Analysis of a Rectangular Actiflo Clarifier under Hydrostatic Pressure via FEA

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Abstract

As the South African population grows, so too is the demand for clean water. There are numerous methods that have been developed over the years for cleaning water. Water purification technologies at Veolia Water Technologies, in Johannesburg, South Africa, is focused on increasing the quality of purifying water systems. However, challenges of building bigger clarifying systems to accommodate for demand is key. In this paper, a structural control system on an existing clarifier is developed and tested in Ansys. This led to the identification of the number of stiffeners needed to support a 4m high rectangular tank, however, the number of stiffeners required for a tank of much larger size is still unknown. Various parameters such as fatigue failure, design variables, as well as the different stiffener positions and sections used to determine the local bucking points of the rectangular structure is tested in the FEA environment using Ansys. This allowed for the examination of the Actiflo's behaviour using several stiffener configurations while simultaneously reducing the thickness of the structure in order to reduce costs. The effects of loads on deflections and stresses on the Actiflo are found to be pronounced around stiffener locations and local buckling points. Building on this a new model of a much larger Actiflo Clarifier is being proposed in this paper.

Keywords

Actiflo, Stiffener, Buckling, Fatigue Failure, Hydrostatic forces, FEM, ANSYS

I. Introduction

An Actiflo is a settling tank built with mechanical means for continuous removal of solids being deposited by sedimentation. The Actiflo was designed by Veolia Wastewater Technologists, with an aim of removing suspended solids and particulate matter. This clarification technology is used in the treatment of some industrial effluent plants. Clarifiers (Actiflo) work on the principle of gravitational settling, where the settled solids sink to the bottom of the base for collection. Almost all clarifier tanks have a circular or rectangular design; they work by permitting the heavier and larger particles from raw river water. The treatment processes feed water before it can be used for public consumption, which is based on the removal level of impurities to comply with various guidelines. The extent of treatment depends on the quality of the feed water and the desired quality of the treated water. The purpose of this paper is to describe numerous methods used for designing a rectangular tank, which will meet the design requirements of the Actiflo. Due to the broad scope of the investigation, other symbols were selected to confirm to other engineering disciplines, the distinctions are made clear in the text. Table 1 represents the quantities of known dimensions. To avoid inconsistency, the SI unit convention was utilised. If no dimension is indicated, the symbol represents a dimensionless number.

Table 1: *Symbols Description*

Symbol	Description	Symbol	Description
α	Dimensionless numerical factor (Appendix 1)	R_b	Bottom edge reaction (N/m)
β	Dimensionless numerical factor (Appendix 1)	R_h	Intermediate horizontal stiffener reaction (N/m)
t	Plate thickness (mm)	R_t	Top edge reaction (N/m)
σ	Stress (MPa)	d_{max}	Maximum deflection (mm)
Z	Elastic modulus (cm^3)	h	Height of tank (m)
I	Moment of inertia (cm^4)	I_{req}	Required moment of inertia (m^4)
d	Deflection (mm)	v	velocity (m/s)
ρ	The density of water (kg/m^3)	A	The cross-sectional area of the pipe (m^2)
P	Pressure Fluid (kPa)	Q	Flow Rate (m^3/h)
g	Acceleration due to gravity, (m/s^2)	V	Volume (m^3)

2. Review of Actiflo Design Requirement

2.1 Material Selection

The material used for the tank is mild steel, properties of the steel material as in Table 2.

Table 2: *Mechanical properties of mild steel*

Description	Property
Mass Density (kg/m^3)	7850
Young’s Modulus (GPa)	206
Poisson’s Ratio	0.3
Yield Stress (MPa)	318

Rupture Stress (MPa)	335
Strength Coefficient	880

2.2 Design Scope

Rectangular storage tanks are usually designed in accordance with the following design criteria;

- Rectangular in shape
- Non pressurized storage
- The tank wall is subjected to hydrostatic head only (i.e. uniformly increasing load from top to bottom and normal to its plane)
- No external pressure
- Design temperature is at room temperature 23°C
- Corrosion allowance to be included in design, if required.

2.3 Plate Deflection Theory

The design of the rectangular storage tank is based on the stress and deformation of the flat rectangular plate under different case loading and stiffeners used. The deformation of the Actiflo wall plate largely depends on its thickness as compared to other dimensions. The Plate theory is usually distinguished into three different categories (Wajtaszak, 1936)

- Thin plates with small deflection
- Thin plates with large deflections
- Thick plates

2.3.1 Thin Plates With Small Deflection

In this approach the author (Wajtaszak, 1936) attempts to include the deflection of a small plate in comparison with its thickness, a satisfactory approximate theory of bending of the plate by lateral loads can be developed by making the following assumptions:

- There is no deformation in the middle plane of the plate. This is often (Guivarch, 2006) called the neutral plane.
- Points of the plate lying initially in a normal-to-the-middle plane of the plate remains in that position after bending of the plane. The effect of shear forces on the deflection of the thin plates is considered negligible.
- The normal stress in the direction transverse to the plate can be disregarded.

For a given set of boundary conditions, the stresses at any point of the plate can be calculated. For rectangular plate analysis, these equations are well explained in plate theory books (Guivarch, 2006).

2.3.2 Thin Plates With Large Deflection

When the deflection becomes larger than one-half of the thickness, there is strain in the middle plane. The stress found in the middle plane cannot be ignored. This stress is called the diaphragm stress of the direct stress (Iremonger M, 1982).

2.3.3 Thick Plates

Figure 1 indicates how the Thick plate theory is applied when thin plates becomes unreliable in the case of plates of considerable thickness (Beghini M, 2006).

The tank wall is subjected to a uniformly increasing load which varies from top to bottom. Hydrostatic pressure can be expressed as follows;

$$P = \gamma h \qquad (1)$$

For conservative design, it is to analyze the longest side wall of the tank, having the greatest span between supports. The Actiflo maximum bending stress and deflection (Chen X, 2007) on the wall can be determined by applying flat plate formulas with the loading and edge conditions aforementioned;

Maximum stress and deflection are given by equation 2 and 3;

$$\sigma_{max} = \beta P b^2 / t^2 \qquad (2)$$

$$d_{max} = \alpha P b^2 / t^2 \qquad (3)$$

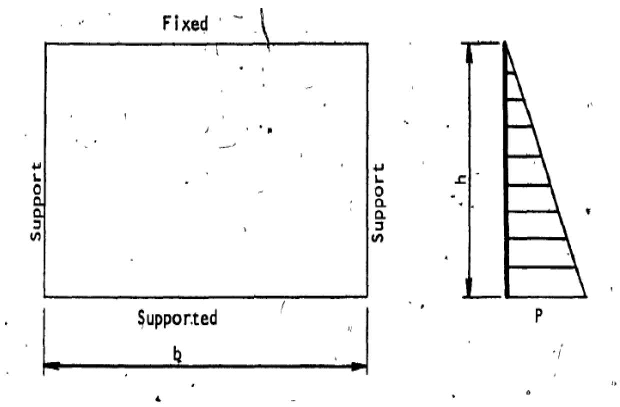

Figure 1: Wall panel without stiffeners

2.3 Design of Tank Side Walls with Top Edge Stiffeners

In the approach the author, uses the plate thickness method as determined in the previous section, his approach is, if the plate deflection is too large and exceeds one half of its thickness, a top edge stiffener should be added. This method suggests analyzing the tanks wall as a simply supported beam (JC, 1992). The minimum wall thickness ad maximum deflection with appropriate values of α and β from the graph attached in appendix 1. Figure 2 illustrates the top edge stiffener addition.

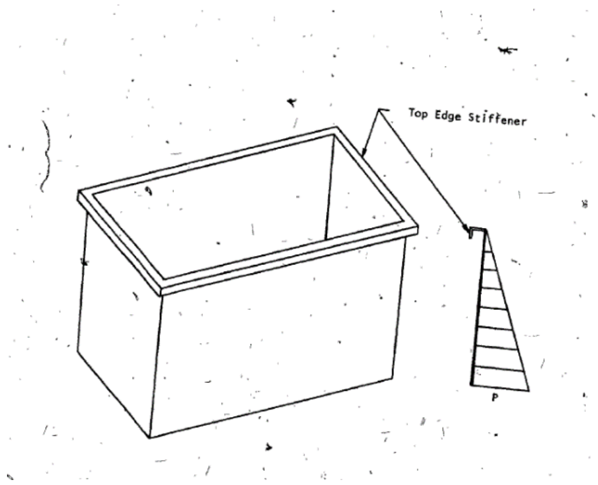

Figure 2: Tank with top-edge stiffener (Wajtaszak, 1936)

The top and bottom reaction can be expressed in equation 4 and 5;

$$R_t = Ph/6 \tag{4}$$

$$R_b = Ph/3 \tag{5}$$

The top edge stiffener is subjected to the uniformly distributed load R_t, while the maximum deflection of the beam for this load is given by;

$$d_{max} = {}^{R_t b^4}\!/_{384\ EI} \tag{6}$$

The maximum deflection of the panel is limited to one half of the plate thickness, we have

$${}^{t_a}\!/_2 = d_{max} \tag{7}$$

By rearranging equation 8 the size of the top stiffener can be determined by its moment of inertia;

$$I_{req} = R_t b^4/192Et_a \tag{8}$$

For economical design, a rigid frame with corner moment connections should be used rather than simply support beams. The stiffeners can be namely analyzed as rigid frames.

2.4 Design of Tank Side Walls with Horizontal Stiffeners

The Actiflo plate thickness can be reduced by adding stiffeners in a vertical or horizontal position. The addition of stiffeners will increase the rigidity of the tank wall by increasing the moment of inertia of the combined section. For a conservative design, wall pa. This is the first stiffener configuration, which consist of 75 x 75mm equal leg angle iron. It contains 4 rows of stiffeners that are placed on critical locations of the basin. The stiffeners run around the outside of the basin, reinforcing the walls of the basin in order to withstand the outward pushing of the fluids contained inside the basin. Below are some project views of the configuration (Kallon et al, 2020).
For this configuration, an equal legged angled iron was selected as the stiffener profile. The equal leg angled iron was selected because it provides a much better welding surface area than a flat bar, hence providing a stronger

joint. In addition, it has a higher moment of inertia than a flat bar, which helps resist the bending stresses exerted by the fluid. Concept 1: Angle Iron (75 X 75 Mm) Stiffener Configuration is depicted in Figure 3.

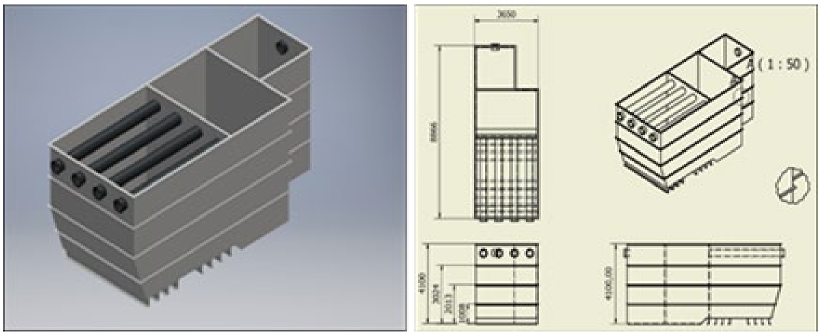

Figure 3: Concept 1: – Angle Iron (75 x 75 mm) stiffener configuration

Concept 2: Parallel Flange (200 X 75 Mm) Stiffener Configuration is shown in Figure 4. The second stiffener configuration consist of 200 x75 mm parallel-flanged channels and is shown in Figure 4. This design consists of two longitudinal channels and two transverse channels that connect to each other. The Longitudinal channels are welded on the outside walls, one at the top and another in the middle. Below are some projected views of the design (Kallon et al, 2020).

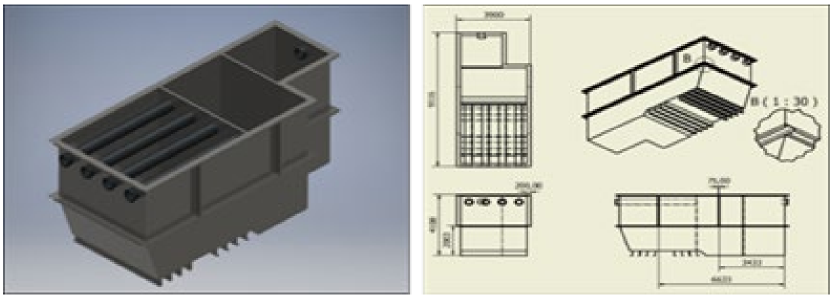

Figure 4: Concept 2: Parallel flange (200 x 75 mm) stiffener configuration

The use of a stiffener profile with a higher moment of inertia will increase the resistance to deflections. In addition, connecting the Transverse and Longitudinal stiffeners increases the strength of the stiffener configuration. The parallel-flanged channel, just like the equal leg angled-iron, provides a large welding surface area as well as area of contact – this allows the channel to withstand higher stresses.

Concept 3: Longitudinal and Transverse Parallel Flanges (200 X 75 Mm) Stiffener Configuration. This third concept is shown in Figure 5.

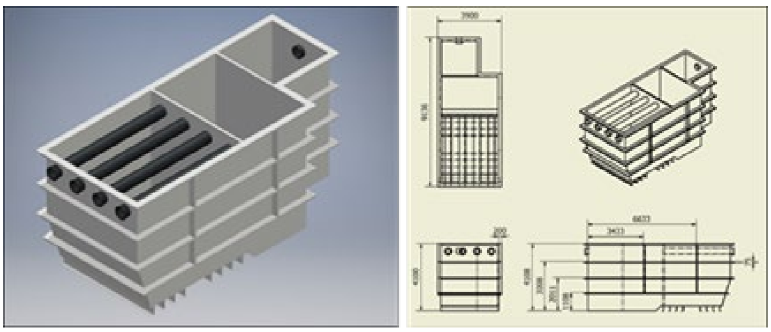

Figure 5: Concept 3: Longitudinal and transverse parallel flanges (200 x 75 mm) stiffener configuration

The concept was developed using the original basin without stiffeners. Pressure was applied on all the inside walls and then simulated to reveal critical points within the structure. After the critical points where identified, corresponding stiffeners were applied in those areas to reinforce the structure. For the development of this configuration, the aim was to provide a rigid structure using the least number of stiffeners without compromising the structural integrity.

3. Simulation Results

Figure 6 illustrates the concept simulations done on ANSYS. With the need to improve on the current design of the Actiflo in terms of its stiffener configuration, where it was overdesigned, a proposal given to draw up 3 different stiffener configurations and gauge them against one another under the same constraints and conditions. Concept 1 deflected 150mm from its initial state, concept 2 deflected by ±100mm while concept 3 only deflected by 18mm. The deflection areas reduced in size as well. The introduction of the vertical columns had a vital role to play. The structure is now more rigid with less material used and less costly.

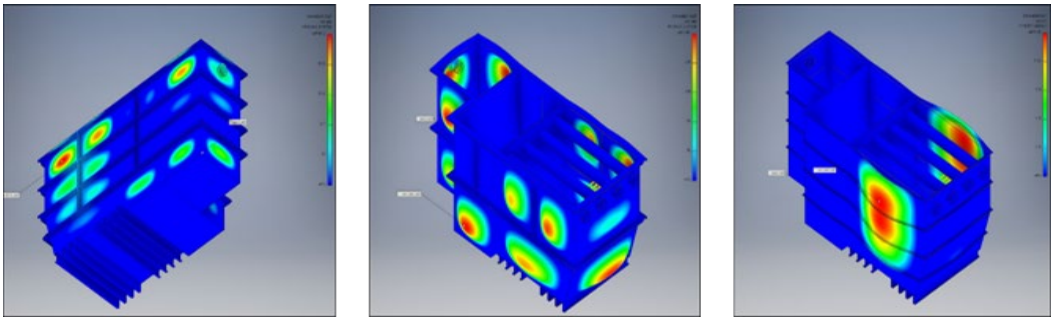

Figure 3: Simulation results for concepts 1, 2 and 3 (left to right).

4. Conclusion

The aim of this project was to effectively investigate methods of optimizing the Actiflos stiffeners. This could not be done without thorough research of how parameters such as the Actiflo wall thickness, stiffener configurations used, optimal stiffener locations as well as identifying local buckling points. The Actiflo was designed in accordance to the volume required per chamber which covers the most important aspect of an Actiflo operation however no structural analysis was done to investigate the number of stiffeners required to resist the internal hydrostatic forces, the type of stiffeners to be used and ideal locations to place stiffeners. This structure was therefore classified as statically indeterminate beam with a VDL (varying distributed load).

The simulation power tool is found compatible for this investigation as it can effectively solve complex problems and any risks by identifying failures prematurely before they occur, this may also cut any manufacturing costs. A second benefit to this application is it increases robustness and reliability of a structure. A baseline model was created without use of stiffeners, to determine the threshold of the plate's deflection. Upon review of the two main factors namely, costing and simulation of the configuration. Configuration 1 is the cheapest but proves the least effective. Configuration 2 is also cheap option as well but does not maintain the structural shape. Deformation is still apparent. Finally, Configuration 3 proves the best option as the saving is drastic as well as the rigidity in comparison to the other two configurations (Maqina, 2021). 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.

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