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Improving Dam Capacity Using a Dredger to Remove Sediment and Prevent Environmental Pollution During the Recovery Process

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Abstract

Coal-ash waste deposit built up in the recovery dam because of a constant inflow from the ash heap. This practice caused an overflow into the land, affected lives of the nearby community members. It also decreased the capacity of the dam and slowed down the plant's operation. In the current study, the design machine that will recover this sediment without it being contaminated or destroyed during the operation was developed and tested. The designed hydraulic dredger removed 20.7kg of excess sediment that was in the dam per second. This achieved through hydraulic forces and pipelines connected to the pump that sent the waste-ash back to the ash heap. The dredger helps the plant as it increased the production and saved the community from land and water pollution. This system revealed the facts during operation. The amount of sediment removed was 372600 kg per day, which emptied the dam by 7.57 % of the total present sediment that was removed. Therefore, flooding was prevented.

Keywords: Sediment, heap, deposits, capacity, pump, and dredger

INTRODUCTION

The sediment reduced the capacity of the dam filled with these waste deposits. Pollution is a global problem, and they needed a solution to remove the sediment from the dam to the heap and prevent contaminated water from flooding into the land. The previous method was unsuccessful; it comprised a pump that pumps water only. They needed a floating machine to draw sediment without it being damaged while in operation, scoop the material and transfer it to the ash heap. As the inflow of sediment was constant, the volume that the dam can hold decreased and resulted in the dam overflowing and spilling sediment into the environment. The process began at the power station, where the waste ash was conveyed from the boilers as a mixture with water in a slurry form. This fed into the main ash heap, which was shaped like a pyramid that had a catchment area in the centre. The inflow of slurry was continuous and raised the water level and sediment in the dam.

The previous method used to remove this sediment was to stop the operation of the plant and pump out the water to an alternative holding dam. They had to wait for the sediment to dry up and brought front-end loaders and tipper trucks. These trucks loaded, transported, and dumped the sediment to another uncontrolled location. An alternative method was to have a machine that removed sediment without disturbing the plant's operating procedure. A hydraulic dredger solved, removed, and minimizes the sediment build-up. The barge, connected to a boom with a suction pipe and cutter, could reach to the bottom of the dam. It sucked the water up through the boom while the cutter rotated and broke down the sediment on the floor. This sediment pumped through a gravel pump on the dredger, drawn through a discharge pipe back to the main ash heap where it settled. This study was aimed to improve the capacity of the dam by removing sediment, improve the plant's performance, and simultaneously create a better environment free from pollution.

An area that experienced flooding, because of the excess sediment, was in the Sasolburg region under the Metsimaholo Municipality. The section that was improved was the secondary dam that was referred to as a recovery dam next to the ash heap. They discarded the waste coal ash in the process flow where it was conveyed with water to the de-watering plant. The solid particles sunk to the bottom of the de-watering system were further conveyed to the thickener. (Sasolburg Operations, 2020)

The coal ash and water mixture, also called slurry, sunk to the bottom of the thickener when contaminates were pumped to the ash heap. It transported all the deposits from the plant boiler in stages through a conveyor to the ash heap. The excessive amount of silt changed the colour of water in the dam. This water spilt out of the ash heap sped up the collection of silt developing in the dam. The water channels and streams stored their sediment loads in settled waters, where the accumulated deposit can affect the environment negatively. (Bennett, 2020)

The previous design for this study comprised two different methods. The first method comprised a pump that returned the excess water to the ash heap. Hence, the method was unsuccessful and led to a build-up of sediment at the base of the dam; this resulted in reducing the capacity of the dam. The pump could not reach the sediment and pumped water only. The second method to assist the first method was the use of excavators and tipper trucks since the pump could not pump the sediment back to the heap. There was a need of having a machine that would remove sediment from all corners of the dam, with high efficiency, to transport sediment back to the ash heap. After the sediment dried up, the contractors removed sediments every month.

Unfortunately, the contractors only had a mechanical method to remove the sediment from the dam. Therefore, it was necessary to have a machine that removed the excess sediment and transfer it to the ash heap. A hydraulic dredger cut, scoop, draw and transfer the sediment through the pipeline. This dredger comprised the major components such as the cutter head, which is a cutting device that helps to remove sediment from the dam. It also comprised a ladder, hydraulic cylinder, pump and a pipeline.

METHODOLOGY

The first and one of the most important components in the Cutter Suction Dredger was a hydraulic cylinder. It was a source of support for the ladder, connected to the dredger and cutter head, and it controlled the ladder's movement.

The force that the cylinders exerted such as the tensile and compressive force as shown in table 1, which was easily computed with the formulas below:

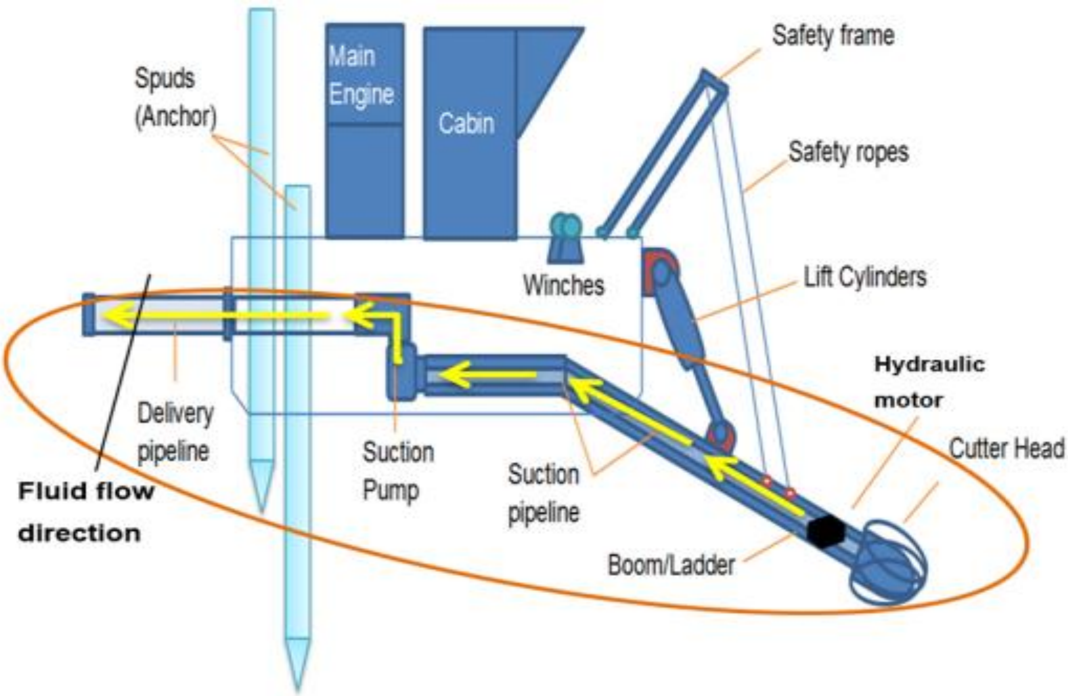
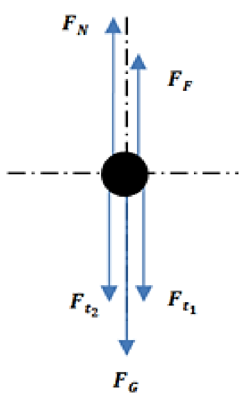
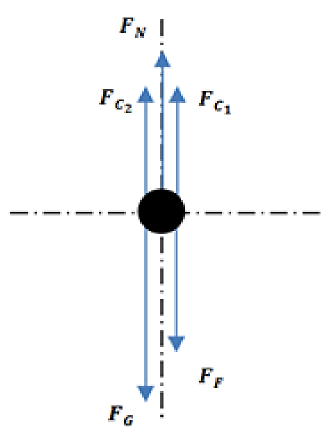
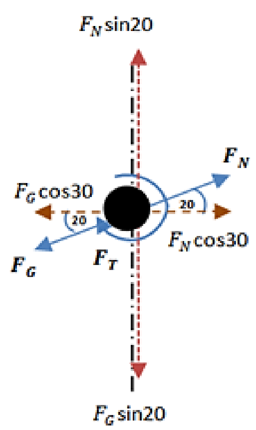


Figure 1. Schematic diagram of a cutter suction dredger

Table 1. Mechanical Force Diagram for the cutter head and the ladder

FB_1 – Ladder (lowered to sediment)	FB_2 – Ladder (raised above sediment)	FB_3– Cutter head (in operation)
		

$\boldsymbol{FB_1}$

Vertical components of the ladder when pushed in the downward direction, to reach the sediment, by the hydraulic cylinder:

$$F_{N_V} = F_{t_2} + F_{t_1} + F_G - F_F \qquad [1]$$

$\boldsymbol{FB_2}$

Vertical components of the ladder when pulled in the upward direction, lifted above the sediment, by the hydraulic cylinder:

$$F_N = F_G + F_F - F_{C_2} - F_{C_1} + F_{Lifting} \qquad [2]$$

$\boldsymbol{FB_3}$

Horizontal components of the cutter head:

$$F_N cos30 = F_T + F_G cos30 \qquad [3]$$

Vertical components of the cutter head:

$$F_N sin30 = F_T + F_G sin30 \qquad [4]$$

RESULTS

They lowered the hydraulic cylinder to 2.5 meters, and it made an angle of 25° when it was fully expanded. The simulation was based on the stress analysis of the cylinder, which was conducted using SimScale online software. This was shown in the diagrams below.

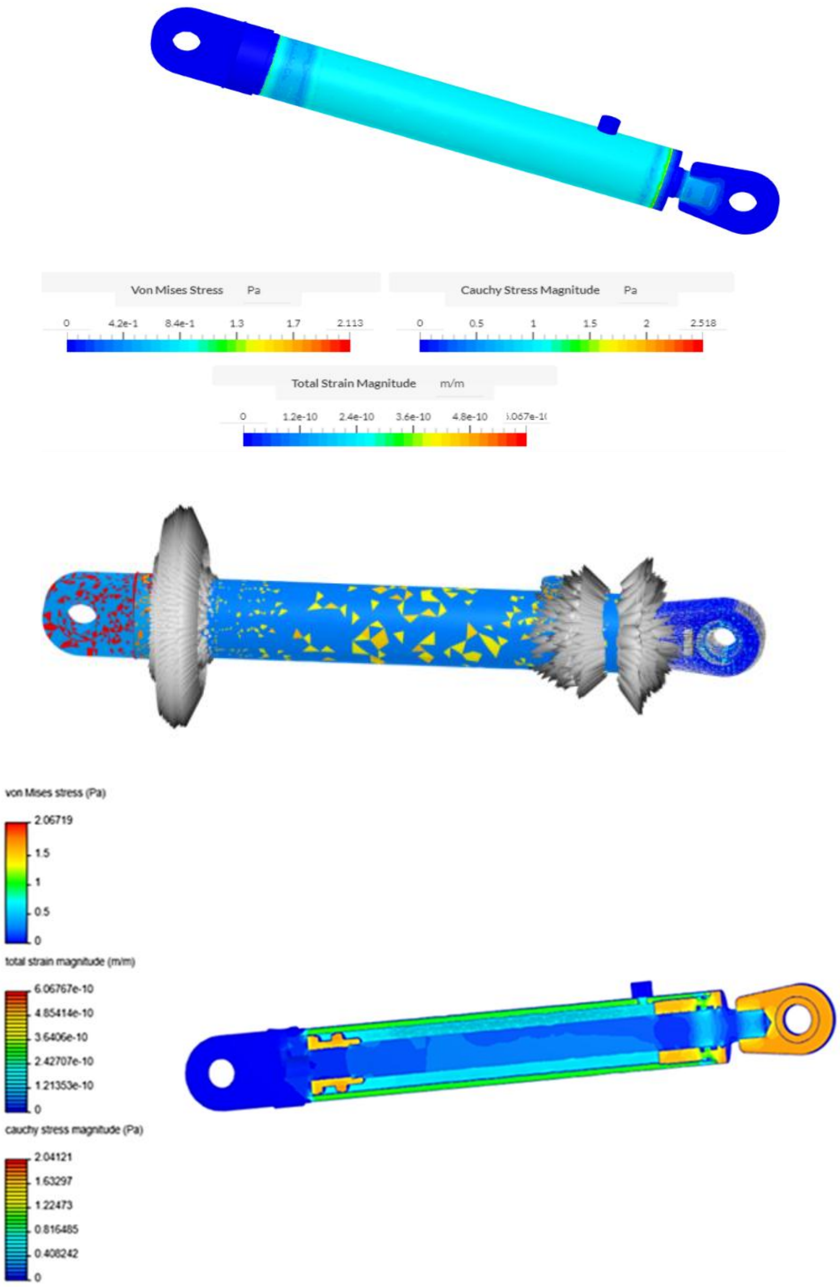


Figure 2. Simulation of stress analysis of a hydraulic lift cylinder

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The colour coding on the figure shows the severity of where the most critical point is and where they are most likely to break if it is under major tension or compression. Dark blue showed that the cylinder would not experience elastic limit, while the green was neutral, (energy was not lost in the process). Light to dark orange was lower to upper yield, alarming that the cylinder is about to reach its breaking point. The red meant rupture where it was most likely to fracture. The first figure showed the stress analysis of the external part of the cylinder, while the third figure was the analysis of the internal part of the rod. The three severity colour codes were based on the Von Mises (Pa), the Strain magnitude (m/m) and the Cauchy stress magnitude (Pa).

The Von mises stress measured on Pascals, in the severity figure, showed where the cylinder would yield or fracture on a material. The Cauchy stress was the small stress that occurred when the object was divided into super small tubes and analysed. It calculated the principal stresses on the cylinder.

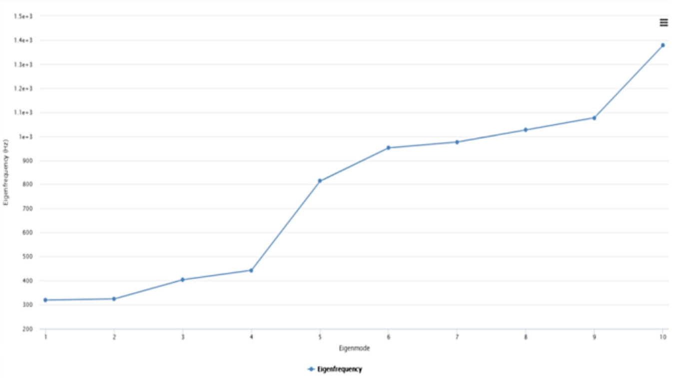

Figure 3. Simulation of the Frequency analysis of the hydraulic cylinder

The above results showed the frequency analysis of the Eigen-mode to Eigen-frequency. There was a drastic increase in frequency between Eigen-mode 4 and 5, and 9 and 10. These were the points where the cylinder extended; the weight of the ladder was lighter because gravity assisted the cylinder when it extended. In addition, the Eigen-mode between 1 to 4 and 6 to 9 was the period where the cylinder retracted. The frequency was low because the ladder was heavier to left as it opposed the gravitational force. (Lim, 2018)

The areas in the hydraulic cylinder experienced little tension, therefore, would lift the weight of the ladder. The heavier side that the cylinder experienced was on the ladder side of it. This side was the pressure side or rod side, which carried the ladder. This part of the cylinder was the most critical position here as it determined the effectiveness and performance of cutting head.

CONCLUSION

The poor management of discharging the wastewater properly led to an environmental effect, which caused pollution. The previous method used, which was the pump, did not pump sediment but water only. This resulted in the build-up of sediment. The design of a cutter suction dredger fixed this problem. The Cutter Suction Dredger was the best solution that was suitable for this study.

The cutter suction dredger comprised components which worked together to successfully remove a large amount of sediment present in the dam. The major components where the cutter head, hydraulic motor, suction and discharge pipe, the ladder, and the hydraulic cylinder. These key components managed to assist the cutter head to draw 37, 83% of sediment in a period of 5 days with a duration of 5 hours per day. The amount of sediment removed was 372600 kg per day, which emptied the dam by 7.57 % of the total present sediment that was removed.

The components worked together to assisted the cutter head to remove 74520 kg of sediment in an hour. This included the hydraulic lift cylinder, which played a vital part in this operation. More sediment was removed to improve the capacity of the dam. The sediment was 3.8 m deep in a 4 m dam. The recorded volume of the dam was 3800 m^3 with sediment that covered 3610 m^3 of it. Since it fully extended the hydraulic lifting cylinder, it was important to test and simulate the stress that is experienced. As mentioned before, the dam was only 4 meters deep and the dredger could dredge only up to 2.5 meters.

The purpose of the study was to improve the dam capacity using a dredger to remove sediment and prevent environmental pollution during the recovery process. The capacity increased, and it prevented pollution as there was more space for water and it pumped more sediment back to the ash heap. This increased the production of the plant because there were less labour and downtime. There was no need to stop the plant from operating for the sediment in the recovery dam to be removed.

RECOMMENDATION

Environmental:

Put danger signs to inform people of the hazardous dam that is not meant for swimming. Cut vegetation around the dam, the sticks might get into the suction pipes and damage the pump and other components on the dredger. This will make it easy to dredge the sediment because there will not be any interruption that will stop the dredger from the operation. Increase the capacity of the dam by creating a berm around it. This will prevent future flooding and spillages into the environment.

Maintenance for the dredger:

Service the dredger every 250 hours run of the dredger, change filters, and check the oil if it is still in pleasant condition. Check the cutter head, pump, and pipes for any clogging. Replace necessary components on time before it makes any further damage to the dredger. After every dredging operation, dredge the top-water by allowing it to be drawn into the pipeline so that excessive or stuck sediment will be pushed through. It is important to check the cylinders if there any sign of distortion or slight cracks, especially on the areas that were more likely to experience

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