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Structural Analysis and Design of Water Treatment Plant Structures

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Abstract: The increasing demand for clean and safe drinking water in urban and semi-urban areas necessitates the establishment of well-designed and efficient water treatment facilities. This thesis focuses on the hydraulic and structural design of a 14.00 million Liters per Day (MLD) conventional Water Treatment Plant (WTP), aiming to ensure structural safety, operational efficiency, and sustainability in water treatment infrastructure. The hydraulic design is based on the latest CPHEEO Manual 2024 guidelines, ensuring proper sizing and layout of essential components including intake chambers, flash mixers, flocculators, sedimentation tanks, rapid sand filters, clear water reservoirs, and pump houses. The structural analysis and design of all major components have been carried out using STAAD Pro software, which enabled precise modeling, load analysis, and efficient reinforcement detailing as per IS 456:2000 and relevant Indian Standard codes. The design process considered various load combinations, including dead load, live load, hydrostatic pressure, and seismic forces as per IS 1893 (Part 1): 2016. A case study approach was adopted for the selected site, evaluating site-specific parameters such as soil bearing capacity and seismic zone. The results demonstrate that all structural components are safe under ultimate and serviceability limit states. The integration of hydraulic functionality with structural integrity ensures long-term performance and safety of the plant. The project highlights the importance of interdisciplinary collaboration between civil and environmental engineering domains and showcases how software tools can be leveraged to enhance design accuracy, optimize material usage, and reduce construction costs. This study provides a reference for future WTP projects, especially in the context of growing urbanization and the need for sustainable water infrastructure.
Keywords: Water Treatment Plant, Hydraulic Design, Structural Design, STAAD Pro, CPHEEO Manual 2024, IS 456:2000, IS 1893:2016, Reinforced Concrete Design.

I. INTRODUCTION

Access to safe and clean drinking water is fundamental to human health and well-being. Globally, waterborne diseases such as cholera, typhoid, and dysentery continue to pose significant health risks, particularly in regions lacking adequate water treatment infrastructure. According to the World Health Organization, approximately 1.1 billion people lack access to improved drinking water sources, leading to millions of preventable deaths each year. Water treatment plants (WTPs) play a crucial role in mitigating these risks by removing physical, chemical, and biological contaminants from raw water sources, rendering it safe for human consumption. The treatment process typically involves multiple stages, including coagulation, flocculation, sedimentation, filtration, and disinfection. Each stage is designed to target specific types of contaminants, ensuring comprehensive purification of the water supply.In India, the Central Public Health and Environmental Engineering Organization (CPHEEO) provides guidelines for the design and operation of WTPs, emphasizing the need for robust and efficient treatment processes to meet the country's growing water demands. These guidelines serve as a standard for engineers and planners, ensuring consistency and safety across water treatment projects nationwide.The structural integrity of WTP components is equally vital, as failures can lead to service disruptions, contamination, and significant public health crises. Advanced structural analysis tools, such as STAAD Pro, enable engineers to design and evaluate the resilience of WTP structures under various load conditions, including seismic and wind loads, ensuring long-term durability and safety.

II. LITERATURE REVIEW

Gaurank Patil et.al (2018), Water treatment is an essential process to ensure the availability of clean and safe water for human consumption. Efficient water treatment plants (WTPs) play a crucial role in removing contaminants and pathogens from raw water sources to maintain public health.

The study by Patil et al. (2018) provides an analytical review of the Jalgaon Water Treatment Plant, operated by the Jalgaon Municipal Corporation, highlighting its design components and necessary modifications. A typical WTP consists of several stages, including coagulation, sedimentation, filtration, and disinfection. The Jalgaon WTP follows a conventional treatment process to meet water quality standards. The study details key design components such as intake structures for drawing raw water, coagulation and flocculation units for destabilizing suspended particles, sedimentation tanks for settling heavier particles, filtration systems comprising sand and gravel filters, and disinfection processes using chlorine to eliminate harmful microorganisms. These stages collectively enhance treatment efficiency and ensure potable water supply. However, several challenges exist, including aging infrastructure requiring upgrades, the need for advanced water quality monitoring techniques, and the necessity of optimizing treatment processes such as coagulation and filtration to improve resource efficiency. The study suggests modifications such as the automation of treatment processes and the exploration of alternative disinfection methods to reduce chlorine dependency. Addressing these challenges would improve plant performance and ensure long-term sustainability. The findings emphasize the importance of maintaining and upgrading WTPs to enhance operational efficiency and water quality. Future research could explore the integration of advanced treatment technologies like membrane filtration and bio-treatment processes for better water quality management and environmental sustainability.

Alexander Orlov et.al (2020), Water treatment plant (WTP) sludge has gained attention as a potential material for modifying and improving construction materials, particularly structural ceramics. Orlov et al. (2020) investigated the feasibility of using aluminum-containing WTP sludge as a burning-out additive in ceramic brick production. The study aimed to optimize the conditions under which sludge from a large city's WTP could enhance ceramic properties. The raw water used in the treatment process belonged to the hydrocarbonate class with low turbidity (1.5–40 mg/L kaolin). The sludge was collected from sedimentation tanks and dewatered using lime or a freezing-thawing method before being introduced into clay mixtures in varying proportions (5% to 20% by weight). The incorporation of 20% WTP sludge improved brick properties by reducing the sensitivity of clay to drying and lowering the density of the ceramic by 20%. Simultaneously, the compressive strength of the ceramics increased from 7.0 MPa to 10.2 MPa. The research further indicated that pre-treating WTP sludge through the freezing-thawing method led to superior ceramic brick characteristics. These findings suggest that aluminum-containing WTP sludge, when processed appropriately, can serve as a valuable modifying additive in ceramic production. By repurposing WTP sludge in this manner, the study promotes sustainable waste management practices and contributes to circular economy principles in the construction sector. Future research should explore the long-term durability of such modified ceramics, assess their environmental impact, and investigate the economic feasibility of large-scale implementation.

The study by U. Pallavi et al. (2021), focuses on the Design of Water Treatment Plant at Ponukumadu Village, Andhra Pradesh, India, addressing the necessity of assessing surface water quality and its suitability for drinking purposes. The research highlights that Ponukumadu village, located in Nandivada Mandal, Krishna District, relies on surface water collected from Krishna River through the Nehrelli channel, stored in a pond spanning 5 acres with depths varying from 4 to 6 feet. With a population of 650 as per the 2021 Census and a water tank capacity of 40,000 liters, the study systematically evaluates water quality parameters, including chemical, physical, and biological properties, crucial for determining the effectiveness of traditional drinking water treatment processes such as coagulation, flocculation, sedimentation, filtration, and disinfection. The authors emphasize the importance of optimizing each treatment unit based on influent water quality to achieve desired effluent standards during both design and operational stages, thereby ensuring safe drinking water supply for the rural community. The findings contribute significantly to the field of environmental engineering by providing a practical framework for water treatment plant design tailored to local conditions, reinforcing the necessity of site-specific water treatment solutions in rural India.

Haritha M. et. Al (2021), In Kumarakom Panchayath, a local government area in Kerala, India, the primary causes of water quality deterioration are identified as the discharge of domestic and municipal wastes, along with terrestrial runoff from seepage sites. To address this issue, the design of a water treatment plant for Kumarakom Panchayath was undertaken. A proposed layout of the plant was developed, incorporating key treatment components such as screens, cascade aerators, a flash mixer, a clariflocculator, a rapid gravity filter, and a chlorinator. This paper presents the design of the flash mixer unit, rapid sand filter, and chlorinator for the plant. To begin with, a physico-chemical analysis was conducted by collecting and analyzing water quality data from Kumarakom Panchayath. The parameters assessed included pH, turbidity, hardness, alkalinity, acidity, sulphates, chlorides, residual chlorine, nitrates, iron, dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and the most probable number (MPN) of coliform bacteria. Subsequently, a population forecast was carried out based on survey data to estimate the required capacity of the treatment plant.

Using this information, a comprehensive layout of the plant was developed. Finally, the design of individual treatment components was completed based on the water quality parameters and projected plant capacity.

N H Pakharuddin et.al (2021), Water treatment is the process of removing all those substances, whether biological, chemical, or physical, that are potentially harmful to the water supply for human and domestic use. This treatment helps to produce water that is safe, palatable, clear, colorless, and odorless. The basic steps of water treatment include coagulation, precipitation, filtration, and disinfection. Water treatment before supplying water to consumers is essential to improve water quality to create a sustainable life. Water treatment can eliminate potential or certain harmful substances in the water to prevent the consumption of contaminated water sources that can cause potential health problems. Therefore, it is important to establish a water treatment facility with sufficient capacity to remove pollutants according to standards before being supplied to consumers. In this study, the focus of the discussion is on the use of river water as a source of water for consumers in Japan, Australia, Canada, and Malaysia after a water treatment process. This paper reviews the recent progresses of water treatment process using both conventional and advanced methods. A brief discussion on the water quality index of each country's rivers is presented. Several potential applications of Industrial Revolution 4.0 technology in the water treatment process are discussed. Adoption of the industrial revolution of technology in water treatment may provide many benefits to this field and excavate more potential improvement. This paper will deliver a scientific and technical overview and useful information to scientists, engineers, and stakeholders who work in this field.

Hazal Gulhan et.al (2023), The disposal of sludge generated in water treatment plants (WTPs) remains a significant environmental and economic challenge. Traditionally, coagulants like aluminum sulfate ($Al_2(SO_4)_3$) and ferric chloride ($FeCl_3$) are used in WTPs, leading to the accumulation of sludge, which is often discarded in landfills. However, the increasing focus on sustainable development has encouraged the utilization of WTP sludge in wastewater treatment processes. Gulhan et al. (2023) investigated the feasibility of using WTP sludge in a high-rate activated sludge (HRAS) system as a substitute for conventional coagulants. Their study found that iron sludge exhibited superior treatment efficiency compared to alum sludge. When applied in a pilot-scale HRAS system, iron sludge at a dosage of 20.1 ± 1.6 mg dry sludge/L wastewater improved the removal efficiency of particulate chemical oxygen demand (pCOD) from 74% to 81%. Additionally, it enhanced sludge settleability by increasing the median particle size from 96 ± 3 to 163 ± 14 µm. However, the biochemical methane potential (BMP) of the HRAS process sludge decreased by 8.9%, indicating a trade-off between enhanced treatment performance and reduced biogas production. A techno-economic analysis revealed that the integration of WTP sludge into the HRAS process reduced overall operational costs by 11% without significantly impacting the effluent quality index (EQI). These findings suggest that reusing WTP sludge in HRAS systems can provide mutual benefits for both water and wastewater treatment plants, promoting a circular economy approach in environmental engineering. Future research should focus on optimizing sludge dosages, evaluating long-term performance, and exploring potential applications in full-scale treatment plants.

Abhijit Mangarajet.al (2024), The 6.6 million liters per day (MLD) water treatment plant (WTP) in Belpada Village, Odisha, is designed to meet increasing water demand while ensuring public health through effective treatment processes. Sourcing raw water from the Tel River, the plant follows a structured treatment process, including aeration, sedimentation, filtration, and disinfection. This paper outlines the hydraulic design, treatment schemes, and structural components of the WTP. Design calculations, based on CPHEEO standards, are discussed, covering hydraulic detention times, surface loading, filtration rates, and sludge management techniques. Water treatment plant (WTP) design plays a critical role in delivering safe drinking water, particularly in regions with high population density and industrial growth. The Belpada Village WTP incorporates a cascade aeration system for contaminant removal. This study focuses on hydraulic and process design, emphasizing flow rates, detention times, and surface loading parameters in compliance with Central Public Health and Environmental Engineering Organization (CPHEEO) standards.

III. PROPOSED METHODOLOGY

A. Selection of Design Parameters

The selection of design parameters is a critical step in the planning and development of a conventional water treatment plant. These parameters are determined based on various factors, including raw water characteristics, expected water demand, regulatory guidelines, and site-specific constraints. The key design parameters include flow rate, detention time, filtration rate, chemical dosing requirements, and hydraulic gradients. The capacity of the treatment plant is based on projected population growth and per capita water consumption, ensuring that the facility can meet future demands. Other important parameters include turbidity and suspended solids removal efficiency, disinfection contact time, and sludge management provisions. Design parameters must comply with CPHEEO guidelines, BIS standards, and AMRUT 2.0 recommendations to ensure water quality and operational efficiency.

Additionally, considerations such as redundancy in critical components, energy efficiency, and automation for process control play a significant role in optimizing plant performance.

B. Hydraulic Design Considerations

Hydraulic design plays a crucial role in ensuring the smooth operation of a water treatment plant by maintaining appropriate flow rates, pressure levels, and head losses throughout the system. Key hydraulic considerations include the design of pipelines, pumping stations, distribution networks, and gravity-based flow mechanisms. The velocity of water flow in conduits and channels must be maintained within recommended limits to prevent sedimentation and excessive head losses. Hydraulic calculations ensure proper sizing of sedimentation tanks, filter beds, and chemical dosing systems to optimize treatment efficiency.

C. Structural Design Aspects

The structural design of water treatment plant components involves considerations related to load-bearing capacity, seismic resistance, durability, and material selection. The design of tanks, reservoirs, and treatment units follows IS 456:2000 (Reinforced Concrete Design Code) and IS 3370 (Code for Water Retaining Structures). Factors such as soil conditions, foundation stability, wind loads, and earthquake resistance are considered in structural calculations. Corrosion-resistant materials such as epoxy-coated steel or high-grade concrete are used to enhance the longevity of structures exposed to water and chemicals. The structural design also incorporates safety features such as access platforms, drainage systems, and emergency overflow provisions.

IV. RESULTS AND DISCUSSION

A. Hydraulic Design of WTP Components

The hydraulic design of a 14 million liters per day (MLD) conventional water treatment plant (WTP) is a critical process that ensures the plant's ability to effectively treat raw water to meet potable standards. Adhering to the Central Public Health and Environmental Engineering Organization (CPHEEO) guidelines, the design process begins with a comprehensive analysis of the raw water characteristics, including parameters such as turbidity, suspended solids, and microbial content. These parameters inform the selection and sizing of various treatment units, including aeration tanks, sedimentation basins, clarifiers, and filtration units. For instance, the design of sedimentation tanks involves calculating the surface loading rate and detention time to ensure adequate settling of suspended particles. Similarly, filtration units are designed based on factors like filtration rate and media depth to achieve the desired removal efficiency. The CPHEEO guidelines provide standardized formulas and design criteria that facilitate the determination of optimal dimensions and capacities for each treatment unit, ensuring the plant operates efficiently under varying flow conditions.

Hydraulic Design of 14.0 MLD Conventional WTP Components			
Hydraulic Calculations			
Flow rate	14	MLD	
	583.333	m^3/hr	
	9.722	m^3/min	
	0.162	m^3/sec	
Flow rate with 20 % Overloading	16.8	MLD	
	700	m^3/hr	
	11.667	m^3/min	
	0.194	m^3/sec	

1.0 Aeration Fountain						
1.1 Cascade Fountain						
Capacity with 20% Overloading				16.8	MLD	
Flow rate with 20 % Overloading				700.000	m^3/hr	
Central pipe diameter				0.700	m	Assumed
Dia of bell mouth of pipe at top				0.700	m	
Proposed no. of cascade				5	nos	
Tread				0.400	m	
Rise				0.200	m	
Diameter of steps						
Dia of 1st step	1.500	m	drop step	0.200	m	
Dia of 2nd step	2.300	m	drop step	0.200	m	
Dia of 3rd step	3.100	m	drop step	0.200	m	
Dia of 4th step	3.900	m	drop step	0.200	m	
Dia of 5th step	4.700	m	drop step	0.200	m	
Dia of lower cascade	4.700	m				
Surface area				16.956	m^2	
Surface loading				0.024	m^2/m^3/hr	
1.2 Peripheral collection channel						
Design flow with 20% Overloading				700.000	m^3/hr	
Rate of flow with 20% Overloading				0.194	m^3/hr	
Rate of Flow in one direction				0.097	m^3/sec	
Maximum permissible velocity				0.600	m/s	As per CPHEEO, Velocity shall be 0.6 - 1.2 m/s
Required Area of Channel				0.162	m^2	

Provide Width of Channel	0.500	m	
Required Depth of Channel	0.324	m	
Provide Depth of Channel	0.350	m	
Provide Free Board	0.300	m	
Overall depth of channel	0.650	m	
2.0 Parshall Flume			
2.1 Channel before Parshall Flume			
Design flow with 20% Overloading	700.000	m^3/hr	
Rate of flow with 20% Overloading	0.194	m^3/hr	
Maximum permissible velocity	0.600	m/s	As per CPHEEO, Velocity shall be 0.6 - 1.2 m/s
Provide Depth of Channel	0.510	m	
Length of Channel 10 X Throat Width	3.000	m	
2.2 Parshall Flume			
Discharge with 50% Overloading	21.000	MLD	
	875.000	m^3/hr	
	0.243	m^3/sec	
Throat Width, b	300	mm	
Throat Length, l	600	mm	
Width at Entrance, b1	840	mm	
Say Width of Channel, bc	900	mm	
Axial length in meters of entrance section, l1	1350	mm	
Converging wall length at entrance section, le	1377	mm	
Width at exit section, b2	600	mm	
Water Head over Creast, ha	509	mm	
Side Wall Height for Hc	510	mm	

	Free Board, FB						300	mm	
	Consider Height of Wall, Hw						810	mm	
	2.2 Downstream Channel								
	Discharge with 20% Overloading						0.243	m^3/sec	
	Length of Channel = 7 x Throat Width						2100	mm	
	Provide Downstream Length of Channel						3.000	m	
3.0 Flash Mixer									
	3.1 Gate								
	Rate of flow with 20% Overloading						700.000	m^3/hr	
							11.667	m^3/min	
							0.194	m^3/sec	
	Provide Inlet Gate						1.000	Nos	
	Consider Velocity of Flow						1.200	m/s	Maximum 2 m/s allowable
	Required Area						0.162	m^2	
	Provide Width of Gate						0.600	m	
	Required Height of Gate						0.270	m	
	Provide Height of Gate						0.300	m	
	3.2 Flash Mixer								
	Rate of flow with 20% Overloading						700.000	m^3/hr	
							0.162	m^3/sec	
	Detention time						60	sec	
	Volume						9.722	m^3	
	Area Required						3.038	m^2	

	Adopt Depth to Diameter Ratio			
	Required Dia of Tank	2.134	m	
	Provide Dia of Tank	2.200	m	
	Side Water Depth = 1.5 x Dia	3.300	m	
	Provide Side Water Depth	3.200	m	
	Free Board	0.735	m	
	3.3 Diameter of outlet pipe from flash mixer to central shaft of Clariflocculator			
	Consider 20% overloading & velocity 1.20 m/s			
	Rate of Flow with 20% Overloading	0.194	m^3/sec	
	Assume Velocity in Pipe	1.200	m/sec	Maximum 2 m/s allowable as per CPHEEO
	Required Area of Pipe	0.162	m^2	
	Required Dia of Pipe	0.454	m	
	Provide Dia of Pipe	0.500	m	
4.0 Clarifloculator				
	4.1 Central Shaft			
	Rate of flow with 20% Overloading	700.000	m^3/hr	
		11.667	m^3/min	
		0.194	m^3/sec	
	Assume Velocity at exit of central column	0.500	m/sec	Assumed
	Area of Opening	0.389	m^2	
	Provide Slots	4.000	Nos	
	Area of Opening per slots	0.097	m^2	
	Height of Each Slots	0.400	m	
	Required Length of Each Slots	0.243	m	
	Provide Length of Slots	0.250	m	

Assume Velocity in Central Column	0.500	m/sec	Assumed
Area of Central Column	0.389	m^2	
Dia of Central Column	0.704	m	
Provide Dia of Central Column	0.750	m	
Inner Circumference of Central Column	2.356	m	
Spacing between slots	0.339	m	>0.15 m
4.2 Floculator			
Rate of flow	583.333	m^3/hr	
	9.722	m^3/min	
	0.162	m^3/sec	
Detention Time	30	min	
Volume of Flocculator	291.667	m^3	
Outer Dia of Central Column assume 0.2m Wall Thickness	1.150	m	
Area of Central Column with Wall	1.038	m^2	
Consider Depth of Flocculator	3.000	m	
Area of Flocculator	97.222	m^2	
Area of Central Column + Area of Flocculator	98.260	m^2	
Required Outer Dia of Flocculator	11.188	m	
Provide Outer Dia of Flocculator	11.200	m	
4.3 Clarifier			
Rate of flow	583.333	m^3/hr	
	9.722	m^3/min	
	0.162	m^3/sec	
Detention Time	150	min	
Volumn of Clarifier	1458.333	m^3	

	Consider Depth of Clarifier	3.000	m	
	Outer Dia of Flocculator assume 0.2m Wall Thickness	11.200	m	
	Area of Flocculator with Wall	98.470	m^2	
	Area of Clarifier	486.111	m^2	
	Area of Flocculator + Area of Clarifier	584.582	m^2	
	Required Internal Dia of Clarifier	27.289	m	
	Provide Internal Dia of Clarifier	27.300	m	
	Check for SOR = Cap / Area	23.929	< 30 m^3/m^2.Day	
	Check for Weir Loading = Cap with 20% Overloading / Circum	195.883	< 300 m^3/m^2.Day	
	Free Board	0.500	m	
	4.4 Peripheral Launder			
	Rate of Flow with 20% Overloading	0.194	m^3/sec	
	Rate of Flow with 20% Overloading at Half Circumference	0.097	m^3/sec	
	Consider Velocity in Launder	0.400	m/sec	Assumed
	Required Area of Launder	0.243	m^2	
	Provide Width of Launder	0.600	m	
	Required Depth of Launder	0.405	m	
	Provide Depth of Launder	0.420	m	
	Free Board	0.300	m	
	4.5 Slope Calculation			
	Slope as per BOQ/Tender	1:10		
	Vertical	1.000	m	
	Horizontal	10.000	m	
	Diameter	27.300	m	
	Radius	13.650	m	

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	Central Column				0.750	m	
	Radius Central Column				0.375	m	
	Sludge Drain				0.750	m	
	Distance				12.325	m	
	Vertical Distance as per Slope				1.233	m	
	Consider Vertical Distance				1.235	m	
5.0 Rapid Sand Gravity Filter Beds							
	5.1 Filter Water Inlet Channel						
	Rate of Flow with 20% Overloading				0.194	m^3/sec	
	Consider Velocity in Channel				1.000	m/s	Assumed
	Required Area of Channel				0.194	m^2	
	Consider Width of Channel				0.600	m	
	Required Depth of Channel				0.324	m	
	Provide Depth of Channel				0.350	m	
	Free Board				0.300	m	
	5.2 Filter Water Inlet Gate						
	Rate of Flow with 20% Overloading				0.194	m^3/sec	
	Assuming 3 Open Gate at one time				0.065	m^3/sec	
	Consider Velocity in Channel				0.750	m/s	
	Required Area of Gate				0.086	m^2	
	Consider Width of Gate				0.350	m	
	Required Depth of Gate				0.247	m	
	Provide Depth of Gate				0.300	m	
	5.3 Rapid Sand Filter						

	Rate of Flow with 20% Overloading	700.000	m^3/hr	
		11.667	m^3/min	
		0.194	m^3/sec	
	Rate of Flow with Overloading	700.000	m^3/hr	
		11.667	m^3/min	
		0.194	m^3/sec	
	Rate of Filtration	4800.000	Lit/hr	
		4.800	m^3/hr	
	Required Surface Area	145.833	m^2	
	No. of Bed to be provided	4.000	Nos.	
	Area of Each Bed	36.458	m^2	
	Consider Width of Bed	5.250	m	
	Required Length of Bed	6.944	m	
	Provide Length of Bed	7.000	m	
	Ratio of Length to Width	1.333		Range - 1.11 - 1.66 as per CPHEEO Pg 245
	Depth of Sand Bed	0.750	m	
	Depth of Gravel Bed	0.450	m	
	Depth of Water over the Filter Bed	2.000	m	
	Free Board	0.500	m	
	Total Depth of Filter Bed	3.700	m	
	5.4 Underdrainage System			
	Area of filter bed	36.750	m^2	
	Required area of orifices - 0.30% of area of filter bed			

	Total area of orifices	0.110	m^2	0.3% of filter bed C/S As per CPHEEO Page 247
	Ratio of area of orifice to area of laterals	0.500		<=0.5 for 12 mm perforation; <=0.25
				for 5 mm perforation As per CPHEEO Pg 247
	Ratio of area of manifold to area of laterals	1.500		As per CPHEEO Page 247
	Cross Sectional area of Laterals	0.221	m^2	
	Outer Dia of Laterals	0.090	m	
	Internal Dia of Laterals	0.083	m	Outer Dia = 90mm PVC
	C/S area of Laterals	0.005	m^2	
	Required Number of Laterals	40.774	Nos.	
	Provide Number of Laterals on each side of Filter Bed	42.000	Nos.	
	Provide Number of Laterals on both side of Filter Bed	21.000	Nos.	
	C/S area of all Laterals in each filter bed	0.227	m^2	OK
	Ratio of Length to Dia of Laterals	29.167		Max per value = 60 As per CPHEEO Pg 247
	5.5 Perforations			
	Perforations of size	12.000	mm	
	Surface area of perforations	0.000113	m^2	
	Required No of perforations	975.400	Nos	
	No. of Perforations per Laterals	23.224	Nos	
	Provide No. of Perforations per Laterals	24.000	Nos	
	Length available for laterals	4.300	m	
	Spacing of perforations	0.179	mm C/C	Max per spac = 0.200m for 12 mm dia perforations

	5.6 Manifold			
	C/S of Manifold	0.331	m^2	
	Size of Manifold	0.575	m	As per CPHEEO Manual
	Provide Manifold Size	0.650	m	
	5.7 Filter Outlet Pipe			
	Rate of Flow with 20% Overloading	0.049	m^3/sec	
	Considering Velocity	1.000	m/s	
	Required Area	0.049	m^2	
	Required inner dia of pipe	0.249	m	
	Provide Dia of Pipe	0.300	m	
	5.8 Inspection Chamber			
	Considering size of inspection chamber			
	Length	1.000	m	
	Breadth	1.000	m	
	Rectangular weir of width	0.750	m	
	Flowrate	0.061	m/s	
	Water depth over weir during the above flow	0.144	m	
	Free Board	0.300	m	
	5.9a Treated Water Channel Pure Water Channel			
	Rate of Flow with 20%	0.194	m^3/sec	
	Considering Velocity	1.000	m/s	
	Required C/S area of channel	0.194	m^2	

	Provide Width						0.500	m	
	Required Depth						0.389	m	
	Provide Depth						0.400	m	
	Free Board						0.300	m	
	5.9b Treated Water Channel from Filter to Clear Water Sump Through Pipe								
	Rate of Flow with 20%						0.194	m^3/sec	
	Considering Velocity						1.200	m/s	
	Required C/S area of pipe						0.162	m^2	
	Required dia of pipe						0.454	m	
	Provide Dia of Pipe						0.500	m	
	5.10 Clear Water Sump								
	Detention Time						1.000	Hr	
	Volumn of Sump						583.333	m^3	
	5.11 Air Blower								
	Air flow rate						750.000	Lit/min/m^2	
	Area of one bed						36.750	m^2	
	No. of bed						1.000	Nos.	
	Air flow rate per bed						27562.500	Lit/min	
							27.563	m^3/min	
	No. of blowers						2.000	(1W + 1SB)	
	Capacity of blower for washing one bed at a time with 50% overloading						41.344	m^3/min	
	Provide Air Blower (0.35Kg/cm^2) of capacity						42.000	m^3/min	

	5.12 Washwater Tank			
	Rate of backwash	600.000	l/m^2/min	
	Rate of backwash	36.000	m/hr	
	Area of each filter bed	36.750	m^2	
	Backwash water rate per unit	1323.000	m^3/hr	
	Number of filters to be backwashed simultaneously	1.000	Units	
	Duration of Backwash	12.000	min	
	Washwater requirement	264.600	m^3	
	Capacity of Washwater Tank 10 Cum Extra	10.000	m^3	
	Provide Washwater Tank of Capacity	274.600	m^3	
	5.13 Washwater Piping From Tank to Filter Bed			
	Rate of BackWash Flow	600.000	l/m^2/min	
	Designed Flow	0.441	m^3/sec	
	Consider Velocity	3.000	m/s	
	Cross Sectional Area	0.147	m^2	
	Internal Dia of Pipe	0.433	m	
	Provide Dia of Pipe	0.450	m	
	5.15 Wash water Collection & Disposal			
	5.15.1 Cross Troughs			
	Washwater Rate per Unit	11.025	m^3/min	
	Spacing of Cross Trough	2.500	m	
	No. of Cross Trough / Bed	2.000	Nos on Each Sides	
	Rate of Flow/Trough	5.513	m^3/min	

	Width of Trough	0.450	m	
	Depth of Trough	0.280	m	As per CPHEEO Equation of Free-Flowing Weir, Pg no. 250
	Provide, Depth of Water in Trough	0.300	m	
	Velocity of Flow in Trough	0.68	m/s	V < 1.3 m/s
	5.15.2 Main Trough			
	Number of Main Trough / Twin Filter	1.000	Nos	
	Rate of Flow / Trough	11.025	m^3/min	
	Provide Width of Trough	0.600	m	
	Depth of Trough	0.367	m	As per CPHEEO Equation of Free-Flowing Weir, Page No. 250
	Provide, Depth of Water in Main Trough	0.400	m	
	Free Board	0.100	m	
	Velocity of Flow in Main Trough	0.77	m/s	V < 1.3 m/s
	Number of Main Trough / Twin Filter	2.000	Nos	
	Rate of Flow / Trough	22.050	m^3/min	
	Provide Width of Trough	1.200	m	
	Depth of Trough	0.367	m	As per CPHEEO Equation of Free-Flowing Weir, Page No. 250
	Provide, Depth of Water in Main Trough	0.400	m	
	Free Board	0.100	m	
	Velocity of Flow in Main Trough	0.77	m/s	V < 1.3 m/s
	Expansion of Bed	0.350	m	As per CPHEEO Providing 20% height for bed expansion + 20% factor of safety + 0.05

5.15.3 Disposal Gutter			
Washwater Rate of Flow	1323.000	m^3/hr	
Number of filters to be backwashed simultaneously	1.000	Units	
Total Rate of Flow	1323.000	m^3/hr	
	0.368	m^3/sec	
Consider Velocity of Flow	1.500	m/s	
Required Cross Section of Pipe	0.245	m^2	
Provide Width of Channel	0.600	m	
Required Depth of Channel	0.408	m	
Provide Depth of Channel	0.420	m	
6.0 Chemical House			
6.1 Alum Solution Tank			
No. of tanks	3	Nos.	
Rate of flow with 20% Overloading	700.000	m^3/hr	
	11.667	m^3/min	
Maximum dose of alum	30.000	mg/lit	
Daily alum requirement	504.000	kg/day	
Hourly alum requirement	21.000	kg/hour	
Strength of solution	5.000	%	
Consumption of alum/hr	420.000	lit/hr	
Required alum/ 12hr	252.000	kg	
Capacity of tank required	3.360	m^3	
Provide liquid depth of Tank	1.700	m	
Required area	1.976	m^2	
Required width/length	1.500	m	

	Provide width/length			1.500	m	
	Gross Capacity			3.825	m^3	
	6.2 Bleaching powder dosing tanks					
	Maximum dose of free chlorine			2	mg/lit	
	Consumption of chlorine per day			33.60	kg/day	
	Consumption of chlorine per hour			1.400	kg/hr	
	Chlorine content in TCL powder			25.000	%	
	Consumption of TCL powder			5.600	kg	
	No. of tanks			3.000	Nos.	
	Rating of tanks			8.000	Hrs	
	Requirement of powder / 8 hr			44.800	kg	
	Strength of solution			5.000	%	
	Consumption of bleaching power			2.240	lit/hr	
	Capacity of tank			0.018	m^3	
	Provide liquid depth of Tank			1.000	m	
	Required area			0.018	m^2	
	Required width/length			1.100	m	
	Provide width/length			1.100	m	
	Gross Capacity			1.210	m^3	
7.0 Chlorination Units						
	a) Chlorination’s					
	Total flow to be disinfected			16.80	Mld	
	Maximum dose of chlorine			3	mg/lit	
	Chlorine requirements per day			50.40	Kg/day	
	Provide suitable chlorinators					

	b) Emergency Chlorination by TCL							
	Provide No of tanks					2		
	Assume 25% available chlorine							
	Bleaching Power required per day					201.60	Kg	
	Capacity of each tank for 12 hours					100.80	Kg	
	Assuming 10% strength of solution							
	Volume of solution Tank					1008	litre	
						1.008	Cum	
	Size of tank =	1	x	1	x	1.20	m	
	c) Chlorine Room and Chlorine Tonner Room							
	Tonner available in market					900	Kg	
	Daily requirement of chlorine					50.40	Kg/day	
	No of days tonner last					18	Days	
	1 No of tonner each 900 Kg will be installed and 1 tonner will be stand by.							
	The tonner room is normally adjoining to chlorine room							
8.0 Drains for Disposal of Waste Water								
	Drains for Clarifier							
	Assume 3% sludge generation							
	Rate of Flow with 20% Overloading					16.8	MLD	
	Quantity of Sludge Generation per Day					504	m^3/day	
	The Sludge drains 2 times a day for duration of 30 Min					0.14	m^3/sec	
	Design Flow					0.14	m^3/sec	
	Consider Velocity of Flow					2.000	m/s	
	Required Inner Dia of Pipe					0.299	m	
	Provide Dia of Pipe					0.300	m	

	Drains for Filter Backwash						
	Qty of Backwash per day				0.368	m^3/sec	
	Design Flow				0.368	m^3/sec	
	Consider Velocity of Flow				2.5	m/s	
	Required Inner Dia of Pipe				0.433	m	
	Provide Dia of Pipe				0.45	m	
	Drains for combined flow from Clarifier & Filter Backwash						
	Combined Flow				0.508	m^3/sec	
	Assume Velocity of Flow				2.5	m/s	
	Required Inner Dia of Pipe				0.509	m	
	Provide Dia of Pipe				0.55	m	

B. *Structural Analysis Using STAAD Pro*

Once the hydraulic design establishes the functional requirements and dimensions of the treatment units, the focus shifts to the structural modeling and analysis of these components using STAAD Pro software. STAAD Pro, a widely used structural analysis and design application, enables engineers to create detailed 3D models of the WTP structures, incorporating the geometries and material properties derived from the hydraulic design. The software allows for the application of various load conditions, including dead loads from the structure's self-weight, live loads from operational activities, hydrostatic pressures from stored water, and environmental loads such as wind and seismic forces. By simulating these load scenarios, STAAD Pro performs rigorous analyses to assess the structural integrity and performance of each component, identifying potential stress concentrations and deflection patterns. This comprehensive analysis ensures that the structures are designed to withstand all anticipated loads throughout their service life, adhering to relevant Indian Standards (IS) codes for safety and durability.

The integration of hydraulic design with structural modeling using STAAD Pro thus ensures that the WTP not only meets its treatment objectives but also maintains structural resilience and longevity.

1) *Data:*

- SBC as per Geotechnical Report @ 3.0m = 38.64 T/m2
- SBC Considered in Design = 20 T/m2
- Seismic Zone = III

2) *Applicable Code & Reference:*

The codes, standards, and references listed below will serve as the basis for structural design:

- IS 456 - Plain and Reinforced Concrete Code of Practice
- SP 16 - Structural Use of Concrete. Design charts for singly reinforced beams, doubly reinforced beams and columns.
- SP 34 - Handbook on Concrete Reinforcement & Detailing
- IS 1904 - Indian Standard Code of Practice for Design & Construction Foundations in Soil: General Requirements
- IS 2950- Indian Standard Code of Practice for Design and Construction of Raft Foundation (Part – 1)
- IS 1893:2016- Criteria for Earthquake Resistant Design of Structures.
- IS 13920:2016- Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces - Code of Practice.
- IS 875(Part 1): 1987 - Dead Loads - Unit Weight of Building Material and Stored Material
- IS 875(Part 2): 1987 - Imposed Loads

- IS 875(Part 3): 1987 - Wind Loads
- IITK – GSDMA – Guidelines for Seismic Design of Liquid Storage Tanks

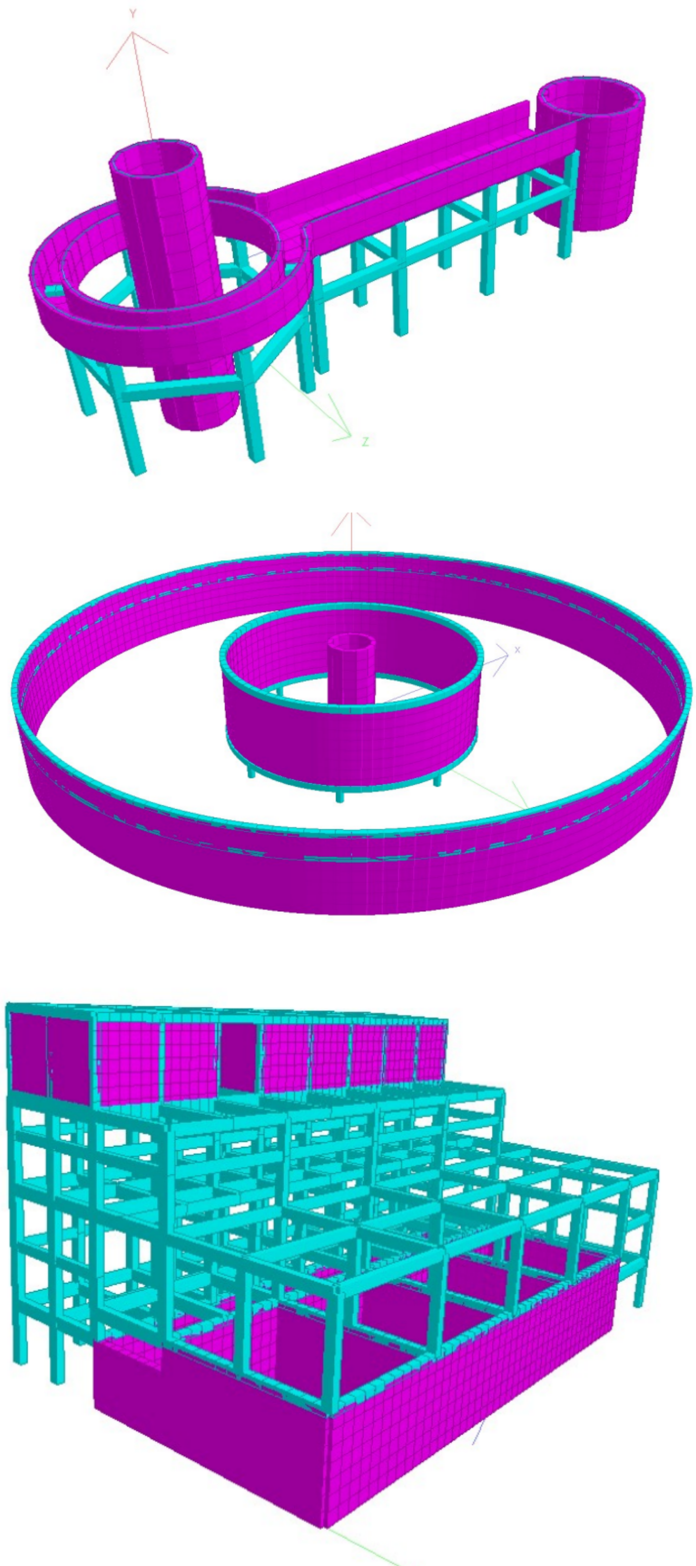

Fig. 4.1: STAAD Pro Working Interface

V. CONCLUSION

The design and analysis of the 14.00 MLD Conventional Water Treatment Plant (WTP) was carried out with a comprehensive approach integrating hydraulic and structural engineering principles. This project provided a detailed understanding of the functional requirements and structural demands of a WTP, including components like sedimentation tanks, filtration units, clear water reservoirs, and overhead tanks.Hydraulic design ensured the optimal flow of water through each unit, adhering to CPHEEO 2024 guidelines, while the structural design was validated using STAAD Pro software. Structural analysis considered critical loads including dead load, live load, hydrostatic pressure, and seismic forces. The results confirmed the stability, strength, and serviceability of all components, complying with IS 456:2000 and relevant codes.The use of STAAD Pro enabled precise modeling and design optimization, reducing material waste and improving structural efficiency. The integrated approach ensured the development of a durable, safe, and cost-effective WTP that can function reliably under varying operational conditions.

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