressure is due to the weight of the contents (Wajtaszak, 1936).

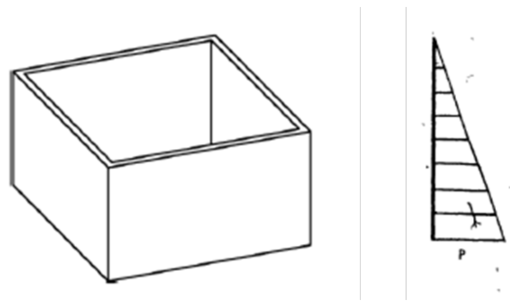

Figure 4. Unstiffened tank (Left) (BS., 2000).

A) Top Edge Stiffener

If the plate thickness seems uneconomical, or the plate deflection is too large and exceeds one half of its thickness, a top edge stiffener should be added (Figure 5). Top- edge stiffeners are required for open-top tanks. Stiffeners shall be located at the top and preferably on the outside of the tank shell. All edges will be considered to be simply supported (Blodgett, 1975).

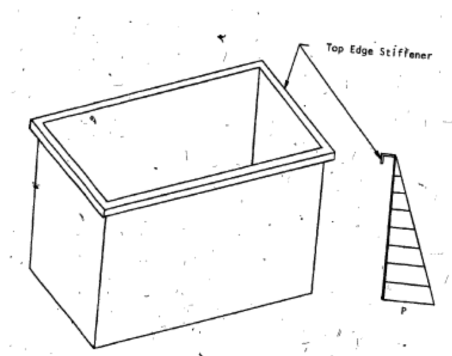

Figure 5. Tank with Top-Edge Stiffener (BS., 2000).

B) Tank with Horizontal Stiffener

The plate thickness can be reduced considerably by adding horizontal stiffeners or vertical stiffeners or a combination of both. The additional of stiffeners indicated in Figure 6 increases the rigidity off the tank wall by increasing the moment of inertia of the combined section. For a conservative design, wall panels may be analysed as a straight beam by considering strips of unit width, of the plate under the hydrostatic load (Anon., 1967).

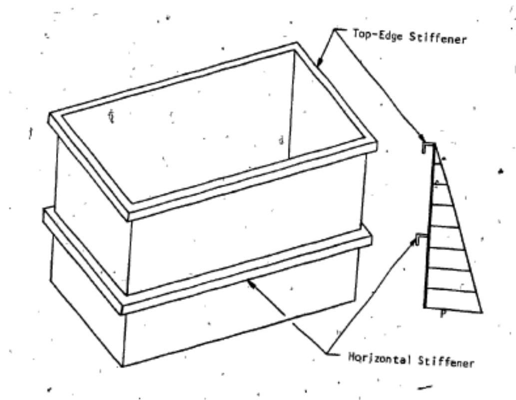

Figure 6. Tank with Horizontal Stiffeners (BS., 2000).

Dimensioning of elements is carried out to bending in horizontal plane, where bending is the result of pressure of the liquid which is exerted perpendicular to the tank wall. In design it is necessary to consider the membrane tensile stresses occurring in the walls as a result of hydrostatic pressure on the walls perpendicular to the wall that is being analysed. It is also necessary to consider membrane compression stresses occurring in the walls as a result of a wind load on the walls perpendicular to the wall however to simplify the design wind will not be considered according to the claim that the tank will be located indoors. Local bending effects from additional elements or pipes on the tanks should be avoided as much as possible. If this is not possible, it is necessary to examine the stress and strain state near the hole (Kallon et al, 2020).

2.8. Structural Elements of a Tank for Wine - 100m3

Material used for the tank that is analysed in the next chapter is austenitic steel 1.4301. According to (3, 2006), properties of stainless steel for material used (nominal values) are stipulated in Table 2. Further tank dimensions and manual calculations are found in Appendix. A, this case study only reviews the approach and results.

Table 2: Structural Properties for Wine Tank **(3, 2006)**.

Yield strength (f_y)	21.0kN / cm2
Ultimate tensile strength (f_u)	52.0kN / cm2
Modulus of elasticity (E)	200000N /mm
Poisson's ratio (□□	0.3
Coefficient □□for stainless steel	1.4301

2.9. Model of the Tank Construction on ABAQUS

ABAQUS 6.7 software package based on FEM (Finite Element Method) consists of a number of engineering programs. It was developed by Hibbitt, Karlsson & Sorensen Inc. ABAQUS represents one of the comprehensive programs, intended to address a wide range of problems, both related to the mechanics, and the other fields of science. Model of a tank depicted in Figure 7, is composed of thin plates (3D shell deformable part), where all the parts, tank shell and all stiffeners are modelled as thin plates connected with tie constrains. The model consists of 95 parts, connected with 94 tie constrains (Wajtaszak, 1936).

Figure 7. Model of the rectangular tank on ABAQUS (Wajtaszak, 1936).

Figure 7 indicates the numbering of the 5 stiffeners (*left*) and the numbering of the sections in between the stiffeners (*Right*). The tank is clamped per lower edge, thereby boundary conditions with the bottom of the tank and all welds are simulated. All parts are modelled as thin plates, with three nodes, each consisting of 6 degrees of freedom.
This is the only element in ABAQUS library (according to (Abaqus, 2007)) designed to solve thin plates. While modelling the plates, the width of elements used was approximate 0.1m. Considering that the geometry of the elements of tank demanded denser mesh of finite elements in certain places, densifying of a mesh was performed. For purposes of numerical modelling, the study of convergence was performed, in which the results of a several numerical models were compared. The models differed among themselves by the number and the density of the finite element mesh. The convergence of the results of such a complex numerical model requires significant computing resources, particularly working memory. Since these devices are currently not available to the authors, the listed mesh was adopted. It is observed that the results obtained are of the same order of magnitude as those obtained by calculation according to the Eurocode (Wajtaszak, 1936).

2.10. Simulations

The simulated model made in Abaqus, Figure 8 , indicates the absolute displacements of points with respect to the undeformed position of construction elements obtained.

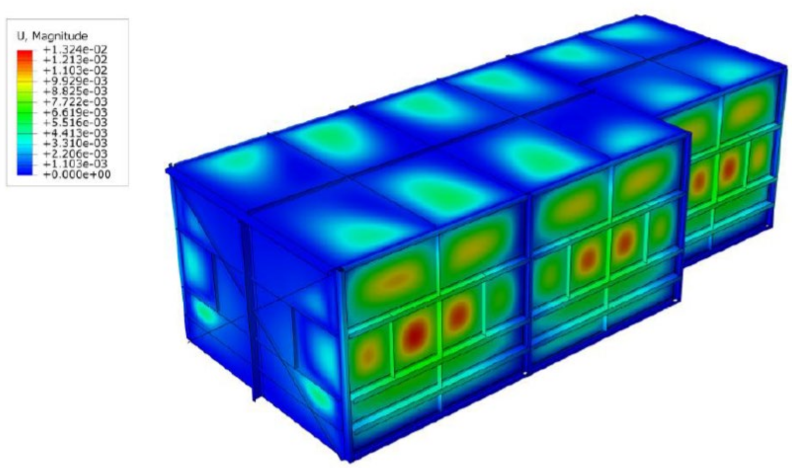

Figure 8. Model of tank with values of displacements perpendicular to the plane of plate, of points of elements (Wajtaszak, 1936).

The Comparison of the results obtained from the Eurocode and those obtained in Abaqus showed significant differences.

2.11. Discussion of the Results

A comparison of the absolute deflections is obtained in both cases. In the first case, in design according to the Eurocode, the segment is treated as a plate with all edges clamped (according to (Abaqus, 2007)), wherein the obtained plate deflections are deflections obtained so that the edges of segment are treated as immovable parts of plates out of their planes, which is definitely not the case in a real model.

Table 3: Deflections of points of plates **(Wajtaszak, 1936).**

Part	Point	Calculation by the EC	ABAQUS	Difference
3 – 4 of vertical plate	1	0.0102289*m*	0.0132377 *m*	22.7%
	2	0	0.00726218 *m*	-
4 – 5 of vertical plate	1	0.00949*m*	0.0103487 *m*	8.3%
	2	0	0.00557701 *m*	-

Displacements of all points of construction are shown in **Error! Reference source not found.** Values of displacements in the legend are given in meters. Table 3 indicates deflections in sections 3 (between stiffener 3 and 4) are much greater than deflections in section 4 (between stiffener 4 and 5). A comparison of the absolute deflections is obtained in both cases. Bearing in mind that the numerical model in Abaqus is geometrically identical, spatial, structural model, these differences are expected. That is, it is assumed that these differences are a consequence of a greater displacements of observed cross sections in the spatial model, unlike the model in Eurocode in which the supporting elements are hardwired. In this case study, the design of elements of a rectangular tank construction by the Eurocode were performed. With obtained dimensions of elements, tank was modelled in the software package ABAQUS, and displacement (perpendicular to the plane of plates) values, as well as values of maximum stresses were compared. Due to the need for making the rational numerical model that can be used in practical calculations in project design companies with standard computer equipment, the model of a given mesh size is adopted. Deviations in the results of two very different approaches applied are expected, given the complexity

3. Methods

The main objective was to analyse the current designs material behaviour. Other problems with the current design was the large volume and mass footprint (4.7m Ø x 6.7m height) it carried on the vessel as well as how material is vertically fed into the dewatering bin, which also compromises the separation efficiency. Specifically, the investigation focused on the effect of the annular gap design on the separation efficiency. It was anticipated that the project would enhance ones understanding of the physical parameters influencing the flow of particles. Recognising the gap of knowledge, the methodology used to achieve this was to firstly design concepts using the existing design as baseline. A full technology scan was done to possibly find ways to optimise the current design. A lamella clarifier was then established and further research was conducted for a better understanding of its fundamentals, operations and run CFDs of the current model.

4. Concept Development

Two concepts were created from the baseline dewatering bin shown in Figure 9 **(1)**. The original design was derived from an Elutriator, where gravitational sedimentation the particles move vertically downward while the fluid travels upward through the Annular gap. If the velocity of the fluid is less than the settling velocity of the particles, the particles will then move downwards against the stream of fluid. If the settling velocity of particles is less than the velocity fluid, the particles will move upward (D.M. Hunter, 2019). The problem with the initial design is +1.4 mm sized particles would result to the overflow, resulting into diamond losses.

A technological scan was done and found that adding plates within the annular gap would add value in controlling the velocities within the Elutriator as seen **(2)**. Alternatively using a wastewater treatment device in the mining environment later resulted into the development of the lamella clarifier.

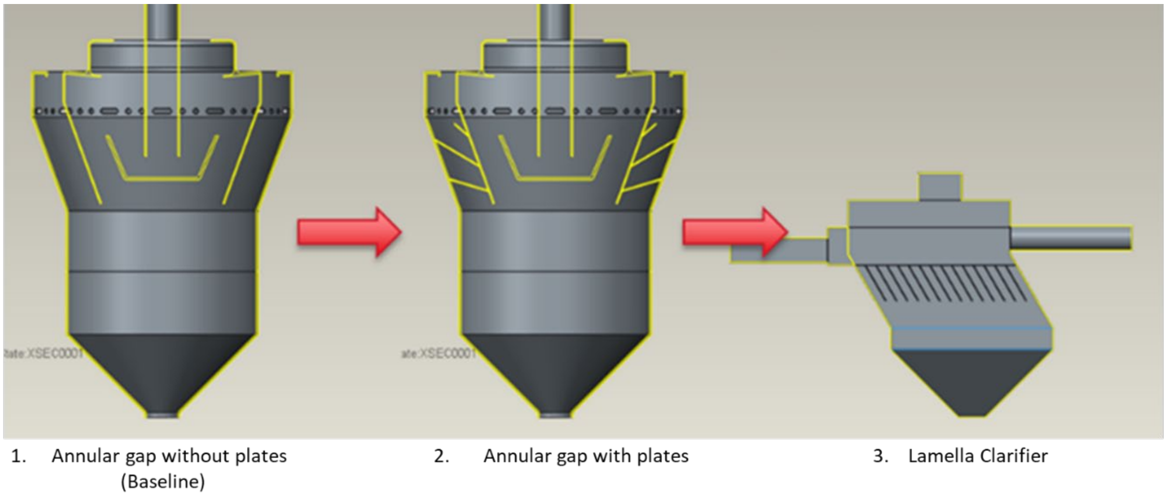

Figure 9. Proposed concepts of Dewatering Bin.

5. Summary of Results and Discussion

5.1. CFD Analysis

Further on a CFD Analysis was done on the current design with additions of plates, depicted in Figure 10. It was decided to simplify the problem by making assumptions. Firstly, there is no air in the system and the flow is at a nominal rate. The blue illustrates the 0.5mm particles and the red illustrates the 1mm particles. The 0.5mm particles are not seen displaced with 10mm plate gaps however particle losses are seen with the baseline concept and the 5mm gaped profile. Manufacturing steel plates within the Elutriator was seen as a complex task also considering the safety hazards of working within a confined space. A need existed to explore the lamella clarifier concept.

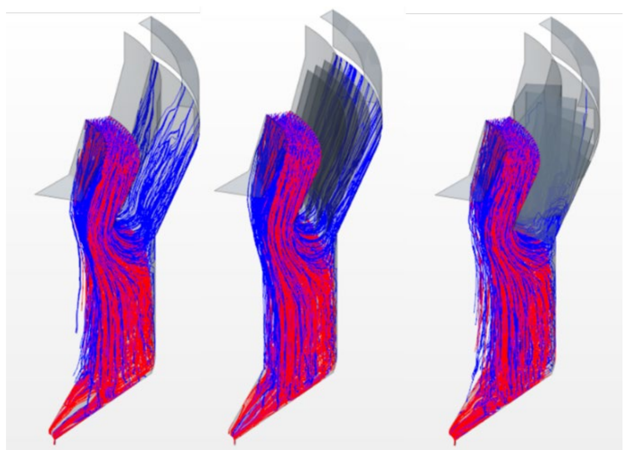

Figure 10. Annular Gap Baseline (Left), with 5mm plate gaps (Middle), with 10 mm plate gaps (Right).

5.2. Lamella Clarifier Development

A Lamella clarifier was developed to determine the effect of various operating parameters on the amount of material being carried to the overflow. In addition, Figure 11 shows the 1:7 Froude scaled Lamella clarifier concept design built to demonstrate the clarifier concept to De Beers Marine to provide confidence in its inclusion onto the vessel.

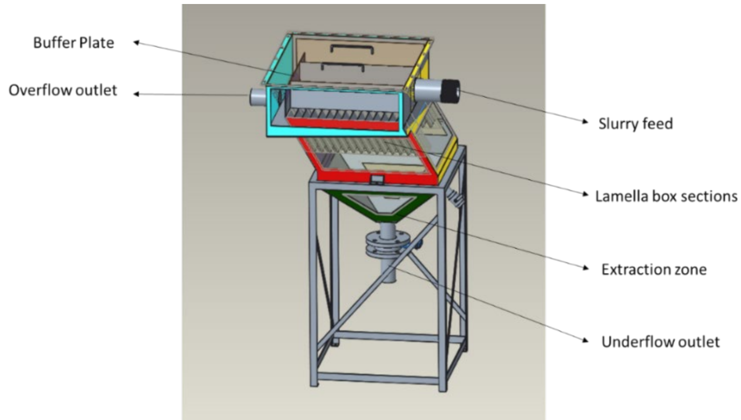

Figure 11. Lamella clarifier Design Development on Creo 4.0.

However, for the purpose of this paper the main focus will be directed to the design elements of the Lamella clarifier. Figure 12 depicts the layout of the Dewatering Bin (Lamella Clarifier).

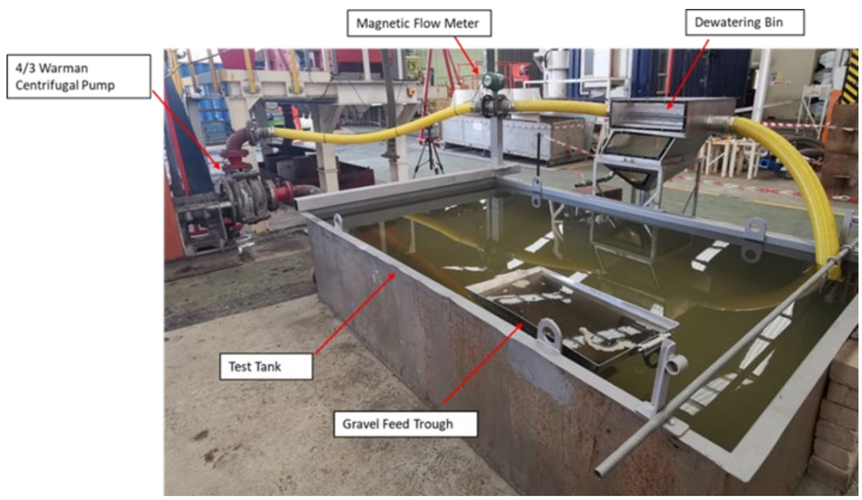

Figure 12. Layout of Lamella Clarifier Test Rig and Pump. [Curtesy of De Beers Marine Test Facility].

6. Conclusion

The results, theories and techniques used, can be extended into other studies of driven Structural optimization. The simulations and numerical results successfully showed the level of influence of the parameters investigated as well as effectiveness of FEM through ANSYS. By the end of the study, the reader should have a clear understanding of applying and testing complex systems through FEM.

7.Reference

E., 2006. Design of steel structures. In: *Supplementary rules for stainless steels..* s.l.:CEN, pp. Part 1-4.
Abaqus, 2007. Theory Manual. In: *Dassault Systems.* s.l.:s.n., p. Version 6.11.
Anon., 1967. *Manual of Steel Construction, Sixth Edition.* s.l.:American Institute of Steel Construction.
Anon., 1997. Eurocode 1. In: *Basis of structural design and action on structures, Silos and tanks.* s.l.:University of Belgrade,, p. Part 4.
Anon., 1997. *Silos and tanks.* Belgrade: University of Belgrade, Institute form Materials.
Anon., 2009. Eurocode 1. In: *Action on structures. Faculty of Civil Engineering.* Belgrade: University of Belgrade.

Blodgett, W., 1975. *Design of Welded Structures,* Cleveland: Lincoln Arc Welding Foundation.
BS., 2000. Design and calculation for single skin rectangular tanks. In: *Welded static non-pressurized thermoplastic tanks.* s.l.:CEN, p. Part 3.
D.M. Hunter, S. I. K. G., 2019. Size seperation. *The role of viscosity in the density fraction od particles in a laboratory-scale Reflux Classifier,* Volume 129, pp. 188-196.
G.Raubenheimer, 2019. *Drainage Fundamental Test Summary Report,* Cape Town: De Beers Marine.
JUS.MZ, 1981. *Jugoslovenski standard,,* Volume 3. 054.
Marine, D. B., n.d. [Online]
Available at: https://www.debeersgroup.com/the-group/about-debeers-group/mines/namibia/offshore
[Accessed 9 2 2020].
Maqina P, Kallon D.V.V., Tekweme F., Mutyavavire R. Analysis of a rectangular actiflo under hydrostatic pressure via fea. *Proceedings of the International Conference on Industrial Engineering and Operations Management. 2*020. 59. Pp 308 – 315.
Maqina P, Kallon D.V.V. Investigating the optimal stiffener locations of an actiflo clarifier under hydrostatic pressure. *Proceedings of the International Conference on Industrial Engineering and Operations Management. 2*020. 59. Pp 316 – 323.
D.V.V. Kallon, P. Maqina, P. Pilley, K.N. Baloyi, M.D. Ledwaba. 2020. Effect of Loading on Stiffener Configuration of an Actiflo Clarifier. *Procedia CIRP Vol 91.* 2020. Pp 776 – 780.
Miroslav T. Bešević, N. M. D. K. A. P. &. R. C., 2015. DIMENSIONING STEEL STRUCTURE OF RECTANGULAR TANK ACCORDING TO THE EUROCODE. *JOURNAL OF FACULTY OF CIVIL ENGINEERING,* 1(1), p. 22.
Part, E. 3. –. D. o. s. s. –., 2007. Plated structures subject to out of plane loading.. In: *Eurocode 3 – Design of steel structures.* Europe: CEN, pp. Part 1-7.
Pietersen, K., 2013. *ELUTRIATOR CONCEPTS INPUT BY PATERSON & COOKE FOR ARDC FEASIBILITY STUDY,* Cape Town: Paterson & Cooke.
Qiu, Z., 2017. *Investigation of Hydro-Mechanical Particle Flow through Horizontal Orifices,* Cape Town: University of Cape Town.
Richardson, k., 2007. A Perspective of Marine Mining within De Beers. *Journal of the Southern African Institute of Mining and Metallurgy,* 6(107), pp. 393-402.
Richardson, K., 2013. Crawling for Diamonds.
Siedd, K., 2017. *In depths of Atlantic, a quest for diamonds,* Washington: De Beers .
Wajtaszak, I., 1936. Stress and Deflection of Rectangular Plates. *Journal of Applied Mechanics.*