Design of A Water Transmission and Storage System for Sustainable Reuse of Wastewater Within A University Community

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Design of A Water Transmission and Storage System for Sustainable Reuse of Wastewater Within A University Community

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Abstract.
This research is aimed at designing a wastewater transmission system from storage to treatment and, eventually to storage in an elevated steel tank. The work includes the design of a 750,000-litre capacity underground concrete reservoir and a 125,000-litre capacity elevated steel tank. For the transmission design, field activities involved the use of Magellan eXplorist 350H North America G.P.S. and Google Earth to determine coordinates of different points in a selected private university campus, southwest Nigeria as well as the lowest and the highest elevation points. The highest point in the university was located at the postgraduate hall of residence, and the lowest point was located at the schools constructed wetland within the campus. WaterCAD was used to design the flow path network, while the water storage design software used for this project are StaadPro.V8i, Orion 18, and AutoCAD 2013. StaadPro.V8i was employed for the analysis and design of the underground storage facility and the elevated steel tank, while the Orion software was utilized for concrete design and detailing of the underground storage facility. The results from all the design applications were exported to the AutoCAD environment for editing and proper scaling. This study has revealed that the construction of a 750 m³ underground storage tank would be highly efficient and economical when compared to a smaller tank. Also, both the hydrostatic forces acting internally within the underground tank and active and passive pressure acting externally toward the wall has shown to possess zero impact on the shear wall.

Keyword: Wastewater, reuse, design, hydraulic

1. Introduction

As the global water demand continues to rise, the strain on freshwater sources is also on the rise [1], [2]. According to the US EPA, [3], water is a limited resource, and as such, the stresses imposed on aquifers and other groundwater sources should be reduced or well managed. Pressure on water resources come from increased population, rapid urbanization, as well as industrial and economic development [4]. Groundwater resources are especially being exploited by more than half of the world's population [1].

Water is classified as a waste if it no longer serves the purpose for which it is required. Wastewater can be defined as any water that is not needed again, as no further advantage can be gotten from it [5]. Wastewater can also be classified as water that contains solids that exist as settled particles or distributed colloids [6]. Wastewater reuse, also known as water reclamation, is the use of wastewater from one application for another application [3]. Wastewater reuse is an essential method of conserving freshwater resources [7]. The reuse of wastewater has been in practice for a very long time, especially in parts of the world that suffer from water scarcity and drought [1]. In India, for instance, studies have shown that wastewater has been a crucial part of irrigation as it is used to irrigate over 70,000 acres of land for the cultivation of certain crops and flora [8], [9]. The reuse of untreated wastewater for landscape applications, dust control, groundwater recharge, and irrigation in agriculture

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has been practiced in some countries for many years. This comes with the added benefit of diverting human waste away from urban settlements [10]. Wastewater reuse is essential for water conservation because of how it allows water to stay within Earth being preserved for impending utilization, while likewise attaining the necessary water quality guidelines. Criteria for the quality of water can affect public acceptance, development, and economic viability of the reuse of wastewater and related projects [11], [12].

For this reason, it is impractical and less economical to utilize water resources without a reuse consideration. Therefore, it is crucial to determine sustainable ways to recycle and reuse wastewater [5]. Studies have shown that about 30% to 50% of domestic wastewater can be reused if treated [13]. However, before wastewater can be reused, it must fulfill some elementary requirements like a comprehensive collection technique and adequate operation of wastewater treatment flairs (collection, treatment, and reuse). The reuse and recycling of wastewater are beneficial in reducing environmental pollution, water resource management, and sustainability and cost reduction. Therefore, wastewater reutilization is deemed a sustainable and less cost-intensive alternative of water supply [1].

Wastewater recycling has given researchers and developers an insight into the treatment of wastewater and technological advancements that can lead to the development of water quality standards [14]. An example of technological progress over the years is the use of hydraulic structures such as underground tanks and overhead tanks for the storage of reusable water wastewater resources. For the determination of the possibility of any wastewater reuse project, the design and development of a wastewater reuse project have to be in place [5]. This study focuses on designing a water transmission and storage mechanism for wastewater reuse in Covenant University.

1.1 Background

Covenant University (C.U.), located in the premises of the headquarters of Living Faith Church (Canaan land, Ota, Nigeria), has a population of about ten thousand people living on campus. Over a million liters of water are pumped daily to serve various needs in this community (approximately 100 liters/head/day). Over 800,000 liters of wastewater are generated daily, making about 80% of the freshwater pumped for use [15]. The wastewater generated from Canaanland also flows through the same channel for treatment and discharge, making a total of about a million liters of wastewater generated by the whole community every day. The wastewater generated flows through a channel into a wetland where it is treated before being discharged into the river. The treatment of wastewater is necessary as this contaminated water eventually goes back to water bodies and groundwater, thereby reducing the quality of water already present in them and causing pollution. The treated wastewater can be useful for various purposes, such as Water Closet (W.C.) flushers, irrigation of plants, sprinklers in the dry season, aesthetics (fountains, and human-made ponds/lakes) and for washing cars. Figure 1 displays the aerial perspective of the campus with the treatment facility.

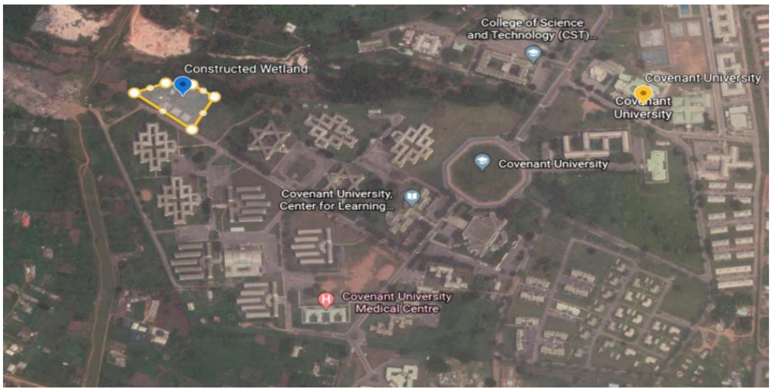

Figure 1: Aerial perspective of the University campus showing the water treatment facility

1.2 Elevated Water Tanks

Elevated water tanks are large water retaining facilities constructed to hold in the water supply at a height to provide sufficient pressure head for the water to flow under gravity. Overhead liquid storage tanks are the most effective type of storage facility used for local, and sometimes, industrial uses. Depending on the site at which the water tank is located, it can be suspended, underground, or on-ground water tanks. Concrete or structural steel could be adopted for the construction of tanks for various purposes and applications. The utilization of steel as materials for tank fabrication is common in the railway industry for overhead storage for water [16]. Several studies have been carried out on the numerous perspectives of the seismic behavior and schematic of suspended water tanks. [17] examined the dynamic behavior of elevated water tanks and liquid structure interaction in their study. A high water tank is one of the essential lifeline structures, especially in regions that are prone to earthquakes. Suspended water tanks form a fundamental aspect of the water supply system in cities and rural areas. The construction of these tanks has huge mass concerted on the top region of the slender framework; thus, these frameworks are exposed to lateral forces during earthquakes. Suspended water tanks designed and analyzed inadequately have experienced wide-ranging destruction in past times. According to [18], the failure of tank structures during tectonic movements in 1960 and 1964 gave way for investigations to be carried out on the seismic analysis of water storage tanks covering the sloshing effects of liquid, the flexibility of the container wall, energy absorbent capacity, redundancy and versatility of these tanks. These tanks must be designed to withstand natural disasters like earthquakes and remain operative even after the supply of drinking water and firefighting purposes [19]. Several municipalities have water supply systems that are dependent on elevated tanks for storage. Some cities have principal supply schemes being developed by the privatized supply system of estates and institutions that have already integrated into their system.

2. Methodology

This study was focused on designing a concrete reservoir that can store 750,000 liters of treated wastewater and an overhead steel tank that can store 125,000 liters. This study also develops a water transmission system that conveys water from the reservoir to the overhead tank so that wastewater can be treated, stored, and reused hence reducing the amount of water being pumped daily. The pipe grid of the underground tank to the overhead tank has also been identified. Structural engineering software was used to design the water storage facilities, while WaterCAD was used for the transmission system design.

2.1 Materials

The design work of this study is divided into two (2) significant aspects:

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i. Transmission system: the tool used for the ground operations is the 350H model Magellan eXplorist North America G.P.S. (Global Positioning System) and application used include Google Earth and WaterCAD.
ii. Design of water storage structures: The applications adopted for this research include Orion 18, StaadPro.V8i SS5, and AutoCAD Version 2013.

The materials used for design and the amount of each can be found in Table 1.

Table 1: Summary of Materials and the Amounts Used

Material Summary			Tons
Underground Concrete tank	**Total Volume of Concrete**	254 m^3	
Steel Reinforcement	**Undergroud top & bottom slab reinforcement**	Y12	9.0434
	Base slab beams reinforcement	Y20	0.984
		Y25	0.4652
	Top slab beams reinforcement	Y10 links	0.4389
		Y16	0.5896
	Column/shear wall reinforcement	Y12	1.9278
		Y16	5.164
Total Steel Tonnage			11.5211

Elevated Steel Tank		
Steel Take off	**Length (m)**	**Weight (K.N.)**
ST UC203X203X46kg/m2	157.5	71.022
ST UA90X90X10kg/m2	751.77	98.754
ST UB254X146X43kg/m2	116	48.833
ST TUB80403.0	37.4	1.936
Total Weight		220.545

Reticulation System	
From Intake	
Pipe Diameter	300mm
Length of Pipes	29m
Material Type	Concrete Pipe
From Pump to hydrant	
Pipe Diameter	300mm
Pipe Length	53m
Material Type	Ductile Iron

From hydrant to last point	
Pipe Diameter	300mm
Pipe Length	1174m
Material Type	Iron (Highly-ductile)
Summary of Reticulation System	
Number of Pumps	2
Number of hydrants	2

2.2 Method

i. **Magellan eXplorist 350H North America G.P.S.:**
Magellan eXplorist 350H North America G.P.S. was utilized in this study to decide the directions (Longitudinal and Latitudinal) of different areas of focuses on the campus. The basic utilization was to decide the highest and lowest elevations within the university community, whereby the projected buried water tank and the steel tank is to be constructed and fabricated, respectively. Over ten coordinates where taken. The least elevation was determined utilizing the G.P.S. at the posterior end of the current ground-water wastewater facility beside a hall of residence, which was the main geographic point. Every of the height estimations taken was determined utilizing the path to the most elevated geographic point. Every coordinate point obtained was moved to the Google Earth software to achieve accurate length estimation, draw the vertical profile and, determine the heights.

ii. **Google Earth**
The Google Earth program was utilized to decide the coordinates' positions, heights' lengths, and vertical profiles. The coordinates obtained from the G.P.S. tool were entered using the "add path tool" of the software, respectively. This enables easy navigation within the campus using the program. The connection of the paths' beginning with the initial geographic coordinate point to the final, enabled the production of the leveling profile.

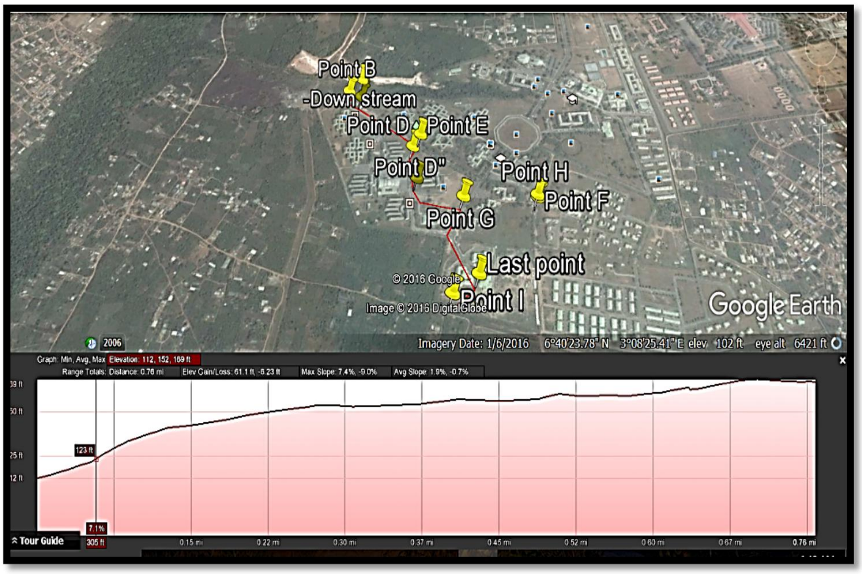

Figure 2: Aerial perspective, geographic coordinates, and vertical profile of Covenant University's transmission path.

iii. **WaterCAD**:
This is a program that allows engineering designers and officials to calculate and manage dispersal grids based on geographic information management. The pipe grid network from the posterior end to the suspended tank was designed using WaterCAD. The elevation and distance parameters obtained from the Google Earth software were entered into the WaterCAD modeling tool's database. Prior to analysis in the WaterCAD software, the resemblance was first exported to the Autodesk AutoCAD program for initial editing and configuration. The ensuing tools were employed while using the WaterCAD program: Pressure Reducing Valves (P.R.V.), Reservoir, Junction, Pump, Tank, Hydrant, and Pipes. The diameter and types of pipes used are listed below:

a) The utilized pipes to convey water from the tank to the Pumping station, and then from the Pumping station to junction classified (J-16) are manufactured from concrete and highly-ductile iron, respectively, and of diameter 30 cm.
b) The Hazen-Williams-C used is 110mm in diameter for the concrete pipe and 130 mm in diameter for highly-ductile iron.
c) All distinctive pipes categorized (J-16) from the junction to the remaining terminal classified (J-8) is 5 cm in radius for highly-ductile iron and 130 mm in diameter for Hazen-Williams C.

The need for water at every junction is assumed based on the number of inhabitants across the terminals. The pump classification kind used is the same old (three factors):

a. Shutoff: zero (float Length/minute), 3000 cm (Head)

b. layout: 3800 (float Length/minute), 2740 cm (Head)

c. maximum running: 7500 (go with the flow Length/minute), 2480 cm (Head).

The type of pump efficiency adopted is the Best-Efficiency-Point (B.E.P.) with a flow of 0 (L/min), B.E.P. efficiency of 100%, and motor efficiency of 100%. When results are computed and analysis run, the software alerts to any errors and indicates where the error occurred, with the opportunity for necessary adjustments.

iv. **STAAD.Pro V8i**:
This software was employed to create the structural modeling, analysis, and design of the concrete buried water tank and the steel elevated water tank. After modeling, the designation of properties (design steel section) was carried out, followed by the assigning of loads, analysis, and lastly, the design, carried out in line with BS 5950 (2000). Note that before the chose segments were picked, the arrangement of sections was determined via the trial-by-error approach. Yet, they fizzled in structure till a segmented meeting the design requirement was chosen and afterward prescribed to be utilized.

v. **Orion 18**:
Sequel to the completion of the STAAD.Pro. V8i Software analysis, Orion Version 18, was then adopted in producing the detailed drawings of the concrete buried storage tank. Using a column dimension of 15 cm x 15 cm, the modeling was repeated on Orion 18, the same as on the STAAD.Pro. V8i software, after which the materials were selected. The reason for the columns was to provide support for the suspended deck and also to withstand forces from imposed loads. Hidden beams were additionally taken into consideration at the top deck and the base deck, respectively, situated on the columns directly. The shaft dimensions intended for was 20 cm x 20 cm, and the top chunk with a thickness of 20 cm was thought of. A cantilevered sort of shear dividers with a heel length of 1000 mm and a distance across of 300 mm was utilized. Likewise, a base

section of 300mm, obliging a shrouded light emission 300 mm X 300 mm in other to settle the forced stacking following up on the base of the piece, was utilized. The heaps following up on the divider were thought about, after which the Finite Element technique for examination was utilized. The structure was designed utilizing BS code 8110, which generated detailings automatically.

vi. **AutoCAD 2013**:
In this research, AutoCAD 2013 was adopted for the final editing of the developed designs, resizing of drawings exported from all the computer applications employed for the various projects. It was mandatory and recommended to export the developed drawings from the other design software to AutoCAD for a more precise production.

3. Result and Discussion

The findings from this study are categorized into two sections; these sections include the Mesh System and Structural Hydraulic design.

3.1 Mesh System

The results obtained from the field investigations using the 350H Magellan-eXplorist North America G.P.S. are shown in Table 2. The values were inputted to show the path of flow from the posterior end to the topmost point. Results obtained from the use of WaterCAD based on the data imputed to the software are shown in Table 3, together with the synthesis of materials that most suitably balance the route of flow post-analysis. From the information, the table gives the method of function of every section whereby they all have distinct nodes for starting and stopping, velocity (m/s), pipe diameter (cm), and flow (m/s) respectively to enhance their method of operating efficiently.

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Table 2: G.P.S. results from field investigations indicating the elevations, distances, and, coordinates of various points within the campus.

S/N	POINT	COORDINATE	DISTANCE (m)	ELEVATION (m)
		6° 40’ 23.40″ N		
1	Downstream	3° 09’10.40″ E	0	34
		6° 40’21.30″ N		
2	B	3° 9’ 8.70″ E	83	41
		6° 40’ 20.30″ N		
3	C	3° 09’ 10.30″ E	57	43
		6° 40’ 14.50″ N		
4	D	3° 9’ 17.90″ E	294	48
		6° 40’ 12.83″ N		
5	E	3° 09’ 16.91″ E	4	48
		6° 40’ 6.30″ N		
6	D″	3° 9’ 22.40″ E	60	49
		6° 40’ 6.21″ N		
7	D″2	3° 09’ 22.70″ E	133	50
		6° 40’ 06.00″ N		
8	G	3° 9’ 22.70″ E	201	51
		6° 39’ 55.30″ N		
9	ELEVATED TANK	3° 09’ 27.83″ E	319	54
		6° 39’ 57.30″ N		
10	I	3° 09’ 24.00″ E	106	52
			TOTAL=1, 257m	

Table 3: Parameters for flow and selected transmission pipe materials

Node Label	Start Node	Stop Node	Diameter (mm)	Material	Hazen Williams C (L/min)	Flow (m/s)	Velocity Gradient (m/s)	Headloss Gradient (m/m)	Length
P-4	J-1	J-2	300	Ductile Iron	130	184	0.39	0.002	4
P-7	J-4	J-5	300	Ductile Iron	130	81	0.17	0	35
P-5	J-2	J-3	300	Ductile Iron	130	153	0.32	0.002	60
P-12	T-1	J-8	300	Ductile Iron	130	0	0	0	106
P-2	J-16	H-2	300	Ductile Iron	130	222	0.47	0.003	57
P-11	J-7	T-1	300	Ductile Iron	130	0	0	0	159
P-6	J-3	J-4	300	Ductile Iron	130	119	0.25	0.001	133
P-8	J-5	J-6	300	Ductile Iron	130	81	0.17	0	166
P-3	H-2	J-1	300	Ductile Iron	130	222	0.47	0.003	294
P-9	J-6	PRV-1	300	Ductile Iron	130	41	0.09	0	80
P-10	PRV-1	J-7	300	Ductile Iron	130	41	0.09	0	80
P-5	R-1	PMP-2	300	Concrete	130	222	0.02	0	29
P-6	PMP-2	J-16	300	Ductile Iron	130	222	0.02	0	54

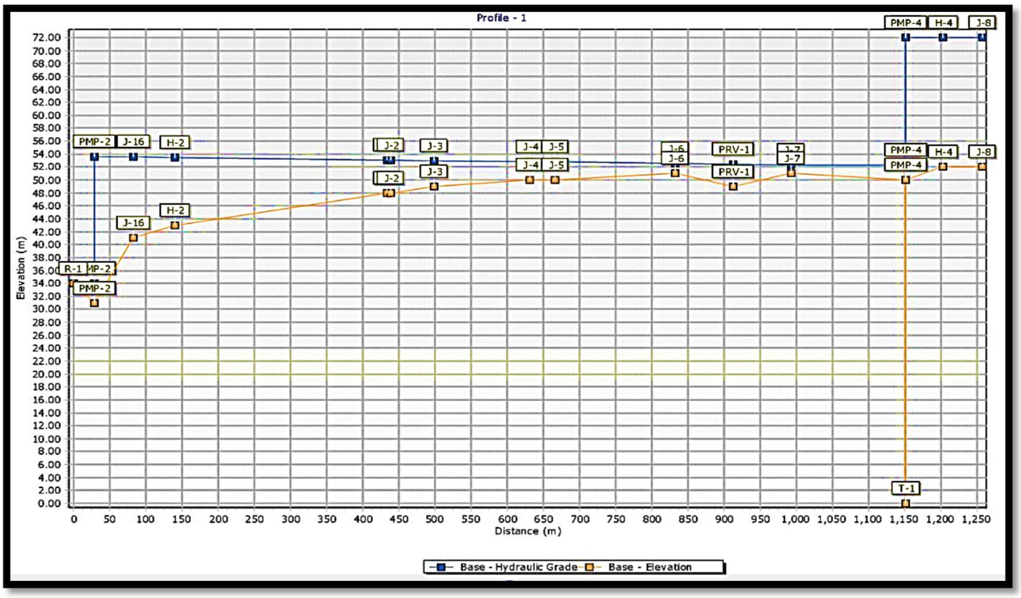

Figure 3: Graphs for the Base-Elevation and Base-Hydraulic Grade.

From Figure 3, the blue line represents the base-hydraulic grade graph. The base represents all the default data keyed in the computer software, whereas the summation of p/γ (the pressure head) and z (the elevation head) is known as the Hydraulic grade. From this chart, the Pump effectiveness delivers considerable potential energy (P.E), which creates a natural flow pathway of the water from the inlet to the storage point. The Base (m) – Elevation (m) chart are indicated with the yellow lines, which illustrates the numerous elevations, distances, and points entered into the computer program.

3.2 Hydraulic Structure

For the concrete buried water tank, the volume of water that it was designed to capture is 750, 000 liters. In this way, the absolute size of the buried concrete tank was inferred utilizing equation 1:

$$\frac{Total\,number\,of\,liters}{1000} = \frac{750000}{1000} = 750\text{m}^3. \qquad (1)$$

Consequently, the size of the concrete structure was (1500 cm x 1000 cm x 500m).

The model was drawn utilizing the additional beam and node tool on the application. In this manner, the properties to be utilized (concrete) were assigned to the model utilizing a thickness of 300mm for the wall and ground deck, and 20 cm depth was chosen for the top section. The loadings which were allocated are:

a. **Self-weight:** A load factor in kN/m² of 1.5 was adopted for the concrete structure.
b. **Dead Load:** A deadweight of 90 KN/m² was chosen. That is, the bulk density of soil multiplied by the depth of the wall
   $\gamma_s \times D =$ 18.5 x 5
   Dead load =90KN/m².
   There is a decrease in hydrostatic pressures at the peak points of the reservoir to zero as an increase in pressures are recorded. In contrast, the hydrostatic stress at the reservoir base is 90KN/m². This assumption was adopted for the externally acting soil pressures on the wall.
c. **Live load**: The active and passive pressures acting on the external soils to the wall, and the hydraulic stresses acting internally on the wall were determined. The live load was determined as the product of the bulk density of water and the wall height:
   $\gamma_s \times H$= 9.81KN/m² 10KN/m² = 10 x 5 = 50KN/m².
   There is a decrease in hydrostatic pressures at the peak points of the reservoir to zero as an increase in pressures are recorded. In the meantime, hydrostatic stress of 50KN/m² is obtained beneath the reservoir. This value was utilized for the water forces acting internally on the wall.

   Afterward, the assessment was performed, and after that, the design was performed using the BS code 8110.

For the suspended steel tank, the capacity of water that the suspended steel tank was designed to retain is 125,000 liters, determined as:

$$\frac{Total\,capacity}{1000} = \frac{125000}{1000} = 125\text{m}^3.$$

Therefore, the size of the suspended steel tank fabricated is 125m³ of dimension (500 cm X 500 cm X 500 cm) and the height of the stanchion is 17500 cm. The modeling was simulated via the add beam and node tools, and afterward, the section properties were designated as:

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a. UC (203 X 203 X 46) kg/ m^2, for stanchion.
b. The horizontal beams and brace used are U.A. (90X 90 X 10) kg/ m^2.
c. Sit of the reservoir beam utilized was (254 X 146 X 43) kg/ m^2.
d. The depth of the plate utilized for the reservoir is 1.5 cm.

Afterward, the loadings were allocated to each of the material after selection, and the weights considered include:

a. **Dead load**: 1.5kN/m^2 was used as the load factor for the steel structure.
b. **Live load**: the hydrostatic stress acting inwards to the wall of the reservoir is derived by multiplying the bulk density of water by the depth of the reservoir
   $\gamma_w \times D$ = 9.81KN/m^2 10KN/m^2 = 10 x 5 = 50KN/m^2.
   There is a decrease in hydrostatic pressures at the peak points of the reservoir to zero as an increase in pressures are recorded. In the meantime, the hydrostatic stress of 50KN/m^2 is obtained beneath the reservoir.
c. **Live load**: 0.6KN/m^2 was used as the live load imposed on the stanchion.
d. **Wind load**: adopting a wind speed of 55 m/sec from the base of the tank to the topmost part of the reservoir, the simulation was performed at all four possible wind directions, thus determining wind loads acting horizontally to the steel member.

Plate 1 displays the modeling of the buried water tank, as well as the internal columns and beams using all design requirements, stated previously. The steel tank modeling, as well as its principal major and minor stresses, can be seen in Plate 2.

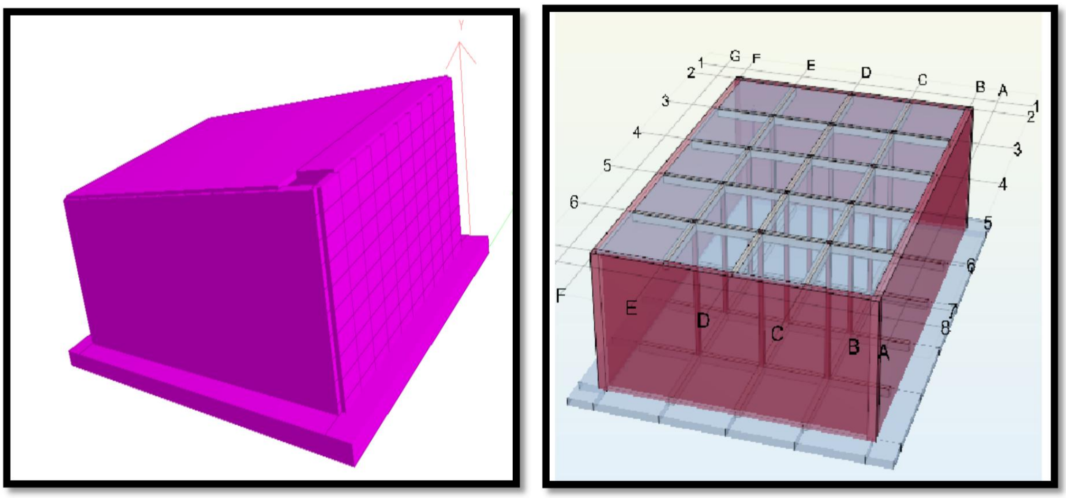

Figure 4: the 3-D perspective of buried water tank modeling with internally-embedded beams and columns

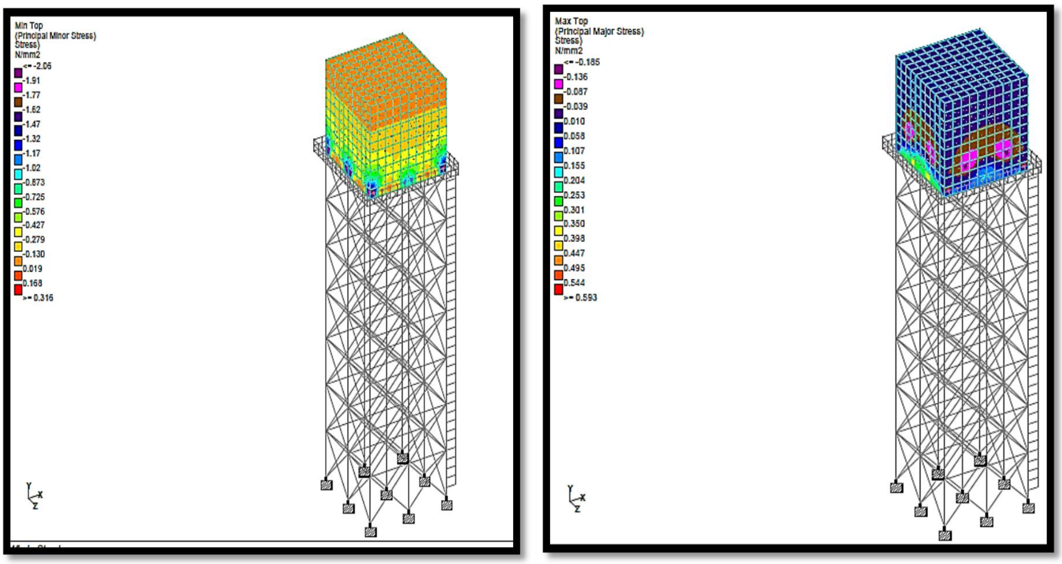

Figure 5: Model of steel tank and principal minor and significant stresses.

Conclusion

From the study and analysis above, a 750 m³ capacity buried water storage tank was designed, with a capacity to contain about 750,000 liters of treated wastewater. This storage facility has been developed for wastewater reuse purposes such as toilet flushing or car washing. This study has revealed that the construction of a 750 m³ buried storage tank would be highly efficient and economical when compared to a smaller tank. Also, both the internally- acting hydrostatic forces within the buried tank, and the passive and active stresses imposed externally in the direction of the wall has shown to possess zero effect on the shear wall. The suspended steel tank is designed to be constructed at the topmost point within the campus to allow for maximum flow under gravitational forces, from the discharge point to the consumption points.

It is recommended that further research work be conducted on the impact of treated wastewater on suspended steel tanks. In order to store the design capacity of treated wastewater in the buried water tank (750m³), six (6) elevated steel tanks of size 125 m³, is suggested for construction. However, as demand increases due to population rise, it is required that a second 750 m³ of the buried water tank, as well as another six suspended steel tanks of 125m³, be taken into consideration for development. Further studies ought to be conducted for the required degree of treatment on the wastewater within the campus, and enhancement of the nature of the treated wastewater needs to be taken into consideration for future studies.

The management of our limited water resources is very crucial because human lives depend on it for survival. Management would be as a result of the application of various economic mechanisms towards the attainment of an optimal demand and supply situation. Some of the benefits of good water resource management could include the following:

i. Management of water and wastewater Resources will lead to an improvement in sanitation facilities. This will go a long way in reducing diarrhea and other health-related cases among children by more than one-third [20].

ii. Effective Water Resources Management will help quicken financial and social improvement in nations where sanitation is a noteworthy reason for lost work and school days due to disease [20].

iii. There will be an increased financial return as a result of the investment in Water Resources. This could be very important in developing nations such as Nigeria, which has a very high population. Studies show that annual investments of 11.3 billion dollars are required to achieve the Sustainable Development Goals' Sanitation and Water Needs. In return, an overall payback of 84 billion dollars is yielded [20].

Other benefits of Water Resources Management have increased school and work attendance per annum, and healthcare savings are improved and very high mitigation of death-causing diseases (people will live longer).

Conflicts of Interest
The authors declare no known conflict of interest.

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