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Economic Efficiency of Discharging Problematic Sediments behind High Concrete Dams with the Invention of Pneumatic Momentum

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Abstract

Sedimentary sludge is harvested hydraulically with pump suction, which converts the solid to liquid sediment 1.10t/m^3 density. Using the momentum of compressed air, it is first blown into the dense layers to transfer into liquid. Then the irrigation sluiceway will be opened to discharge the sediment flow by TPM- Turk Pneumatic Momentum. If during the flushing, the water flow speed increases, it can decrease the sediment flow by TPM. The point of this invention lies in this principle that the flow density can be continuously controlled by TPM. So, the compressed air momentum performs two economic hydraulic tasks. First: dense sediment 1.65t/m^3 should be change to sediment flow 1.30t/m^3. Second: sediment flow is prohibited less than 1.15t/m^3.When the sediment flow drops below 1.10t/m^3, the fresh water speed increases to DEZ dam shake tremendously. In the DEZ dam (H= 202m), sediment layers have increased to 108m where the outlet pipe was wrongly designed. It causes a serious vibration that should close the valves. In this method, only the sedimentary layers can be discharged due to the water head. In each flushing, after a few hours, the thick chocolate slurry turns into clear liquid water with a density of 1.05t/m^3, and the fresh water is quickly drained. But in TPM, the flow can be controlled to maximize the efficiency. Sediment could be discharged below the irrigation sluiceway. Flexible joint and pipe are achievements of this invention, which can sweep under the outlet (+222.7m).

Keywords

DEZ Dam, Economic, Sediment, Flushing, Vibration, Irrigation sluiceway.

1. Introduction

DEZ Dam, an arch concrete dam across the DEZ River in the SW of Iran, completed in 1960. DEZ River is oriented from the middle Zagros Mountain. Huge sediments are deposited in the dam lake every year. It should remove behind the dam by flushing in flood condition. Table 1 presents the flushing years. Sedimentation rate is evaluated by Figure $\Delta H/\Delta t$ and cumulative rates $\bar{U}i = Hi/ti$ in Table 1 according to the meter per year. Flushing 2016 was operated to discharge the sediment. Influence radius of flushing with hydrographic operation was measured to be more than 300m, while the required radius should be less than 30m near the irrigation sluiceways. Also, compared to the dead deposit of the lake and the annual sediment load, the discharged sludge is estimated to be insignificant and useless. Therefore, the sediment above the sluiceway should be dredged to increase the utilizing life by TPM. Warning, flushing and other existing methods require economic budget and a lot of time, which actually dredges up to 15% of the dead volume. In fact, it is impossible to discharge the sediment in the entire lake. TPM will try to reduce the sediment level behind the dam (+265.0m to +215.0m) which will be the main cause of cavitation disaster in power intakes (webuilt, 1960).

2. Flushing Non Economic Method

Three Sluiceways were mounted in the concrete dam (+222.70m) with 22m length, conic extrados (D= 4.50m), steel liner pipe (D= 2.74m), gate valve (D= 1.55m, A=1.887m^2), conical dispersion valve and steel pipe nozzle (L= 4.0m). While the sluiceways are opened to discharge the sediment flow, a dense flow of 1.40 to 1.45t/m^3 is temporarily discharged and after a short time it decreases to 1.15, 1.10 and 1.05t/m^3. When the specific gravity drops, the exit nozzle vibrates exceptional, causing the operator to close the valves. Outlet extraordinary resonance can be related to the length of steel pipe (4.0m). The nozzle pipe was modeled by Physical Prototypical (Neilson, 1967) to study the extra vibration of the outlet cylindrical hood, which concluded that it should be 2.0m long, in order to minimize the vibration but unfortunately it was implemented in 1960 with 4.0m long. Vibration could be reduced by the sediment dense flow through the cylindrical hood of nozzle. Table 2 and Equation 1 will describe the situation of opening the gates and discharge percentages. All results were mandated for use by the dam operator (Emamgholizadeh, 2005), (Acres, 2004) and (KWPA, 2016). The ΔZ in Equation 1 is referred to the difference in the water level (ZR -222.7m).

Table 1. Bed levels (DEZ Dam, 1959) are presented behind the arch dam by the sedimentation rate (m/year), Fig. 2.

i	ti (year)	Hi (m)	ΔH (m)	Δt (year)	ΔH/Δt	Ui=Hi/ti	Remarks
1	1960	+162.0	-	-	-	-	River bed level at 1958
2	1972	+200.0	38.0	12	38/12=3.16	3.16	Maximum rate of sedimentation 3.16m/y
3	1983	+223.0	23.0	11	23/11=2.09	2.65	(223m-162m)/(1983-1960)=2.65m/y
4	1997	+247.0	24.0	14	24/14=1.71	2.30	Ūi(2 to 4)=(3.16+2.65+2.3)/3= 2.70m/y
5	2002	+225.0	11.0	5	11/5=2.20	2.29	November
6	2003	+258.0	33.0	7/12	-	-	May- Flood
7	2003	+223.0	-35.0	1/12	-	-	June- Flushing
8	2016	+261.0	38.0	13	38/13=2.92	1.77	(261m-162m)/(2016-1960)=1.77m/y
9	2016	+234.0	-27.0	-3	-	-	Flushing
10	2019	+261.0	27.0	3	⅓ 9=3	1.68	Prismatic excavation
11	2021	+265.0	4.0	2	4/2=2.0	1.69	Ūi(8 to 11)=(1.77+1.68+1.69)/3= 1.71m/y

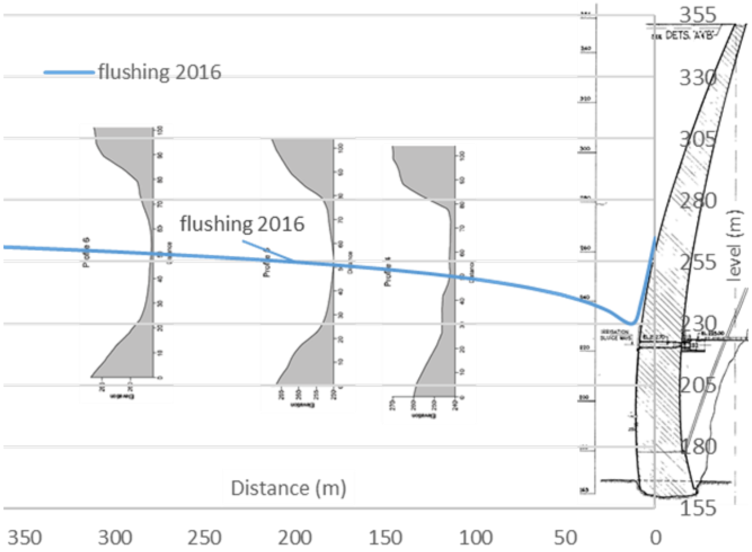

Fig. 1. Flushing 2016 worked for 9days (Aug. 16 –24) in 400m of influence radius and a volume of 140,000m^3 (KWPA, 2016).

$$Q\left(\frac{m^3}{s}\right) = AC_D\sqrt{2g}\sqrt{\Delta Z} = 8.357C_D\sqrt{\Delta Z} \qquad (1)$$

Table 2. The prototype Q was calculated based on CD, valve opening and water head (Neilson, 1967).

CD Coefficient of Q (CMS)	ΔZ(m)	0.789	0.644	0.479
Valve opening percentage		90%	70%	50%
ΔZ (12.5atm) = (352.0m - 222.7m)	129.3	75(m^3/s)	61(m^3/s)	46(m^3/s)
ΔZ (10.6atm) = (332.0m - 222.7m)	109.3	69	56	42
ΔZ (8.3atm) = (308.0m - 222.7m)	85.3	61	50	37

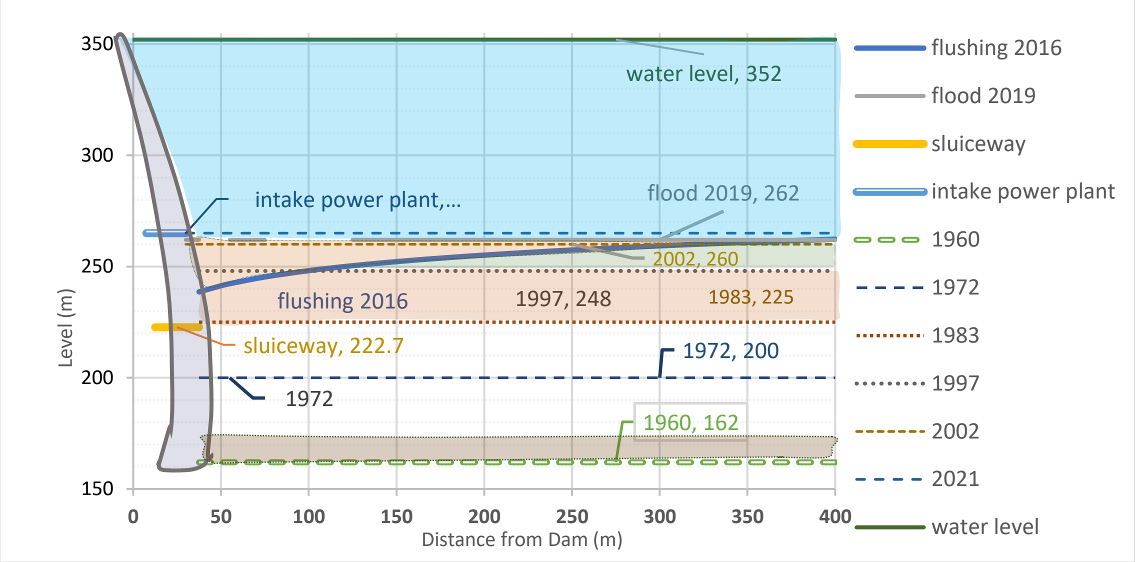

Fig. 2. Sedimentation makes a new bed level though flushing volume is negligible (Emamgholizadeh, 2005) and (KWPA, 2016).

2. Underwater Docking System Requirements

Installing the tools inside the hatch is important for connecting the TPM underwater. The available methods to find the best ones will be shown. The water level will rise to +352.0m, where the valve level will be +222.7m with a water height of 130.0m. In recent research, a novel cable-drogue docking system is proposed between an Autonomous Underwater Vehicle (AUV) and one mobile underwater platform, to increase the docking safety and reduce the negative influences of turbulences around the platform shell on the AUV (Juhyun, 2014), (Zeyu, 2022). In Fig. 3, the docking station can be modeled at the entrance of the hatch where the AUV will be a TPM guiding instrument. This docking must be modified to accommodate the sediment flow. The NASA space docking is shown in Fig. 4. In space, vacuum conditions are very different from underwater operations with 13atm pressure and fluid dynamics.

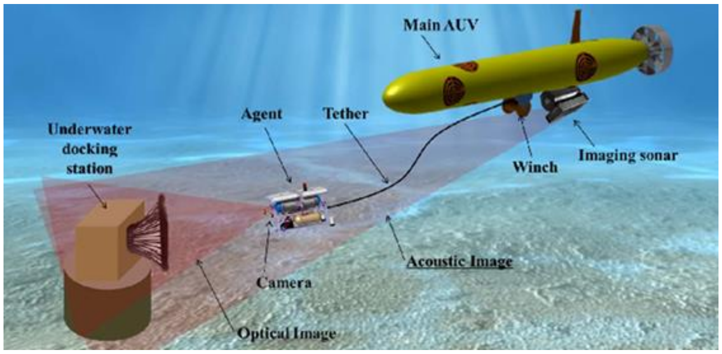

Fig. 3. High resolution image sonar based underwater vehicle's localization method docking (Juhyun, 2014).

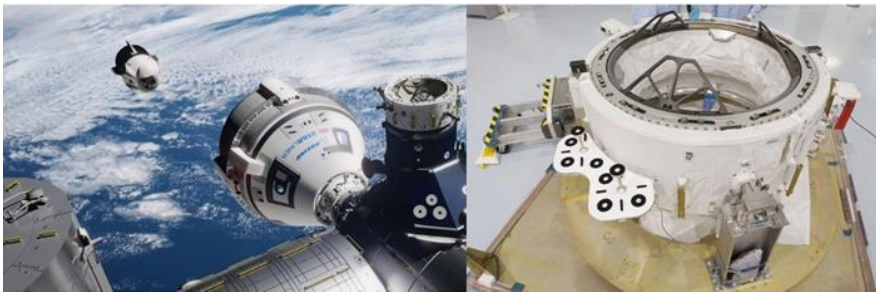

Fig. 4. NASA- Space X Dragon 2 to dock to the ISS with AI in vacuum condition and zero pressure (Space X, 2018).

3. Turk Invention: Magnetic Movable Cone Triquetrous -MMCT

In Extrados sluiceway, a conical inlet was constructed in the dam (D= 4.5m) to discharge the flow through the steel pipe (D= 2.74m). Turk invention of MMCT must be sharp in shape to find the inlet in the deep water. It should also be able to connect to the steel liner surface by the electrical magnetic power. Also, MMCT should be moved toward the sluiceway by the rotating nozzles that are mounted in the outer radius of MMCT. It should be connected to the steel liner surface. Pneumatic nozzles will produce the propulsion to moving the MMCT by Fig. 5 (Turk, 2006).

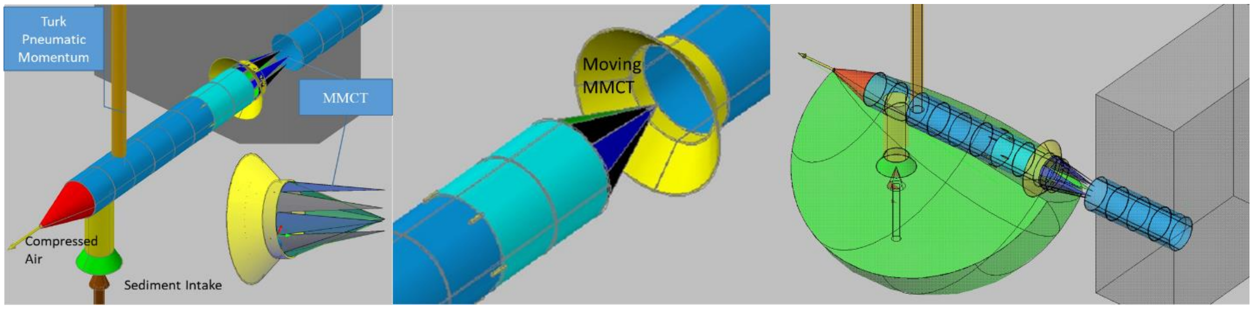

Fig. 5. Triquetrous plates can be conjoined on the liner pipes inside the sluiceway by electromagnetic power. MMCT sweeps the sediment layer below the sluiceway like a piece of watermelon (Turk, 2007).

Fig. 6. Overhead crane with electromagnetic beam will be simulated in the triquetrous of MMCT.

Pneumatic system works in two phases, which requires an air compressor above the water level of the lake. The first is the loosening of dense sediment layers that have been deposited around the sluiceway for more than 40years. It is mentioned that the flushing operation can only drain the sediment layers above +222.7m with a length of 350.0m. Therefore, the sedimentary layers are condensed from the level of +222.7m to +200.0m in the past years. The second phase is related to the resonance vibration of the outlet nozzle (Neilson, 1967). The hood of nozzle is 4.0m long, which after 7years, the appropriate length of 2.0m was calculated through the research physical model. The length can-not be reduced, but the valves are limited to opening. The final decision was informed to decreasing the length by research team. Innovative solution will be advised to discharge dense sediment flow that could be control the velocity and outlet momentum. Also, MMCT provides an innovative new discharging method to sweep inaccessible layers under the outlet (White, 2004). Three separate modifications are recommended as follows by prototype result in Table 3. In MMCT, the sediment flows through valves with a high density of 1.30- 1.45t/m^3. Thus, the discharge rate is reduced and resonance may be eliminated. Also, dense sediment layers will be removed by TPM to reduce the deposit live loads against the concrete dam. Fig. 5 and Fig. 6 demonstrate the finding the underwater outlet easily that may be a very hard work. Sometimes it could be impossible efforts to find the hole in the extrados surface. Anyway, cone is sharp and can be intern into the sluiceway by magnetic field power (Turk, 2005), (Turk, 2009a) and (Turk, 2009b).

Table 3. Recommendations to reduce vibration (Neilson, 1967).

First	Eliminate backsplash re-entrainment by allowing backsplash water to flow through drain holes in the bottom of the valve chamber and thence to fall to the dam toe
Second	Improve the flow-passage configuration where the free jet is deflected by in-stalling a 20-degree conical deflector
Third	Minimize the surface of the structure upon which flow-induced pressure pulses can act by reducing the length of the cylindrical hood from 4.00m to 2.00m.

4. Turk Pneumatic Momentum - TPM

In flushing, the density is varying to discharge the dense sediment. In Flushing 2005, the turbulence density current changed from outlet to steady flow after initiation at time intervals (hours) 1 to 4, 9 to 21, 22 to 27, 35 to 53. Also, in Flushing 2016, the turbulence sediment current improved to steady flow at time intervals (hours) 6 to 17, 18 to 24 and 21 to 36. Therefore, the density difference will be zero per time ($\partial\rho/\partial t \equiv 0$), Equation 2 to Equation 5 and Fig. 7. Then the input and output momentum will be equal to Equation 3. In practice, the compressed air at the inlet and outlet of TPM is constant, Equation 6 to Equation 10. The invention of TPM is explained through Equation 11 to Equation 15 that all P_{Si} can be reduced to 1atm. Equation 16 through Equation 18 describe the way in which water head pressure can be reduced by TPM. In addition, the excess vibration of the outlet pipe is reduced (White, 2004) and (Turk, 2006).

$$\int_{CV} \frac{\partial\rho}{\partial t} d\upsilon + \sum_i(\rho_i A_i v_i)_{out} - \sum_i(\rho_i A_i v_i)_{in} = 0 \tag{2}$$

$$\sum_i(\rho_i A_i v_i)_{out} = \sum_i(\rho_i A_i v_i)_{in} \tag{3}$$

$$\sum_i(\rho_i A_i v_i)_{out} = (\rho_{air3} A_{air3} v_{air3})_{out} + (\rho_{air4} A_{air4} v_{air4})_{out} + (\rho_{s4} A_{s4} v_{s4})_{out} \tag{4}$$

$$\sum_i(\rho_i A_i v_i)_{in} = (\rho_{air1} A_{air1} v_{air1})_{in} + (\rho_{s2} A_{s2} v_{s2})_{in} \tag{5}$$

$$\rho_{air1} = \rho_{air2} = \rho_{air3} \tag{6}$$

$$(\rho_{air1} A_{air1} v_{air1})_{in} = (\rho_{air3} A_{air3} v_{air3})_{out} + (\rho_{air4} A_{air4} v_{air4})_{out} \tag{7}$$

$$(\rho_{s2} A_{s2} v_{s2})_{in} = (\rho_{s4} A_{s4} v_{s4})_{out} \tag{8}$$

$$(Q_{Sediment2})_{in} = (Q_{Sediment4})_{out} \tag{9}$$

$$\rho_{Sediment2} = \rho_{Sediment4} \tag{10}$$

$$10 \ll P_{S_i} = \sum \gamma_i h_i \ll 13atm \therefore 1.5(S.F) \times 10 \ll P_{air} \ll 1.5 \times 12 \tag{11}$$

$$\left(\Delta P = P_{S_i} - P_{air}\right) < 1atm \tag{12}$$

$$P_{S_i}\left(Z_{R_i} = 352m\right) = 13atm \xRightarrow{P_{air}=19.5atm} P_{S_i} = 1atm \tag{13}$$

$$P_{S_i}\left(Z_{R_i} = 342m\right) = 12atm \xRightarrow{P_{air}=18.0atm} P_{S_i} = 1atm \tag{14}$$

$$P_{S_i}\left(Z_{R_i} = 292m\right) = 7.0atm \xRightarrow{P_{air}=10.0atm} P_{S_i} = 1atm \tag{15}$$

$$P_{S_i} \times A_{S_i} = P_{air_i} \times A_{a_i} \therefore P_{air_i} = \frac{A_{S_i}}{A_{a_i}} P_{S_i} \tag{16}$$

$$A_{S_i} = A_{a_i} \therefore P_{air_i} = P_{S_i} \tag{17}$$

$$\tfrac{1}{2} A_{S_i} = A_{a_i} \therefore P_{air_i} = 2P_{S_i} \tag{18}$$

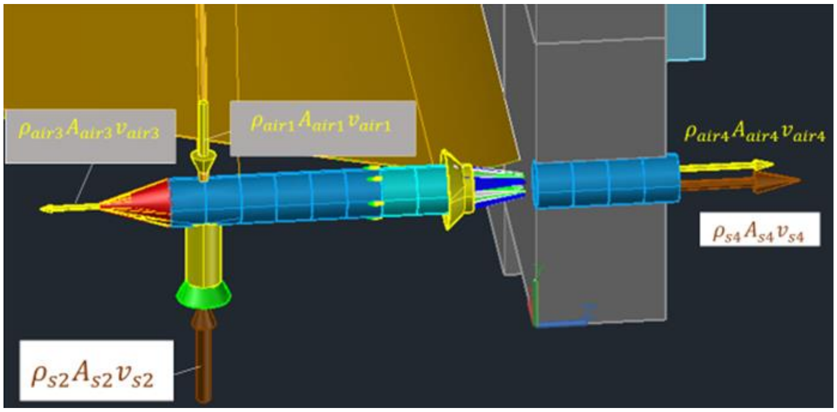

Fig. 7. TPM is explaining with 1 to 4 outlet and inlet momentum of air and sediment.

Section 1 is the inlet of compressed air momentum from the water level compressor. Section 2 will be the inlet of dense sediment flow that can be control by the air pressure. Section 3 is constructed to discharge the extra air pressure that will balance the system. Section 4 may be a combination of two outflows, sediment and excess air pressure. All section will be needed a mechanical diaphragm that can be open and close the current in critical condition. A professional diver knows for sure that the maximum immersion in water is less than 40m. About 130.0m should be considered for submerging the TPM system. As a result, it will be suggested to create a suitable chamber that can withstand the water pressure so that the operator can stay safe. JALEH in Fig. 8 is described the simple submarine.

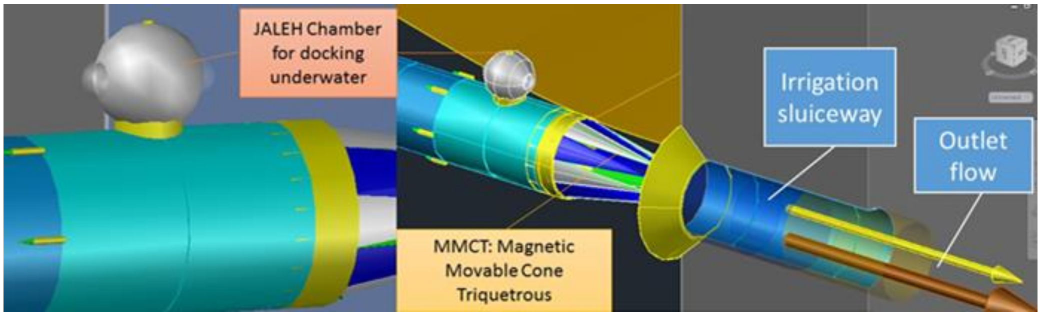

Fig. 8. A complementary design will be installed on TPM (Turk, 2005), (Turk, 2009a), (Turk, 2009b) and (Turk, 2024).

5. Economic Comparison

Sediment removal is necessary to increase the useful life of high dam and its operation (concrete or rockfill). Over the years, the dead volume of the dams will occupy more than 50% of the effective reservoir (DEZ Dam). Fig. 9 demonstrates the facilities to use in deep dredging system such a submersible pumps and cutter suctions. Also, sedimentation and failure may be causes a great disaster for large dams in Brazil. Fig. 10 shows the collapsing effects.

Fig. 9. Dam cleaning project and model for dredging to on-site (NRSST, 2020) and (Benassuti, 2015).

Fig. 10. An aerial view shows a destroyed bridge 2019 after the dam burst, Brazil.

Table 4 shows the total cost of experimental dredging methods. Sometimes, practical methods are limited by obstacles such as economic budget and social conditions (NRSST, 2020). Table 4, Table 5 and Table 6 will interpret the total cost. Dredging Figure ξ and Figure ζ show the ratio of the total cost of TPM to the cutter suction model, which is interpreted by Equation 19 and Equation 20. Figure 11 shows the behavior of saturation sediment versus the volume of water that must be discharged with the sediment. TPM efficiency of operation is presented by Equation 21. Environmental dredging is distinctly different from large- scale dredging because of the approach (NRSST, 2020).

$$\xi = \frac{(i_5)_{Table\ 5}}{(i_5)_{Table\ 4}} = \frac{1.25}{24.3}\left(\frac{\$\ million}{\$\ million}\right) = 0.05 = 5\% \qquad (19)$$

$$\zeta = \frac{(i_{10})_{Table\ 5}}{(i_{10})_{Table\ 4}} = \frac{2}{33.3}\left(\frac{\$\ million}{\$\ million}\right) = 0.06 = 6\% \qquad (20)$$

$$E(x,y)_{TPM} = \left(\frac{y}{x}\right)_{Fig.11} = 0.31e^{0.64x} \qquad (21)$$

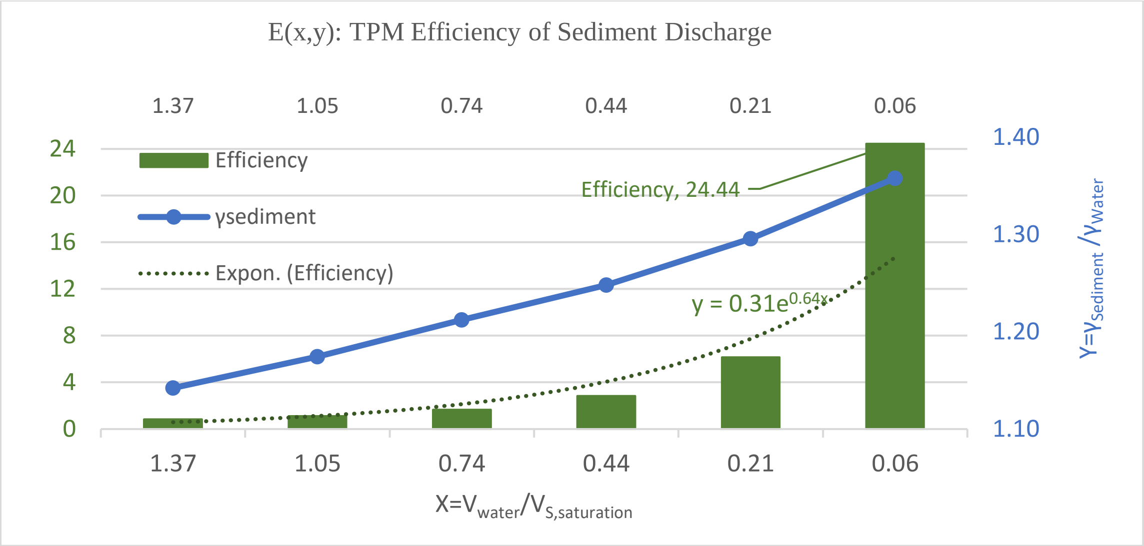

Fig. 11. The efficiency is calculated by Equation 21 and water containing sediment (botanical clay).

Table 4. Cost model for dredging to on-site or local repository, Fig. 9 (NRSST, 2020) and (Benassuti, 2015).

i	Model individual unit costs	Large scale project 100,000 to 1 million m^3
1	Hydraulic dredging, by 14-to-18inch cutter suction	\$1.5–\$6/ m^3
2	Mechanical dewatering or grain size separation	\$4–\$16/ m^3
3	Reclamation of disposal /placement area	\$0.8–\$2.3 m^3
4	unit cost Σi=i(1)+i(2)+i(3) \$/m^3	**\$6.3–\$24.3/ m^3**
5	Total cost: i(4) x (100,000 to 1 million m^3)	\$0.63–\$24.3 million
6	Equipment mobilization (pipelines) and demobilization	\$1.5–\$3 million
7	Preparation of placement/disposal area, if necessary	\$30,000–\$60,000
8	Design, project and construction management	\$2–\$6 million
9	Total of Additional costs Σi=i(6) +i(7)+i(8)	\$3.5–\$9 million
10	Total cost: Σi=i(5) +i(9)	**\$4.13–\$33.3 million**

Table 5. Turk Pneumatic Momentum –TPM- Cost for dredging to on-site, Fig. 8 (Turk, 2024).

I	Model individual unit costs	Large scale project 100,000 to 1 million m^3
1	Water head hydraulic dredging, by 60-to 72inch	\$0.2–\$0.35/ m^3
2	Mechanical dewatering or grain size separation	\$0.1–\$0.3/m^3
3	Reclamation of disposal /placement area	\$0.4–\$0.6/m^3
4	unit cost Σi=i(1) +i(2)+i(3) \$/m3	\$0.7-\$1.25/m^3
5	Total cost: i(4) x (100,000 to 1 million m3)	**\$0.07million –\$1.25 million**
6	Equipment mobilization high pressure pipelines	\$.15–\$0.25 million
7	Preparation of placement/disposal area, if necessary	\$30,000–\$60,000
8	Design of steel submarine and structures, Fig. 10	\$0.15–\$0.5million
9	Total of Additional costs Σi=i(6)+i(7)+i(8)	\$0.3–\$0.75 million
10	Total cost: Σi=i(5) +i(9)	**\$0.37–\$2 million**

Table 6. Turk Pneumatic Momentum –TPM- Cost for dredging to 10, 20, 40 and 50m depth behind the Dez Dam.

I	Model individual total costs per m^3	Dimensions (m^3)	Large scale project 1million to 10 million m^3
1	1 million m^3 per year	320× 320 ×10	\$0.75million + 1× (\$1.25) million= \$2.0 million
2	2 million m^3 per two years	320× 320 ×20	\$0.75million + 2× (\$1.25) million= \$3.3 million
3	4 million m^3 per three years	320× 320 ×40	\$0.75million + 4× (\$1.25) million= \$5.8 million
4	5 million m^3 per four years	320× 320 ×50	\$0.75million + 5× (\$1.25) million= \$7.0 million

6. Conclusion

Every year, the sediment load enters the lake that it causes problems for the power plant intake and irrigation sluiceway. There is no expert economic method to reduce the level of sediment in the DEZ Dam (H=202m). Sedimentation rate is 1.72 meter/year by Table 1 that will be a great alarm for hydropower utilizer. All sediments such as sand, silt and botanical clay pass through the power intake without any obstacles, which causes serious cavitation on the blades. The invention of TPM is presented for economical sediment discharge with available minimum cost and time. The most important point of TPM can be considered to reduce the pressure of the water level by using a column of compressed air pressure in front of sluiceway (13atm water pressure vs 12atm air compressed momentum). The next point refers to MMCT, which will revolutionize underwater maintenance and restoration by robotics devices. Fig. 8, the JALEH control chamber will be provided for the use of the robot or operator. All submarine parts are designed to move by pneumatic system such as MMCT and revolving joints. This may be a follow-up plan. All mechanical bodies will work with pneumatic pressure such as MMCT subsea blowers and thrusters. Electromagnetic sheets are applied to guide MMCT into the sluiceway with a new method. TPM dredging cost can be estimated through Equation 19 to Equation 21. The values of 5% and 6% are excellent compared to the values of common methods in Table 4 to Table 6. Another advantage is the sediment dredging below sluiceway (+222.7m) where dense sediment (1.25-1.40t/m^3) can be continuously removed at any time. Equation 21 estimates the sediment discharge efficiency of TPM. The next step should be to dry the sediment for reuse in the road sub-base, pavements, blocks and concrete materials. The large disaster in Fig. 10 can be mitigated by TPM for Amazon River Dams.

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