

Structural Design of Overhead Intze Water Tank using ARSAP

Aminu Y. M.; Abubakar A. ; Abdulkarim I. I. ; Obadiah M.; and Adetoye O.

Department of Civil Engineering, Abubakar Tafawa Balewa University, P.M.B. 0248, Bauchi, Nigeria.

Corresponding author: aabubakar24@atbu.edu.ng

DOI: <https://doi.org/10.62154/ajastr.2025.019.01019>

Abstract

Reinforced concrete tanks are often used to store and supply safe drinking water. Due to the shortage of water around the world, importance is given to water storage projects. This research tries to address the problem of lack of adequate water supply in a university community. The expansion of academic and residential activities with ageing infrastructure has led to intermittent water supply shortages, low pressures and unsatisfactory water quality in some areas of the campus. The research is aimed at the structural design of the overhead Intze tank using Autodesk Robot Structural Analysis Professional (ARSAP) software, 2019 version and comparing the results obtained with manual design. The tank capacity was based on the projected water demand. Population growth was taken as 2.5% per annum, and estimated using the geometric increment method for a design period of 40 years. Concrete grade C35A and steel bars of Fy-415 N/mm² were used as per BS 8007. Loadings were based on the self-weight, weight of water and wind speed effect. The findings between manual and software design were compared. Reinforcement area calculations for beams and columns were found to be much lower than the manual design. Only slight differences in the reinforcement areas were observed for the shells. Hence, ARSAP was found to best design finite element structures. The software is user-friendly and can model a structure of any shape and size of concrete.

Keywords: Intze Tank, Reinforcements, Crack Width, ARSAP Software.

Introduction

Storage tanks often known as water retention structures are crucial component of water supply systems. Tanks are generally classified based on pressure heads as tank resting on ground Plinth (Surface tanks), underground and overhead/elevated tanks. Depending on their shapes, they are further classified as rectangular tanks, circular tanks or Intze tanks and other custom shapes. Also, based on construction materials, tanks can be constructed of steel, masonry, reinforced concrete (precast or cast-in-place), fiberglass, polyethylene, wooden tanks, etc. The Intze water tank was named after its inventor Friedrich Otto Intze (1843-1904). It is characterized by a cylindrical wall on a conical hopper bottom, a domed-shaped roof, and tower support columns. Bracings are also provided to resist horizontal loads due to winds (Chandana *et al.*, 2021). Design calculations are guided by rules which are based hand/manual calculation methods. The need for computer aided design (CAD) generally arises when construction time gets shorter or the structure is too complex to

design manually. Hence, some sort of verification design using the software maybe necessary. Numerical methods like the finite element method (FEM) are employed in the design of such structures. The force analysis of tanks is about the same irrespective of the nature of the product to be stored. All tanks are designed as crack free structures to eliminate any leakage. Structures designed to retain liquid must fulfill the requirement of strength, durability, deflection, and freedom from excessive cracking. The BS 8007 stipulates crack widths as 0.2mm for underground tanks and 0.1mm for structures exposed. This paper presents the structural design of overhead Intze water tank using ARSAP software and compares the results with the design using Excel template. The design of liquid retaining structures has been revised from working stress method to limit state. The revised edition incorporated limit state design method. The British standard BS 8007:1997 introduced the limit state design approach for liquid retaining structures, emphasizing in consideration on the effect of uncertainties in loads, material properties, and structural behaviour. Shahid and Ashish (2022) analyzed and designed circular overhead Intze water tank using STAAD Pro V8i SS6 software. They concluded that the design results were similar to manual calculations which showed the same amount of reinforcement. Also, Shashank (2014) analyzed and designed Intze type overhead water tank under hydrostatic pressure using software. He concluded that STAAD Pro gives more accurate, economical & fast result. Though design is safe but it was observed that reinforcement was less when compared with manual calculations. The idea of inclining the support columns of the Intze tank to provide more safety against seismic activity was tested and analysed by Nikunj *et al.* (2017) using the STAAD Pro software. The effect of deflection due to hydrostatic pressure on the structure was analyzed using the spectrum technique for both empty and full tank conditions. The staging tower performs better when inclined than the straight support tower under hydrostatic pressure. The use of fixed joint at the base reduces base settlement. Subsequently, the staging height of 20m produces more moments compared to lesser heights but better pressure heads.

Ajagbe, *et al.* (2012) focused on aspects such as formwork and construction materials for a rectangular and circular elevated water tank. They concluded that the amount of formwork and material requirements for a rectangular wall is more compared to a circular wall for equal tank capacity. Hence, the same goes for the cost of construction.

The construction of circular wall is more difficult compared to a rectangular elevated water tank. Bhat and Kumar (2022) also concluded that it is better to design a rectangular water tank for smaller capacities and circular water tank for larger capacities.

Sahil and Ajnal (2019) also noted that the design of elevated water tank is very complex, which involves lots of mathematical calculations and time consuming. Hence STAAD pro gives all parameters which are useful in design of elevated water tank.

Vital research on design and analysis of Intze tank was done by the Gogaraju Rangaraju Institute of Engineering and Technology (GRIET). When comparing working stress method for manual method of design and Staad Pro analysis results obtained, the reinforcement detailing and design shown by manual analysis were more economical and safer than the

STAAD Pro Analysis. Also, Intze tank was found to minimize the project cost because lower dome resists more moments when compared to the conventional slab.

Chandana *et al.* (2021) analyzed and designed Intze water tank using STAAD Pro. They reported that though STAAD pro design is safe but we observed that reinforcement is less when compared with manual calculations.

According to the ACI (2002), model analysis is acceptable as a basis for design or to check the validity of the assumptions involved in a mathematical analysis. Models should be looked upon as auxiliary tools to aid a rational analysis rather than a substitute for a theoretical analysis. It must be emphasized that although the model analysis technique is valuable for the design or analysis problems of complex shells, extreme care must be used in the planning, execution, and interpretation of the model experiments.

Methodology

Materials

A. Concrete requirement

Ordinary Portland cement (OPC) is generally considered for liquid-retaining structures. Grade C35A concrete (28th day cube strength not less than 35 N/mm²) was used at water cement ratio of 0.55 and cement content of 400 kg/m³. Nominal aggregate size of 20mm was used in accordance with BS 8007 specifications.

B. Exposure conditions

The exposure condition was assumed to be severe in accordance with BS 8007 requirements with maximum crack width of 0.1 mm.

C. Permissible stresses in steel

The crack widths in direct tension may be “deemed to be satisfactory” provided the steel stresses do not exceed the permissible limits as stated in BS 5337 and subsequently in BS 8007. The cracked width in flexural tension was controlled using the Table 1 below.

Table 1. Allowable steel stresses in direct or flexural tension for serviceability limit state (SLS).

Design crack width (mm)	Allowable stress	
	Plain bars a (N/mm ²)	Deformed bars b (N/mm ²)
0.1	85	100
0.2	115	130
a. Plain grade 250 bars complying with BS 4449.		
b. Deformed grade 460 bars complying with BS 449 or BS 4461 and high-yield wire fabric complying with BS 4483 having a guaranteed yield or proof stress and guaranteed weld strength.		

Source: BS 8007(1987) *Design of Concrete Structures for Retaining Aqueous Liquids*

Experimental Methods

Design population

The tank was designed for Abubakar Tafawa Balewa University Bauchi, Yelwa Campus. The population was estimated using geometric method as shown in Equation 1. Where i is the percentage decennial increase in population, n is the number of decades, P is the recent known population and P_n is the estimated population in some years.

$$P_n = P \left(1 + \frac{i}{100} \right)^n \quad \dots (1)$$

Design period of 40 years and population growth of 2.5% per annum were used. The estimated population and water demands are shown in Table 2.

Table 2. Population Forecast

Population characteristics	Estimated population in 4 decades ($n=4$, $i=2.5$)	Average per capita water demand (liters/capita/day)
International Secondary School	684	10,260
International Primary School	559	8,385
School clinic	-	Say, 10,000
Staffs living off campus	Say, 100	3,000
Male students	1902	475,500
Female students	1623	405,750
Students living off campus	709	10,635
Fire service and security	-	Say, 44,000
Subtotal		967,530
Unaccounted system loss and leakages	2%	19,350
Total		986,880

Therefore, the tank capacity for a period of 40 years will be 986,880 litres. For this design, a tank capacity of 1,000,000 ltrs (1000 m³) was chosen.

Preliminary analysis and member sizing

Table 3 provides the dimensions of the tank obtained from the results of preliminary analysis.

Table 3. Tank dimensions

Shells/members	Dimensions
Top spherical dome	Th = 100 mm, D = 12 m, r = 2 m, R = 10 m
Cylindrical wall	H = 8 m, D = 12 m, Th = 200 mm -350 mm (varying from top to bottom)
Conical dome	Th = 600 mm, h = 2 m,
Bottom spherical dome	Th = 300 mm, D=8 m, r = 1.6 m, R = 5.8 m
Top ring beam	250 mm x 300 mm, D = 12 m
Bottom ring beam	600 mm x 1200 mm. D = 12 m
Bottom circular girder	1200 mm x 600 mm, D = 8 m
Support columns	650 mm diameter,
Braces	500 mm x 500 mm

Launch ARSAP software 2019 version

To set materials and design codes, select from the text menu "tools">> Job preferences>>.

To set the axis, select "Geometry" from the text menu>>select axis definition>>. Enter axis positions in x, y and z directions as below;

The X-axis positions are: -6, -4, -2.83, 0, 2.83, 4, 6.

The Y-axis positions are: -6, -4, -2.83, 0, 2.83, 4, 6.

The Z-axis positions are: -1, 4, 4, 4, 4, 2, 8, 2.

The Local Z-axes plane definitions are shown in Figure 1. To create sections sizes, go to geometry>> select column>>dropdown section types and select "RC column">>expand section shapes and edit column concrete grade, shape and size>>Add. Place the columns on the appropriate positions. Repeat the same procedure for modelling beams.

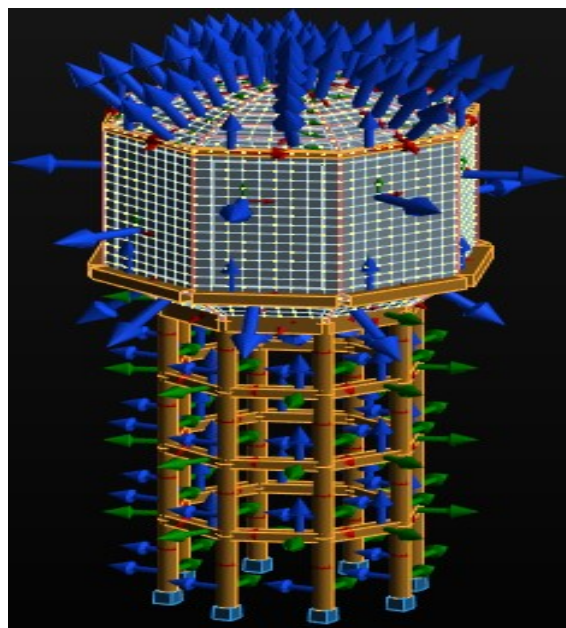


Fig 1. Local Z-axis plane definitions

Select shell thickness

To set shell thicknesses, go to geometry>> properties>> thicknesses>>select new thicknesses>> edit thickness and name of section>> click Add to save the thickness. Create and add the thickness of the bottom dome as 300mm, conical dome as 600mm, cylindrical wall varying 350-200mm and top dome 100mm.

Define the loading

To define loads, go to loads >> select load types>> in the new dialogue, select nature of load>> name and label the load>>Add. For example, go to loads>>load types>>select nature of load as "live">>label and name as hydrostatic>>Add. Repeat the same procedure for dead (self-weight), live-load-on-dome and wind load.

Assign the hydrostatic loading

To assign hydrostatic load, go to loads>>load definition>>select surface load icon>> select hydrostatic pressure icon>> input unit weight of liquid as 1000 kg/m³>> input liquid level as full height of water as 26m from z=0>> select the negative z-axis for direction of load>>click Add.

Modelling

Each panel was modelled separately. The panels were trapezoidal, rectangular and triangular in shape. Uniform mesh sizes of 50mm were used. The local axis direction of the panels were facing outer surfaces for proper hydrostatic loading as shown in figure 2. The hydrostatic pressures on the cylindrical wall, conical dome and bottom dome are also displayed in the Figure 2.

Wind Load Simulation

The software uses computational fluid dynamic (CFD) equations to simulate wind loads in all directions. To do this, go to loads>> wind loads simulation>> generate wind loads>>tick x, -x, y, -y directions, select "wind pressure" and input 1.5kpa, select all elements>> start. Equivalent wind velocity in each direction shown was 49.9 m/s. The simulation is shown in Figure 3.

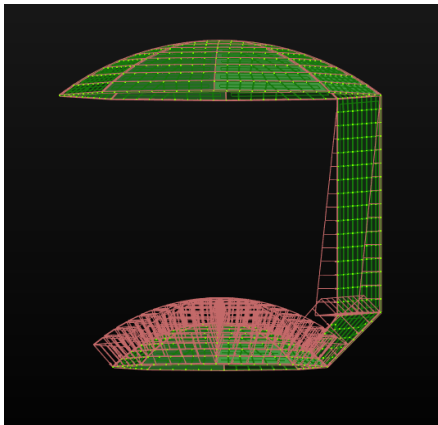


Fig. 2. Hydrostatic loading

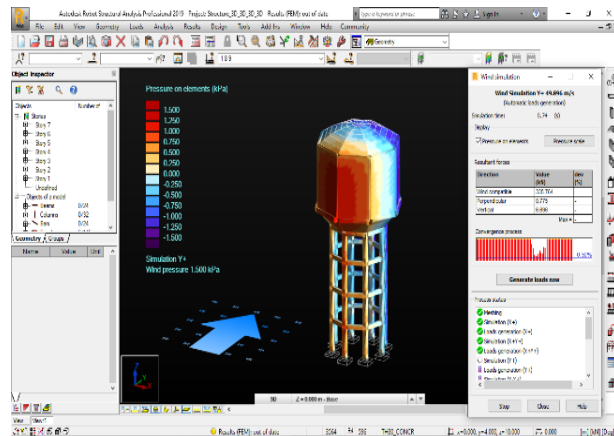


Fig. 3 wind load simulations

Load combinations

Manual load combinations were generated using load case number 12 (SLS + wind loads) as shown below. This comprises of load cases number 1, 2,3,4,8,9,10 and 11 as shown in Table 4.

Table 4. Load Cases and Combinations

Case	Label	Case name	Nature	Analysis type
1	Self weight	Self weight	dead	Static - Linear
2	walls hydrostatic pr	walls hydrostatic pressure	live	Static - Linear
3	dome hydrostatic pr	bottom dome hydrostatic pressure	live	Static - Linear
4	conical hydrostatic	conical hydrostatic pressure	live	Static - Linear
5	live load on dome	live load on dome	live	Static - Linear
6		1.4Gk + 1.6Qk	dead	Linear Combination
7		1.0GK + 1.0Qk	dead	Linear Combination
8	WIND1	Wind Simulation X+ 49.900 m/s	wind	Static - Linear
9	WIND2	Wind Simulation Y+ 49.900 m/s	wind	Static - Linear
10	WIND3	Wind Simulation X- 49.900 m/s	wind	Static - Linear
11	WIND4	Wind Simulation Y- 49.900 m/s	wind	Static - Linear
12		SLS + wind loads	dead	Linear Combination

Results and Discussion

A. Forces and Moments on Supports

The Figures 4a and 4b show vertical reactions (F_z) on each footing, and their corresponding moments acting in x, y and z directions (M_x , M_y and M_z) respectively. These reactions are obtained for the SLS load combination of $1.0Gk + 1.0Qk$. The moments in all the three directions are nearly zero for both full and empty tank condition.

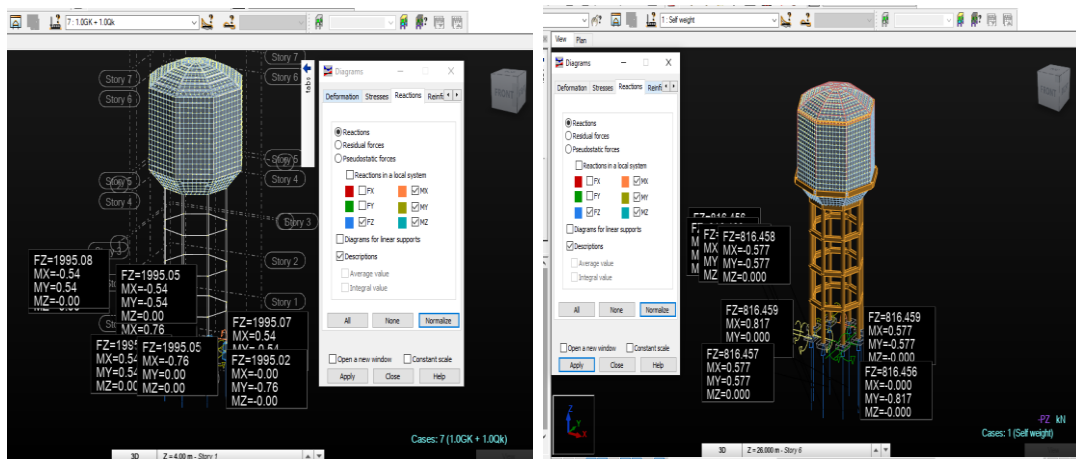


Fig. 4 Reactions and moments (a) full tank condition (b) empty condition (self-weight only)

B. Top Dome Reinforcements Maps

Figures 5 (a) – (d) show the required reinforcements in the top and bottom of the dome sections. The legend shows the reinforcement required in mm^2/m run. The reinforcement ($A_{\min}$) required is $450 \text{ mm}^2/\text{m}$ in both directions.

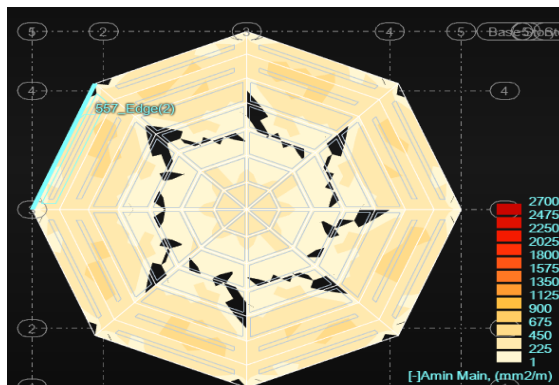


Fig.5(a) Ring reinforcement for bottom face

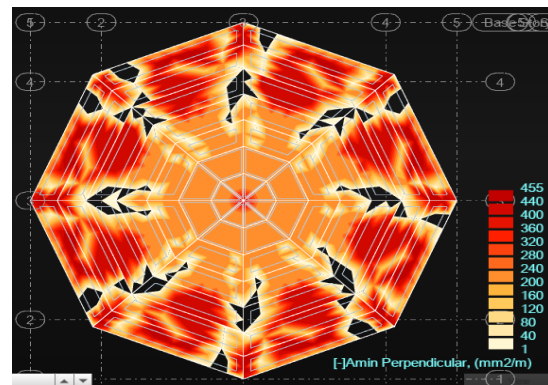


Fig. 5(b) Meridian reinforcement for bottom

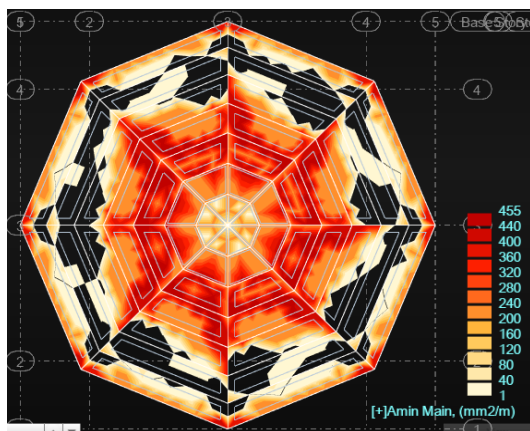


Fig. 5(c) Ring bar maps for top face

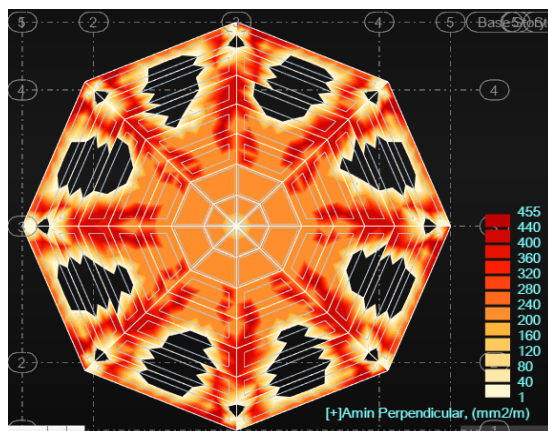


Fig. 5(d) Meridian reinforcements map for top face

C. Cylindrical Walls Reinforcement Maps

Figures 6 (a) – (d) show the reinforcement maps in the first and second faces (internal and external) of the cylindrical walls in mm^2/m run. The area of hoop reinforcements required from the top to $2/3$ rd of the height of the tank wall is $675 \text{ mm}^2/\text{m}$ on both faces. At $1/3$ rd of the height from bottom of tank walls, the hoop reinforcement required is $900 \text{ mm}^2/\text{m}$ on each face. Distribution (vertical) reinforcement required varies from the top to bottom of tank walls. About $560 - 795 \text{ mm}^2/\text{m}$ is required on both faces.

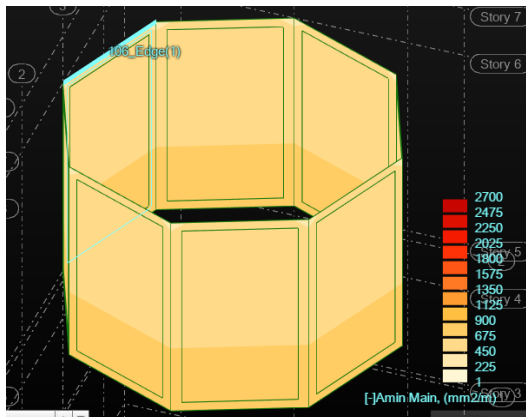


Fig. 6 (a) Ring reinforcement for first face

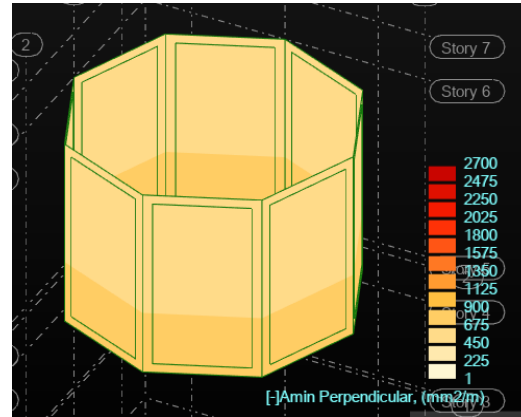


Fig. 6 (b) Meridian reinforcement for first face

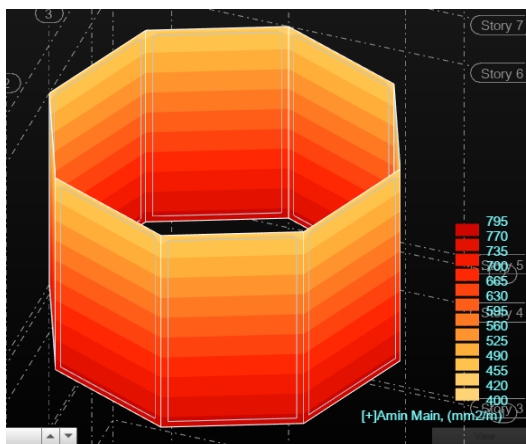


Fig. 6 (c) Ring bar maps for second face

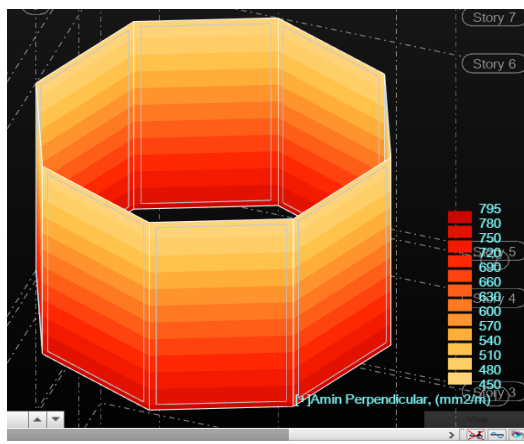


Fig. 6 (d) Meridian reinforcements for second face

D. Conical Dome Reinforcement Maps

Figures 7(a) – (d) show the reinforcement requirement for the top and bottom sections of the conical dome in mm^2/m run. The area of reinforcement required is $2700 \text{ mm}^2/\text{m}$ in both the top and bottom layers for all directions.

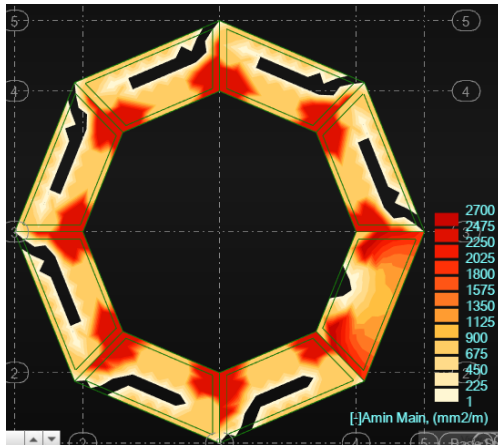


Fig. 7(a) Ring reinforcement for first face

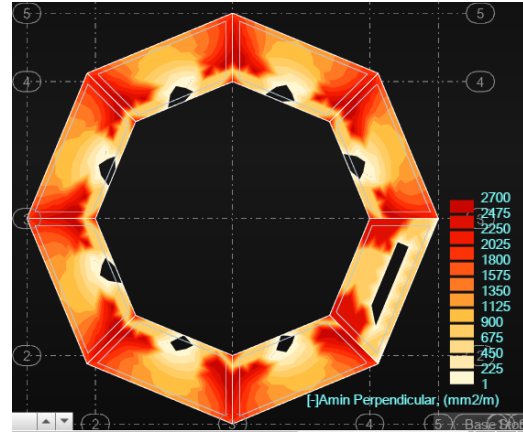


Fig. 7(b) Meridian reinforcement for first face

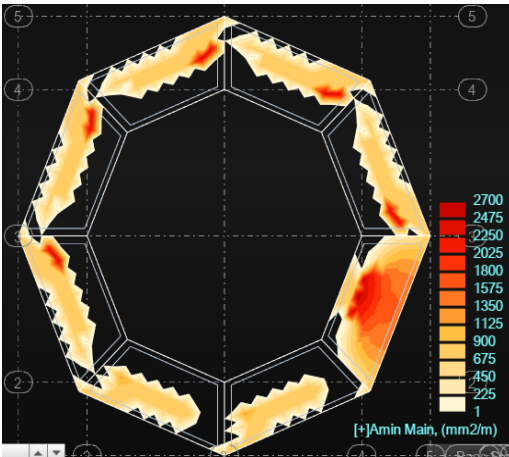


Fig. 7(c) Ring bar maps for second face

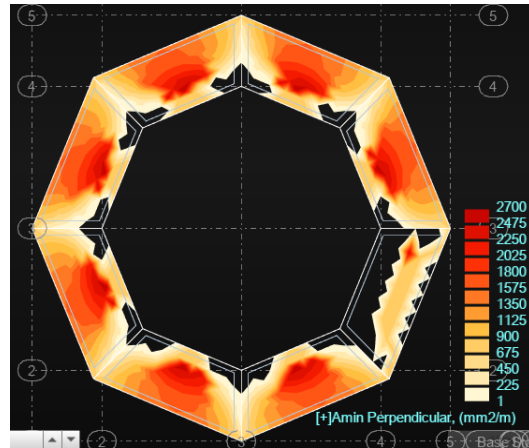


Fig. 7(d) Meridian reinforcements for second face

E. Bottom Dome Reinforcement maps

Figures 8(a) – (d) show the reinforcement requirement for the top and bottom sections of the bottom dome in mm^2/m run. The maximum area of reinforcement required is $1200 \text{ mm}^2/\text{m}$ in the top and bottom layers in both directions.

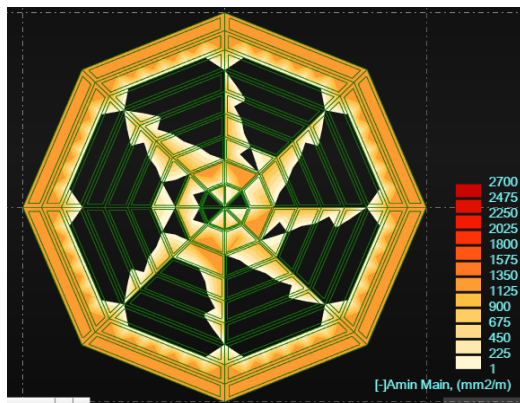


Fig. 8(a) Ring reinforcement for first face

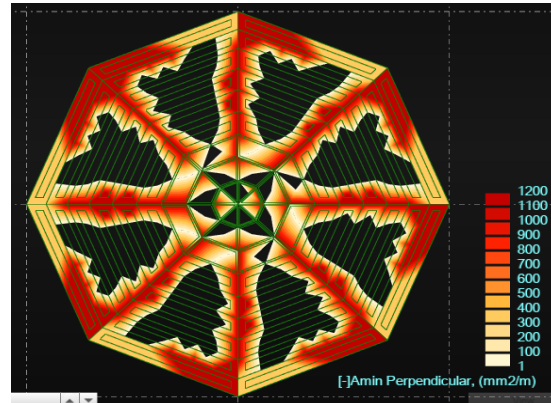


Fig. 8(b) Meridian reinforcement for first face

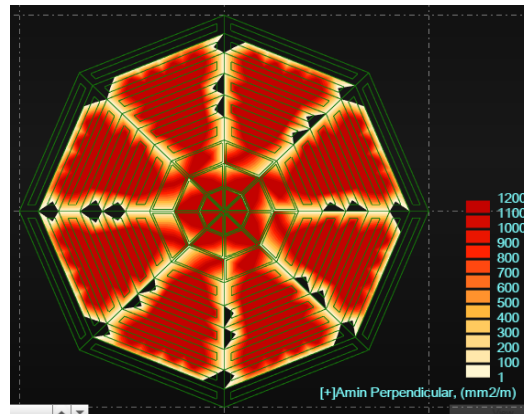
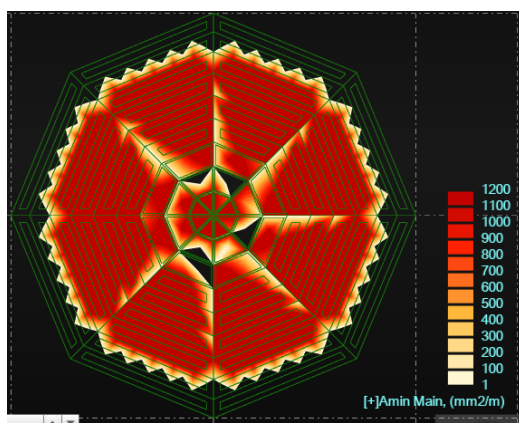


Fig. 8(c) Ring bar maps for second face Fig.8 (d) Meridian reinforcements for second face

F. Horizontal Crack widths maps

Figures 9(a) – (c) show the horizontal crack width maps of the sections in millimeters. The maximum crack widths obtained are less than 0.1 mm specified in BS 8007.

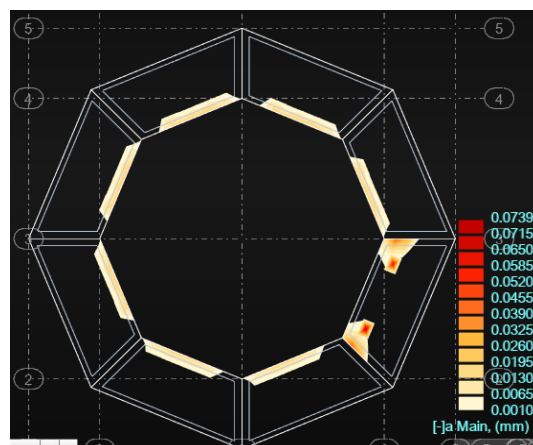
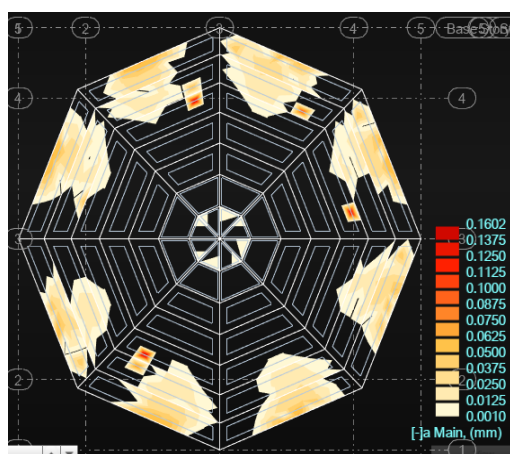


Fig. 9(a) Horizontal crack width for top dome. Fig. 9(b) Horizontal crack width for conical hopper dome

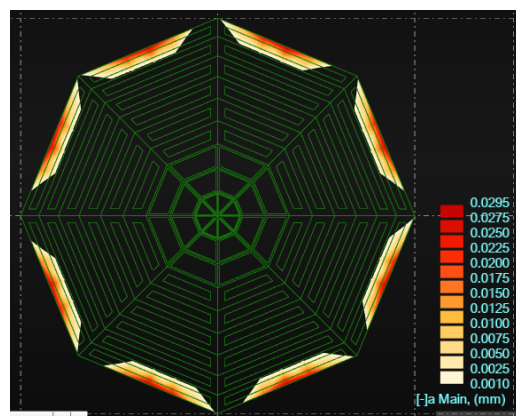


Fig. 9(c) Horizontal crack width for bottom dome

Observations

From the results of the software design, it was observed that;

- i. The total point load on each foundation column was 1995 kN at full tank SLS condition.
- ii. The total point load on each foundation column due to self-weight only is 816.5 kN.
- iii. The moments generated on each supporting columns in both empty and full tank conditions was found be nearly zero.
- iv. The amount of required reinforcement area of both top and bottom dome increases towards the ring beams.
- v. The bottom dome requires more reinforcement than the top dome because of hydrostatic pressure.
- vi. The conical dome reinforcement requirement was found to be more at the bottom ring beam (i.e. at outer diameter 12m) than at the bottom girder (i.e. at inner diameter of 8m).
- vii. Horizontal cracks for top, bottom and conical domes were found to be below 0.1mm and they appear towards the location of the ring beams.

Limitations of designing Intze Tank using ARSAP

The software only provides the reinforcements in form of a map which requires interpretations. Also, errors in modelling due to snapping of nodes or axes are not always reported in the instabilities messages. Though the software's interface is user friendly, but must parameters require manual adjustments which is difficult for beginners.

Comparison using Excel template Design

The required areas of reinforcement for the Excel template design are compared with that of ARSAP design. For the ARSAP design, only the maximum value of reinforcement required were observed and presented, as shown in Table 4. The reinforcement details for the Excel Template design is presented in Figure 10.

Table 4. Reinforcement Requirements for Excel Template and ARSAP Designs

Members	Excel Template design	ARSAP design
Top dome	350 mm ² /m in both directions	450 mm ² /m in both direction
Cylindrical wall	At top (0-2) m: 600 mm ² /m each face both hoop and distribution bars. At middle (2-4) m: 1200 mm ² /m hoop bars both faces. Distribution each face 825 mm ² /m. At bottom (4-8) m: 2400 mm ² /m hoop bars both faces. Distribution each face 1050 mm ² /m	At about 2/3rd height of tank wall from top, 675 mm ² /m hoop bars both faces. At about 1/3rd from bottom of tank walls. 900 mm ² /m hoop bars each face. Distribution (vertical) bars varies linearly from top to bottom of tank walls. About 560 - 795 mm ² /m for both faces.
Conical hopper dome	7652 mm ² /m both faces (i.e. 3826 mm ² /m both top and bottom layer in both directions)	2700 mm ² /m top layer both directions. 2700 mm ² /m bottom layer both directions.
Bottom dome	1050 mm ² /m in both directions	1200 mm ² /m top and bottom layers in both directions.
Top ring beam	1066 mm ² (3Y16 top and 3Y16 bottom)	Top 255mm ² (2Y16) Bottom 321mm ² (2Y16)
Bottom ring beam	8134 mm ² (17Y25) top and bottom	Top 2232mm ² (12Y16) Bottom 1553mm ² (8Y16)
Bottom Circular girder	Top 4348mm ² (9Y25) Bottom 2147mm ² (6Y25)	Top 1597 mm ² (8Y16) Bottom 1106 mm ² (6Y16)
Bracing	1964 mm ² (4Y25 top and 4Y25 bottom)	Top 384 mm ² (2Y16) Bottom 382 mm ² (2Y16)

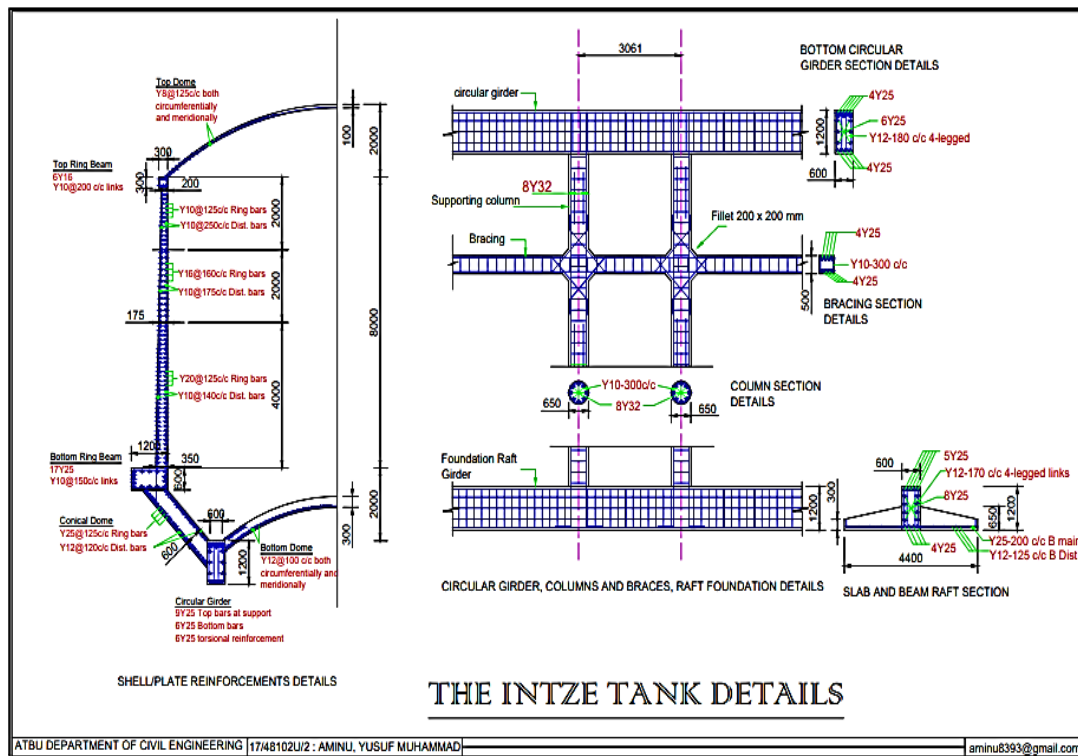


Fig 10. Reinforcement Details for the Excel Template Design

Conclusion

The structural design of Intze water tank using ARSAP and Excel Template has been conducted and the outcome reveals that:

- i. The projected 40 years design per capita water demand for the campus was found to be about 986,886 lcpd for ATBU, Yelwa Campus.
- ii. The ARSAP software design reinforcement areas show slight difference from the Excel Template design calculations for the same size and thicknesses of shells/plate elements.
- iii. The ARSAP software design shows better reinforcement area mapping than the Excel Template design which indicates that ARSAP design is more economical and safer.
- iv. The results of ARSAP software design for long term cracking meets the serviceability limit requirement of 0.1mm.
- v. The research reveals that complex structures can be designed using ARSAP software.

Conflict of Interest

The authors declare that there are no conflicts of interest.

References

ACI 334.1R-92(2002): Concrete Shell Structures Practice and Commentary.

- Ajagbe W.O., Adedokun S.I. and Oyesile W.B (2022).: Comparative Study on the Design of Elevated Rectangular and Circular Concrete Water Tanks. *International Journal of Engineering Research and Development*, IJERD. ISSN: 2278-067X Volume 1, Issue 1, pp 22-30.
- Anchor R.D., (1981). Design of Liquid Retaining Concrete Structures, 2nd Ed. British Library Cataloguing Publications, 1981.
- Ashish Kumar and Shahid Nazir (2022). Design and Analysis of Circular Overhead Intze Water Tank by StaadPro V8i SS6 Software. *International Journal of Innovative Research in Engineering & Management*, IJIREM, Pp393-402.
- Bhat A.A. and Kumar A. (2022). Design and Analysis of R.C.C Overhead Water Tank for Town. *International Journal of Innovative Research in Engineering & Management*, IJIREM. ISSN: 2350-0557, Volume-9, Issue-2.
- BS 8110 (1995) Parts 1-3: Structural Use of Concrete, (formerly CP 110), British Standard Institution.
- BS 8007 (1987) Design of Concrete Structures for Retaining Aqueous Liquids, (Formerly BS 5337), British Standard Institution.
- Chandana I., Padala S. G., Nalla R. K. and Bathula N.. (2021). Analysis and Design of Intze Water Tank by Using STAAD Pro. ICMED 2021. E3S Web of Conferences 309, 01178. <https://doi.org/10.1051/e3sconf/202130901178>
- Issar K., Purav P., Nilesh D., and Nikunj P. (2017). Analysis and Design of INTZE Type Overhead Water Tank under the Hydrostatic Pressure as Per IS: 3370 & IS: 456 -2000 by Using STAAD Pro Software. *International Research Journal of Engineering and Technology* (IRJET). Volume 4 Issue 7.
- Sahil A. and Ajmal T. (2019). Seismic Analysis and Comparison of Overhead Intze Water Tank, Circular Water Tank and Rectangular Water Tank and Response Spectrum Analysis. *International Journal of Civil Engineering and Technology*, IJCIET. Volume 10, Issue 03.
- Shashank, S.S. (2022). Analysis and Design of Intze Type Overhead Water Tank Under the Hydrostatic Pressure by Using Software. Volume 9, Issue 7. www.jetir.org