The Eurasia Proceedings of Science, Technology,
Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2023

Volume 22, Pages 268-273

ICBASET 2023: International Conference on Basic Sciences, Engineering and Technology

Sizing and Structural Analysis of Mechanical Bar Screen

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Abstract: With the increase in the world population and improvement in industrial innovations, amount of municipal and industrial wastewater has increased dramatically. Therefore, municipal wastewater treatment systems have become a vital factor in sustaining water sources and decreasing the wastewater discharge to the environment. The first step in preliminary treatment of the wastewater is generally implemented using screening the large solid contamination. Bar screens are particularly an optimal solution for screening the wastewater in pumping stations, municipal and industrial wastewater treatment plants, and also at the inlet of the power plants. In this study, analytical method is used to determine the relationship between the screen size and the slope of streaming water channel. This correlation is now being used during the design of mechanical bar screens at our facility. In this study, Finite Element Analysis is also used to verify the structural strength of the inclined bar screen systems which have been designed, manufactured, and operated by our team. To investigate structural durability of the frames of the mechanical bar screen, static analysis is first checked by Autodesk Inventor Frame Analysis module, then Autodesk Inventor Nastran is used for detailed Finite Element Analysis.

Keywords: Wastewater, Bar screen, Analytical method, Structural analysis, Finite element analysis

Introduction

Waste treatment plants are established to reduce the possible damage of both municipal and industrial wastewater to the environment and to ensure the continuity of usable water. The treatment system consists of more than one step and different processes according to the characteristics of the wastewater. Preliminary treatment is the first of these steps. There are various treatment systems within the preliminary treatment itself. A successful mechanical preliminary treatment is important to protect the downstream processes from clogging, agglomeration, and wear in downstream equipment. One of the most commonly used methods in preliminary treatment is mechanical screening. In general, the main objectives of mechanical screening are removal of untreated solids, protection of subsequent treatment units, and improvement in the performance of treatment units. Briggs et al. (2005) examined different screen types by evaluating the effect of physical properties in the quality of outlet stream. Zabava et al. (2016) studied different equipment used in mechanical stage of the wastewater treatment plant and compared their effectiveness in removing the solid particles. It has been observed that the most effective mechanical screening approach is to use inclined bar screens for the transport of solid particles. Saju et al. (2020) investigated manual screen design for municipal waste by examining the chemical properties and behavior of various wastes in Khulna city in Bangladesh. In South Asian countries,

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- Selection and peer-review under responsibility of the Organizing Committee of the Conference

where the world's population is dense, it is inevitable that wastes will increase with population. As a results, waste diversity and water pollution are considerably high. By analyzing the chemical properties of the filtered water, it was clear that mechanical bar screen played a crucial rule in reducing the polluting chemical agents. Roth et al. (2018) made design optimizations for sediment removal in streams and floodplains. Similarly, Schalko & Weitbrecht (2022) used mathematical modelling for optimal design of bar screen used for removing sediments as well as large pieces of wood during floods. Ali et al. (2019) carried out a detailed study for the removal of residues in wastewater and provided a mathematical model which illustrates the relationship between water and solids. This study addressed the design of bar screens by obtaining hydrodynamic solutions for water flow, and structural analysis of the rake system used for solids drainage according to Von-mises yield criteria.

In this study, the design of an inclined mechanical bar screen is realized by 3D modeling in Autodesk Inventor and structural analysis with Autodesk Nastran software according to the Von-Mises criterion and obtaining the stress values on the bar screen. The relationship between the screen size and the slope of streaming water channel is also investigated in order to optimize the size of the mechanical bar screen. The goal is to present an improved mechanical bar screen, to effectively reduce water pollution and increase the availability of usable water.

Design of Mechanical Bar Screen

The main parts of the mechanical screen are the screen bars, the screen frame, the drive mechanism, chain group and the harrow system (Figure 1). The system starts to rotate while working with through the instrumentality the gearbox, so that the wastes are transported with a rake on the system, and discharge to the conveyor takes place from there. Conveyor is required to collect the wastes falling from the screen.

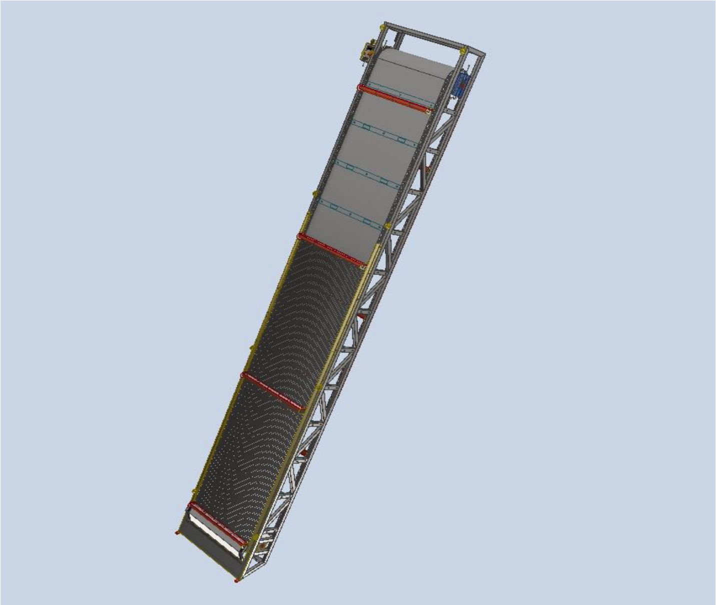

Figure 1. 3D modeling of mechanical bar screen

A safety sensor is used to cut off the energy of gearbox, and level sensor is used to operate the system, which is activated according to a certain height for water height. The level sensor acts as a float, preventing needless operation of the system. The sensor adjusted to the minimum water height continues to operate until the water drops below the adjusted height. Dimensioning is done by analytical and finite element analysis in line with the data obtained during the design of the coarse screen mesh. The work by Metcalf & Eddy (1991) includes design criteria for mechanical bar screen.

Table 1. Screen design criteria

	Manual Cleaning	Mechanical Cleaning
Velocity between screen bars (m / sn)	0.3-0.6	0.6-1
Bar section (thickness / width) (mm)	(4-8) / (25-50)	(8-10) / (50-75)
Cleaning between bars (mm)	25-75	10-50
Horizontal angle of grating with channel (degree)	45-60	70-85

Method

Analytical Method

Parameters for the analytical solution of the model are shown in the figure (Figure 2), channel width b = 1.84 m, distance between screen bars 0.02 m, slope of the channel s = 1/5000, the number of bars 52, the angle of the screen and the screen horizontal is $\gamma = 70°$, the size of the bars is 2 meters in width and 6 meters in length. Depending on the above parameters, depth of water and velocity of the flow through the screen and the approach channel is investigated at the most critical operating conditions according to the minimum and maximum flowrate.

The minimum and maximum velocity between the bars and in front of the screen are taken as, 0.9 m/s < V < 1.2 m/s. Metcalf & Eddy (1991)

$$v = \frac{Q}{A}$$

Energy losses, also known as head losses, occur as the magnitude of the velocity changes due to the screen of the channel. The height of the flow resulting from head loss is driven by the Bernoulli equation as below.

$$h = \frac{1}{0.7}\ x\ \frac{V\imath zgara^2 - V\imath zgara\ \ddot{o}n\ddot{u}^2}{2\ x\ g}$$

Inside the channel, the water depth and velocity are found at points where the flowrate is minimum and maximum, according to the K coefficient. 0.3 m/s < Vmin < 0.5 m/s.

$$K = \frac{Q\ x\ n}{b^{8/3}\ x\ s^{1/2}}$$

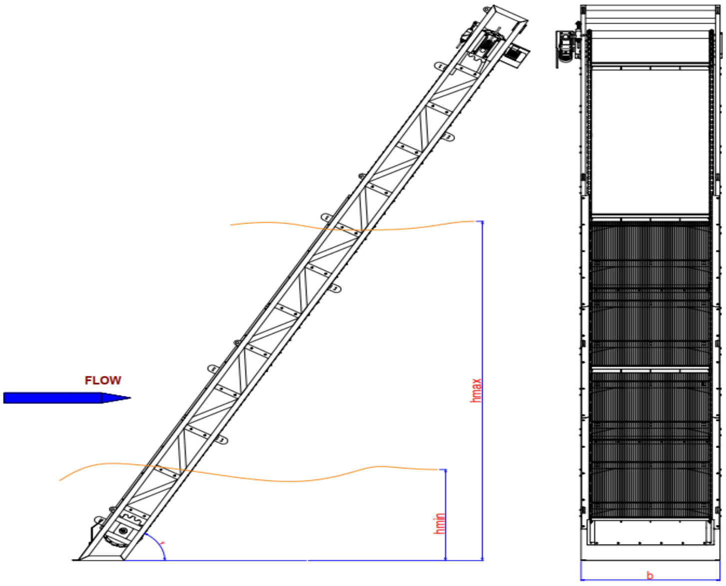

Figure 2. Schematic diagram of bar screen

Finite Element Analysis

Before fabrication stage of the designed system, it is verified by static analysis on the 3D model with the finite element method in line with the process & analytical solutions. Firstly, frame analysis for the frame of the system is examined with Autodesk Inventor Nastran software, and in the next step, static analysis is applied to the screens under a certain load.

Table 2. Properties of the materials

Material	Element Type	Mass Density	Yield Strength	Ultimate Tensile Strength	Young's Modulus	Poisson's Ratio
SS-304	Beam	8 g/ cm³	250 MPa	540 MPa	193 MPa	0.3 ul
SS-304	Bar	8 g/ cm³	250 MPa	540 MPa	193 MPa	0.3 ul

For frame analysis, the system is loaded in the z-axis direction starting at 5000 N and ending at 15000 N. Gravitational flow was estimated in this study. It will not have a high flow rate, but the result of the static analysis has been verified by loading the bars with a continuous pressure of 3 bar. The model consists of a total of 421913 nodes and 177449 elements.

Results and Discussion

The strength of the bars determined by static analysis as seen in the Figure 3, the stress values of the system analyzed according to the Von-Mises criterion are displayed. It has been understood that the bars with a result of 17.74 MPa at the place of maximum is found to be considerably lower than the material yield stress.

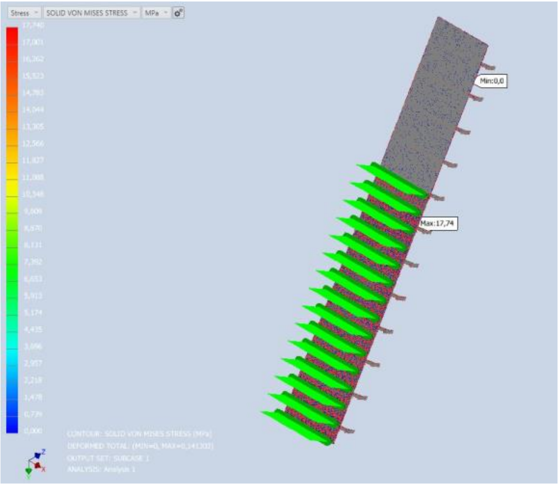

Figure 3. Stress values of mechanical bar screen

Results for the displacement are shown in Figure 4. Maximum deformation is found to be 0.14 mm which does not affect functionality of the mechanical bar screen. To minimize exerted forces due to water flow and particles to be removed from channel, reinforcement plates are placed vertically on the frame. Resulting lower deformation and decreased stress values.

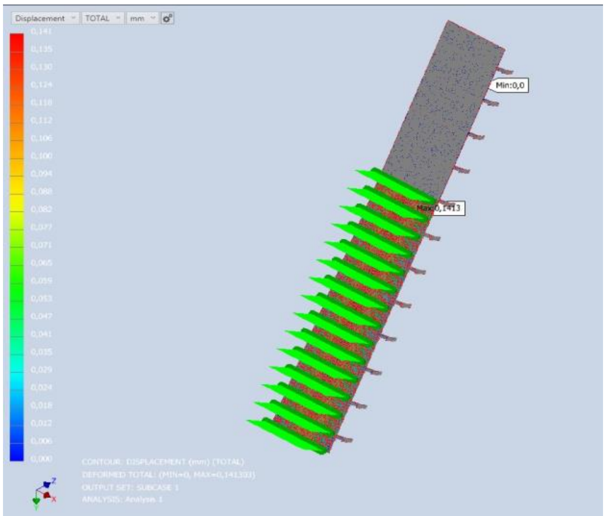

Figure 4. Displacement values of mechanical bar screen

With the analytical solution, the data shown in the Figure 5 is obtained. The results are in line with the relationship between the water height, width, and channel slope. The channel width is kept constant in the obtained data. With the result, it was seen that the water height increased as the slope decreased. The slope of the channel should be taken into account in the field studies. In the channel where the flow is constant, the relationship of the slope with the velocity can be evalueted, but with the increase of the velocity, it becomes more difficult for the screen to hold wastes.

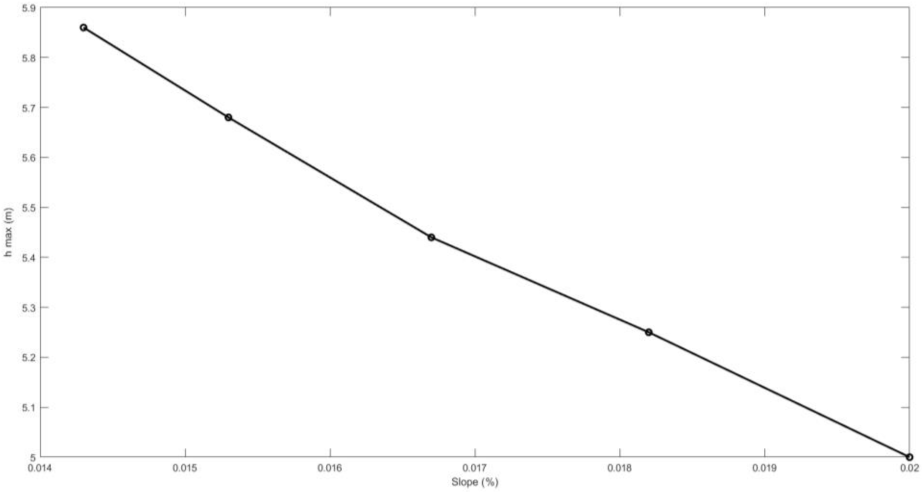

Figure 5. Slope-height relation of screens

Thanks to the mathematical modeling and structural analysis of the bar screen, the performance of the screens fabricated in our company has received positive feedbacks in the field applications. Figure 6a, Figure 6b are two examples of the units which have been designed, verified, fabricated, and commissioned in the site.

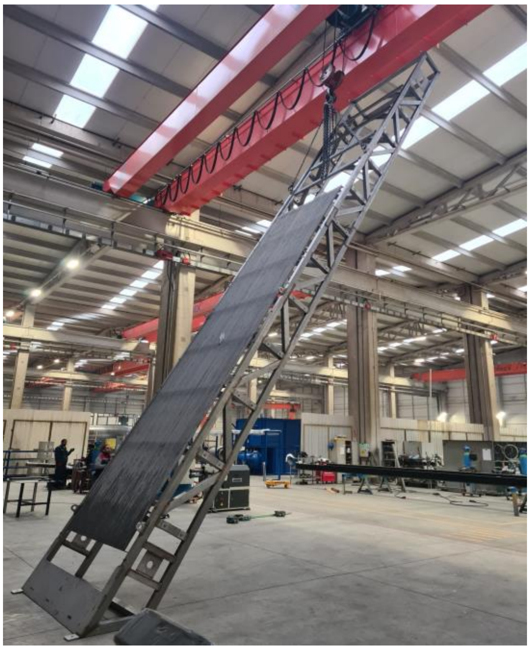

Figure 6a. Mechanical bar screen manufacturing

Figure 6b. Mechanical bar screen field application

Conclusion

The design of the system carried out by sizing the mechanical bar screen with analytical method and analyze the strength of the system with finite element analysis. It has been concluded that attention should be paid to the importance of the parameters and criteria used in the design. These issues are; maximum flow rate, width of the channel, slope of the channel, water height, head losses, distance between the screens, the process to be applied after the screen and the type of waste depending on the process.

Recommendations

Preliminary treatment, which is the first step of the purification process, consists of two processes. In this study, the coarse screen, which is the first stage, mentioned. It can be designed for fine screen by additional flow analysis with the same solution method. In addition, a brush system and irrigation method can be used for the wastes adhering to the screen for the designed coarse screen.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as oral presentation at the International Conference on Basic Sciences, Engineering and Technology (www.icbaset.net) held in Marmaris/Turkey on April 27-30, 2023.

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To cite this article:

Turgut, S., Yenisoy, Y., Mohamadi, Y. & Torun, K. (2023). Sizing and structural analysis of mechanical bar screen. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 22,* 268-273.