Grenze International Journal of Engineering and Technology, June Issue

A Review Paper on Optimal Structural Design of Rapid Sand Filter using Staad pro

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***Abstract*— The design of the Rapid Sand Filter (RSF) structure is extremely significant to enable the water treatment plant to be long-lasting, safe, and functioning. This research is primarily aimed at coming up with a structural design of the optimum structure design of the RSF unit, stability, strength and application of optimal sizes of the member in the process of developing an economical and efficient structure under various operation and environmental loads. The research involves the study of the main construction components such as the filter box, Beams, Columns, slabs and the Beams that hold the structure. The design principles of reinforced concrete were followed in accordance with the required IS codes in order to manage the water pressure, self-weight, soil pressure and even backwash operations loads. STAAD Pro modeling and structural analysis were performed to discover the critical stresses and deflections which will be used to ensure serviceability and control the crack. The resulting design of RSF became structurally sound, economical and long-lasting which was capable of long service years at very minimal maintenance. In general, the research demonstrates the significance of the combination of structural optimization and functional needs to have a sustainable water treatment system.**

***Keyword*— Rapid sand filter (RSF), IS 3370:2021, Limit state method, integrating structural optimization, STAAD PRO Software.**

I. INTRODUCTION

Water is a very essential commodity to life and the provision of clean and safe drinking water is a major duty of any community. In order to realize this, water treatment plants are developed to eliminate the impurities, suspended solids, and various pathogens that render water acceptable to be used in the household and industrial purposes. Filtration is one of the most popular treatment processes; Rapid Sand Filters (RSFs) are the most popular given that they provide high filtration rates, are easy to maintain and they are also useful in minimizing turbidity. This paper is aimed at coming up with an ideal structural design of RSFs that will be stable and cost effective. Design principles in reinforced concrete, which the IS codes, including IS 456:2000 and IS 3370: 2021, addressed, were used to attain strength, durability, and economy. Stresses, deflections and crack control were assessed by analytical and computational techniques in various load conditions so that the design is safe and reliable during its service life. The paper also points out the benefits of optimization in building design in the minimization of the size of members and the use of reinforcing elements without compromising performance or safety.

Grenze ID: 01.GIJET.12.2.62_22

The RSF structure was well integrated not only to reduce the construction cost, but also enhance sustainability of the whole water treatment facility. In the end, the project show how combining structural engineering with environmental and hydraulic aspects can lead to a reliable, efficient, and long-lasting Rapid Sand Filter design which is suitable for today's water treatment systems.

II. Literature Review

Ref. [1]: The requirements for the Water Treatment Plant (WTP) design include the population, geographical location, and variation in future requirements, and so on. For the design of the water treatment plant, highly precise information is needed. The information about the population for the past decade is available with the concerned governmental authority, and based on which population projections can be carried out. The calculation for water requirements will be based on the projected population. The survey will be carried out from the intake well to the water treatment plant to determine the difference in levels (elevation). The length of the pipe line will also be calculated. The design of the hydraulic system is dependent on water requirement, water level difference, and length of pipes. In the design of the component, the Water Supply Manual is used. Another structural design is completed pertaining to the Clariflocculator. In the design process, the conventional method is applied. The drawings are produced using Auto-CAD. Ref. [2]: Water Treatment Plant (WTP) having the capacity of 6.6 Million Liters per Day (MLD) has also been designed and implemented in the Belpada village of Odisha. The main intention behind the implementation of the plant is to satisfy the growing demands for water. The plant requires raw water from the Tel River and uses a simplified process such as Aeration, Sedimentation, Filtration, and Disinfection. This research paper presents the hydraulic design of the WTP, different treatment systems, as well as the different components of the structure. The calculations carried out for the design incorporate the standards of CPHEEO. Water treatment plants are an important part of the provision of safe drinking water, especially in areas where the density of population and industrialization are high. The 6.6 MLD WTP built for the Belpada village (Balangir district) takes its supply from the Tel River and aims to remove contaminants using the "Cascade Aeration System." It is on this background that this paper shall discuss the design parameters related to the water flow rate, capacity, and loading rate that satisfy the norms set by the Central Public Health and Environmental Engineering Organisation (CPHEEO). Ref. [3]: The role of Water Treatment Plants (WTPs) is critical for the provision of clean and potable water. The soundness of the structure of WTPs is important for the efficiency of WTPs. This review paper is set to examine the different structural elements of WTPs, the techniques used, and the design criteria that govern the construction of the structures. This paper seeks to understand both the conventional and contemporary designs of the structures, with particular emphasis on loading, seismic analysis, materials, and sustainability. The aim of this research is to bring together ideas from various research publications and documents to achieve a holistic understanding of structural analysis/design in water treatment plants. Ref. [4]: The quality of potable water deteriorates every day. It is the demand of this time that public is delivered with clean and safe drinking water. Filtration in the sand is one of the methods applied to acquire clean, free-from-infection water. According to the World Health Organization, water and sanitation are some of the most important aspects of public health. The first and foremost aim of this research work is to upgrade the filtration techniques so that they may be more achievable and useful for the people of the community. This deals with designing better and modified operational methods for Rapid Sand Filtration Technology. Ref. [5]: Rapid Sand Filters are widely used in almost all traditional water treatment works. The most prominent difficulty associated with Rapid Sand Filters is stratification, which hinders using these layers of sand fully. The purpose of this article is to devise a filter that is efficient, economical, and has a high rate of filtration. Filtration is an important method of water treatment as it helps to prevent the entrance of (or eliminate) suspended matter, micro-organisms (such as bacteria, viruses, and protozoa cysts), and heavy metals (such as iron and manganese) that may be present within the water.

III. Design Criteria of Rapid Sand Filters (RSF)

- The count of filter modules is determined using the formula: N = 1.22 times the square root of Q,
- Where N stands for the number of filter modules and Q is the plant's daily output in million liters.
- The ratio of length to width typically ranges from 1.25 to 1.33. Dimensions can extend up to 9 meters in width and 12 meters in length as standard.
- The filtration speed is roughly 100 liters per square meter per minute across the sand layer's surface.
- The highest allowable drop in water level is between 2.5 and 3.0 meters.
- For the drainage system beneath:

- The ratio of lateral pipe length to its diameter should not exceed 60.
- Holes in the pipes measure 6 mm to 13 mm in diameter, spaced 7.5 to 20 cm apart accordingly.
- The combined area of all holes equals 0.2% of the entire filter surface.
- The total hole area relative to the lateral pipe area is 0.25 to 0.30, depending on hole sizes of 6 mm or 13 mm.
- Laterals are placed no more than 30 cm apart.
- The main pipe's cross-section should be 1.75 to 2 times the combined area of the lateral pipes.

➢ Cleaning flow rate: 15 to 90 cm per minute, with 45 cm per minute being a common choice. This can be achieved with 500 liters per square meter of bed area per minute.
➢ Volume of cleaning water used: 2 to 4% of the total filtered water.
➢ Cleaning duration: 10 to 15 minutes, with intervals between cleanings of 24 to 28 hours.
➢ Pressure for supplying cleaning water: 1 kg per square cm.
➢ Top speed in the main pipe to deliver the needed cleaning water: 1.8 to 2.5 meters per second.
➢ Each module's output should be in even multiples of a portion between 4.5 million liters per day and 22.5 million liters per day. At least two modules are required, allowing one to serve as a backup.

IV. METHODOLOGY

The methodology adopted for the optimal structural design of the rapid sand filter (RSF) focuses on achieving structural safety, serviceability and efficiency while meeting functional requirement of WTP. The study was carried out through a systematic step by step approach.
The following steps are follow to complete my project study.
Data collection for design
Functional layout of RSF (Ref figure 1)
Load calculation
Structural analysis in Staad pro (ref table II & III)
Structural design of component
Optimization approach
Safety and Serviceability checks
Preparation of drawing & documentation

V. STRUCTURAL ANALYSIS AND DESIGN

A. Design Parameter Consideration:

➢ Scope: This document covers the analysis and design of Filter
➢ Units of measurement: All units used in the analysis and design are SI system unless otherwise specified.
➢ Soil Data: Safe bearing capacity considered in Design 200 KN/ m2 at a depth of 1.5 m below NGL/FGL.
➢ Material

Grade of Material - Reinforced Concrete
Concrete grade for Water retaining structure- M 30
Concrete grade non water retaining structure- M 30
Grade of Steel- Fe 500

Unit weight of material (Ref. IS 875-Part 1)
Reinforced Concrete- 25 KN/ m3
Plain Cement Concrete- 24 KN/ m3
Soil- 18 KN/ m3
Water- 10 KN/ m3

Elastic Modulus
Modulus of elasticity for M 30 Grade concrete 5000xSQRT (Fck) =27386.13 N/ mm2
Modulus of elasticity for Steel = 200000 N/ mm2
IS Code used
Reference, [6], [7], [8], [9], [10], [11] & [12].
Clear Cover as shown in Table I

TABLE I. CLEAR COVERS

Component	Clear Cover in mm
Wall	45
Slab	25
Column	40
Beam	30
Foundation	50

B. Load Consideration:

- Dead load
- Member load

230 mm thk. brick wall load
0.23*25*3 = 13.8 KN/ m

Floor Load
Slab load of 150mm Thk
0.15*25 = 3.75 ~ 4 KN/ m^2
Slab load of 200mm Thk
0.2*25 = 5 KN/ m^2

C. Live load

Live load on slab = 3 KN/ m^2
Live load on Roof slab = 1.5 KN/ m^2

D. Water Load

water load on bottom of backwash tank
10*3.3 = 33 KN/m^2

Load Cases Consideration:
FACTOR LOAD COMB
201 1.2 X (DL+LL+EQX+)
202 1.2 X (DL+LL+EQX-)
203 1.2 X (DL+LL+EQZ+)
204 1.2 X (DL+LL+EQZ-)
205 1.2 X (DL+LL+WLX+)
206 1.2 X (DL+LL+WLX-)
207 1.2 X (DL+LL+WLZ+)
208 1.2 X (DL+LL+WLZ-)
300 1.5 X (DL+LL)
301 1.5 X (DL+EQX)
302 1.5 X (DL+EQX-)
303 1.5 X (DL+EQZ+)
304 1.5 X (DL+EQZ-)
305 1.5 X (DL+WLX+)
306 1.5 X (DL+WLX-)
307 1.5 X (DL+WLZ+)
308 1.5 X (DL+WLZ-)
401 0.9 DL+ 1.5 EQX+
402 0.9 DL+ 1.5 EQX-
403 0.9 DL+ 1.5 EQZ+
404 0.9 DL+ 1.5 EQZ-
405 0.9 DL+ 1.5 WLX+
406 0.9 DL+ 1.5 WLX-
407 0.9 DL+ 1.5 WLZ+
408 0.9 DL- 1.5 WLZ-
UNFACTOR LOAD COMB
501 1DL+1LL+1WTR
502 1DL+1LL+1SOIL

Staad Model - Rapid Sand Filter as shown in Figure 1.

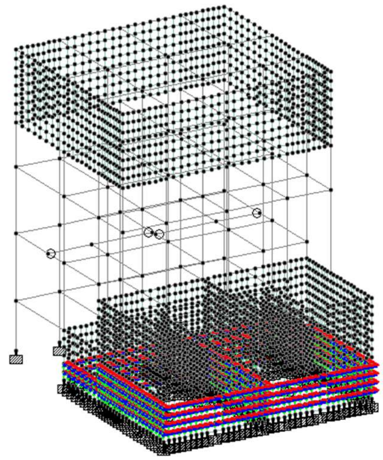

Figure. 1: Staad model- RSF

Plate result - Rapid Sand Filter as shown in Table II and III

TABLE II. PLATE RESULT - SUMMARY TABLE OF FILTER BED

			Shear		Membrane			Bending Moment		
	Plate	L/C	SQX (local) N/mm2	SQY (local) N/mm2	SX (local) N/mm2	SY (local) N/mm2	SXY (local) N/mm2	Mx kN-m/m	My kN-m/m	Mxy kN-m/m
Max Qx	4958	501 1DL+1LL	**0.628**	0.967	0.821	-0.470	-0.220	-28.254	-63.190	-5.828
Min Qx	4887	501 1DL+1LL	**-0.627**	0.964	0.822	-0.471	0.230	-28.114	-63.147	5.823
Max Qy	4958	501 1DL+1LL	0.628	**0.967**	0.821	-0.470	-0.220	-28.254	-63.190	-5.828
Min Qy	4433	501 1DL+1LL	0.469	**-0.493**	-0.294	0.025	-0.023	-18.599	-9.616	2.155
Max Sx	4881	501 1DL+1LL	-0.084	0.149	**0.876**	0.412	-0.009	9.251	-15.661	0.044
Min Sx	4956	501 1DL+1LL	-0.386	-0.297	**-0.687**	-0.143	-0.072	-15.552	7.891	6.204
Max Sy	4711	501 1DL+1LL	-0.026	0.132	0.603	**0.422**	0.041	19.469	1.648	4.143
Min Sy	4788	501 1DL+1LL	0.213	-0.032	0.078	**-2.305**	-0.605	-22.614	-7.756	0.497
Max Sx	4717	501 1DL+1LL	-0.286	-0.047	-0.018	-1.621	**0.637**	-17.065	-4.449	4.677
Min Sxy	5128	501 1DL+1LL	0.285	-0.047	-0.006	-1.577	**-0.629**	-17.092	-4.372	-4.693
Max Mx	4731	501 1DL+1LL	-0.047	0.016	0.143	0.272	0.152	**21.443**	13.394	3.472
Min Mx	4821	501 1DL+1LL	0.264	-0.009	0.362	-0.502	-0.054	**-31.975**	-5.129	-0.579
Max My	5255	501 1DL+1LL	0.006	-0.037	0.086	-0.071	0.064	-2.983	**26.067**	-0.475
Min My	4958	501 1DL+1LL	0.628	0.967	0.821	-0.470	-0.220	-28.254	**-63.190**	-5.828
Max Mx	4871	501 1DL+1LL	-0.144	-0.090	-0.268	-0.176	-0.142	-5.374	9.898	**8.343**
Min Mxy	4209	501 1DL+1LL	-0.040	0.216	0.280	-0.156	0.036	-1.976	1.475	**-8.367**

TABLE II. PLATE RESULT - SUMMARY TABLE OF FILTER BED

			Shear		Membrane			Bending Moment		
	Plate	L/C	SQX (local) N/mm2	SQY (local) N/mm2	SX (local) N/mm2	SY (local) N/mm2	SXY (local) N/mm2	Mx kN-m/m	My kN-m/m	Mxy kN-m/m
Max Qx	1389	501 1DL+1LL	**0.047**	0.060	0.294	-1.663	-0.931	1.653	-1.520	-1.205
Min Qx	1054	501 1DL+1LL	**-0.042**	-0.031	0.066	-1.610	-0.670	-1.649	-3.216	-0.199
Max Qy	3637	501 1DL+1LL	-0.027	**0.072**	0.318	-1.044	0.492	-0.075	-0.060	0.066
Min Qy	5655	501 1DL+1LL	-0.014	**-0.047**	-0.047	-0.849	0.101	-0.057	-1.258	-0.306
Max Sx	1251	501 1DL+1LL	-0.013	0.006	**0.877**	-0.040	-0.025	-0.155	-0.333	0.680
Min Sx	1529	501 1DL+1LL	0.007	0.009	**-1.921**	-3.676	-2.620	0.441	0.489	0.281
Max Sy	205	501 1DL+1LL	0.004	-0.016	0.002	**0.018**	-0.017	0.093	0.550	-0.051
Min Sy	1529	501 1DL+1LL	0.007	0.009	-1.921	**-3.676**	-2.620	0.441	0.489	0.281
Max Sx	1663	501 1DL+1LL	-0.014	0.012	-1.917	-3.671	**2.616**	0.884	0.557	-0.162
Min Sxy	1529	501 1DL+1LL	0.007	0.009	-1.921	-3.676	**-2.620**	0.441	0.489	0.281
Max Mx	1389	501 1DL+1LL	0.047	0.060	0.294	-1.663	-0.931	**1.653**	-1.520	-1.205
Min Mx	1381	501 1DL+1LL	0.035	-0.018	-1.484	-3.247	2.325	**-1.880**	-0.040	-0.456
Max My	1642	502 1DL+1LL	-0.001	-0.010	-0.044	-0.907	-0.159	0.154	**1.289**	-0.011
Min My	1069	501 1DL+1LL	0.015	0.032	-0.998	-2.027	-1.365	-0.728	**-3.476**	-1.873
Max Mx	1177	501 1DL+1LL	-0.014	0.032	-1.001	-2.030	1.367	-0.680	-3.470	**1.787**
Min Mxy	1069	501 1DL+1LL	0.015	0.032	-0.998	-2.027	-1.365	-0.728	-3.476	**-1.873**

VI. CONCLUSION

In this study, I found the limited study available on RSF and there is gap on optimal structural design of RSF component. Since structurally optimized rapid sand filters help to make sure both safety and performance goes together. A reinforced and well-designed tanks, foundations, and support part stop deformation under working loads and backwashing pressure. When we focus more on integrity, like choosing the right material, wall and foundation design, and how the load is distributed. The filter achieves reliable operation over its service life. Structural optimization not only makes it more durable and safer, but also reduces long-term maintenance and repair costs, making the whole water treatment system more sustainable and efficient.

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