Investigating the Optimal Stiffener Locations of an Actiflo Clarifier under Hydrostatic Pressure

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Abstract

An Actiflo Clarifier is a water purification system designed by Veolia Water Solutions in Johannesburg, South Africa, to handle 10 ML of water a day. The tank is relatively large and made using thin plates reinforcement with stiffeners. For the current design, it is found that the plate thickness can be reduced considerable by adding horizontal or vertical stiffeners or a combination of both. The addition of stiffeners will increase the rigidity of the tank wall by increasing the moment of inertia of the combined section. For the design of tank walls with intermediate horizontal stiffeners, there is no simple formula available. This research is focused on investigating the optimal stiffeners locations, in attempt to reduce costs without compromising on the structural integrity. Specifically the investigation focused on investigating the optimal stiffener locations using the 200 x 75mm Parallel Flange. The robustness was tested by developing a conceptual design on AutoCAD inventor and conducting simulations of varying distributed load on a beam (i.e the Actiflo wall) with multiple supports (Stiffeners)

Keywords

Actiflo, Stiffener, AutoCAD, Moment of Inertia, Hydrostatic forces, Parallel Flange, 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)	M_{MAX}	Maximum bending moment (mm)
I	Moment of inertia (cm^4)	h	Height of tank (m)
d	Deflection (mm)	I_{req}	Required moment of inertia (m^4)
ρ	The density of water (kg/m^3)	v	velocity (m/s)
P	Pressure Fluid (kPa)	A	The cross-sectional area of the pipe (m^2)
g	Acceleration due to gravity, (m/s^2)	Q	Flow Rate (m^3/h)
x,y	Deflection, Height (mm)	V	Volume (m^3)

2. Theoretical Framework

Pressure is defined as a normal force exerted by a fluid per unit area – these forces are called Hydrostatic Forces. The atmosphere is also perceived as a fluid, exerting a normal force to the surface of all matter enveloped by it – this is called Atmospheric Pressure. An object submerged in a fluid experiences normal forces exerted by pressure in all its surfaces, hence it is known that pressure is a crashing force that acts in all directions of a point in the fluid (J.M, 2014). The pressure acting on a point located in a fluid is the same in all direction; hence water poured in a glass finds static equilibrium.

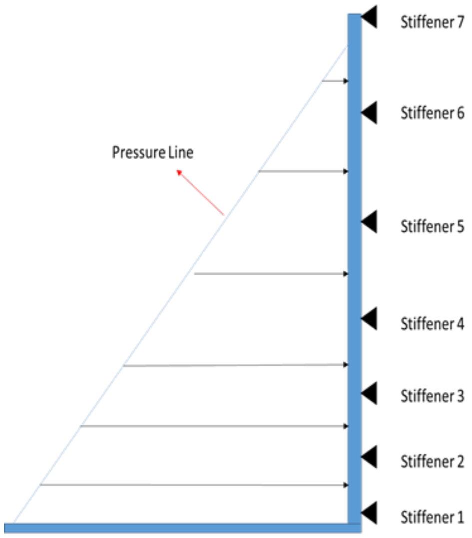

Figure 1: Stiffener locations.

Due to gravity, pressure varies along the vertical within a fluid (variation of Atmospheric Pressure with height), however, it does not vary along the horizontal. This implies that the Atmospheric pressure at any location from sea level is the same. Figure 1 shows the variation of pressure exerted by a fluid on the flat surface walls of a container. The pressure P , at any point within a fluid for the setup shown in Figure 1, is calculated by:

$$P = \rho g h \tag{1}$$

Where ρ is the fluid Density, g is the gravitational acceleration constant and h is the vertical depth from the surface of the fluid.

3. Review of Actiflo Design Requirement

3.1 Objectives

It was anticipated that the analysis would enhance ones understanding of the physical parameters influencing the nature of the applied stiffeners. Recognising the gap of knowledge, the methodology used to achieve these objectives were as follows;

- Investigate how the locations of the stiffener influence bending of the wall.
- Design and develop a conceptual design and conduct simulations on the stiffeners placed in different locations.

3.2 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

3.3 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.

3.4 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

4. Design Approach

For a conservative design, the wall panels may be analyzed as straight beams by considering strips of unit width of the plate under hydrostatic load (Raymond, 1975). The stiffeners are located, using the original design structure as reference. Figure 2 is a typical illustration of the straight beam concept origination of applying bending and moments (Kallon et al, 2020).

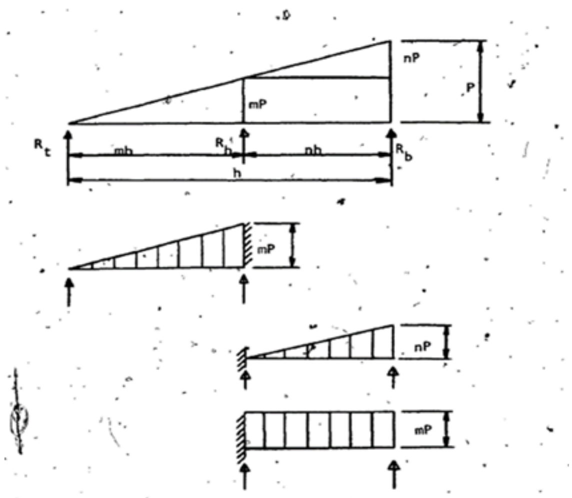

Figure 2: Loading Diagram of Horizontal Stiffeners *(Raymond, 1975)*

The moment R_t is a top edge reaction:

$$\sum M_{Rb} = 0$$

Hence:

$$R_t = (2 \times 2) \times \left(2 + \frac{1}{3} \times 2\right) + (6 \times 2 \times 1)$$

$$= 5.7\ MN$$

From figure 4, the height at *np* is given as:

$$\frac{12}{6} = \frac{np}{(x-2)}$$

$$np = 2(x-2)$$

From figure 4, the height at *mp* is given as:

$$\frac{12}{6} = \frac{mp}{x}$$

$$mp = 2x$$

Hence:

$$EI'' = (0.5 \times b \times h) \times 0.5x + \times\, 0.5(x-2)np \times (x-2) \times \frac{1}{3} + 5.7x$$

$$= -(0.5x \times 2x \times 0.333x) + \times\, (x-2)(x-2) \times (x-2) \times \frac{1}{3} + 5.7x$$

$$= -\frac{1}{3}x^3 + \frac{1}{3}(x-2)^3 + 5.7x$$

$$EIy' = -\tfrac{1}{12}x^4 + \tfrac{1}{12}(x-2)^4 + \tfrac{5.7}{2}x^2 + A \qquad (1)$$

$$EIy = -\frac{1}{60}x^5 + \frac{1}{60}(x-2)^5 + \frac{5.7}{6}x^3 + Ax + B \qquad (2)$$

Apply boundary conditions

$I_y = 0$ at $x = 0$ $y = 0$, $x = 4$

$B = 0$

$$0 = -\frac{1}{60}4^5 + \frac{1}{60}(4-2)^5 + \frac{5.7}{6}4^3 + A4 + 0$$

$$A = -19.6$$

Deflection on each stiffener is then given as:

$$y = \frac{1}{10\times10^3}\left(-\frac{1}{60}x^5 + \frac{1}{60}(x-2)^5 + \frac{5.7}{6}x^3 + Ax + B\right) \quad (3)$$

Equation (3) was derived to serve as a standard equation to obtaining deflections at different locations.

4.1 Calculated Results

Using findings from Eqn. (3). Table 3 summarizes findings. It is seen that the deflection reduced the higher the stiffener was positioned (1 being the stiffener at the top and 6 located at the bottom).

Table 3: Calculated Deflections

Stiffeners	Distance (m)	Deflection (mm)
1	4	-3.173
2	3.333	-3.494
3	2.667	-3.489
4	2	-3.093
5	1.333	-2.315
6	0.0667	-1.238

5. Simulation Results

Comparison of the results obtained from ANSYS and the obtained calculations show important differences. Bearing in mind that the numerical model in ANSYS is a geometrically identical, spatial and a structural model, these variations square measure expected. That is, it's assumed that these differences square measure a consequence of a larger displacement of discovered cross sections within the spatial model, not like the model in ANSYS within which the supporting parts square measure hard wired. These displacements caused an additional favorable distribution of stresses and thus less intensity of a most of stresses. Displacements of all points of construction structure. Figure 3 illustrates the simulation results (Kallon et al, 2020).

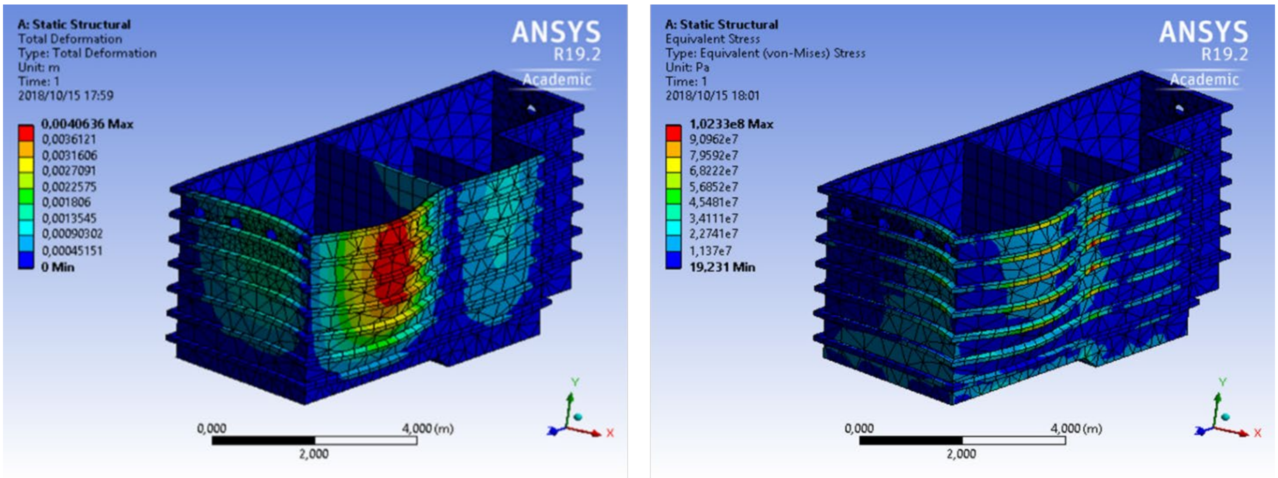

Figure 3: Deformation **(Left)** and Stress **(Right)** simulations

Table 4 summarizes the results obtained from the calculations and simulations.

Table 4: Results of Deflection (Simulations vs Calculations)

Stiffeners	Simulation (Deflection) mm	Calculations (Deflection) mm
1	3.612	3.173
2	3.16	3.494
3	2.709	3.489
4	2.257	3.093
5	1.806	2.315
6	1.355	1.238

6. Conclusion

The aim of this project was to effectively investigate methods of obtaining optimal stiffener locations of the Actiflo Clarifier. 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 (Maqina, 2021). 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).

Therefore an effective approach to solve such a problem was to make substantiated assumptions and limit the number of variables analyzed. The calculated results had 1% error due to human error, the simulations are more accurate, and however for more accurate results it is essential to provide the software with more inputs (Maqina, 2021). 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.

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