Impact of Sedimentation hazard at Jor Reservoir, Batang Padang Hydroelectric Scheme in Malaysia

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Abstract. Sedimentation in reservoir can be treated as a hazard because it affects the overall safety of the dam. It is a growing concern for reservoir operators throughout the world as it impacts the operability of the hydropower plant and its function as flood control. The objective of the study is to carry out reservoir bathymetric survey to determine the storage volume available at Jor reservoir. The paper intends to discuss the results of two successive surveys carried out in year 2007 and 2010 and comparison with historical data in 1968 owing to analyse of sedimentation trend. The result showed that the total storage loss is approximately 43% with an estimated deposited sediment volume of 1.4 million m$^3$ in year 2010. The sedimentation rate is estimated at 3.3% for the years surveyed which is greater than the world average of 0.93%. The findings from the survey are used to develop a revised elevation-storage curve which could be used by the operator and engineers to carry out future power generation planning and flood study predictions. The findings are also expected to be used to determine the optimum method for sediment management and hydro-mechanical protection.

1. Introduction
Sedimentation in reservoir becomes a hazard to energy infrastructure such as hydropower reservoir and dams when it starts to impact both the functionality of reservoir and economic operability of the hydro power plants which includes dam safety constraints and limiting flood controls capabilities. The understanding on the contributing factors of sediments and ultimately their management can therefore extend the useful life and enhance functions of such infrastructures. Sedimentation processes within the reservoir are complex and dynamic in nature. When sediment deposits affect the reservoir useful life, it is necessary to change the reservoir operation or adopt any other corrective measure [1]. In most of the energy production country by large reservoirs, the sedimentation issues are not regarded as very important for production at short and medium term [2]. However, the average useful life of existing reservoirs in all countries of the world decreased from 100 to 22 years [3]. The annual cost for promoting the removal sediments is estimated in US$ 6 billion. The annual average volume loss in reservoir due to sediment deposition was of 0.93% varying from one country to another, as well as from one region to another. The estimated loss of storage capacity in reservoirs in the United States due to sedimentation accounts for an annual monetary loss of US$ 100 million [4]. The sedimentation rates for 28 countries are shown in Figure 1 [5]. Meanwhile many other researchers have determined the annual sedimentation rates for the respective countries as shown in Table 1. World sedimentation overview found that mainly the drought affected countries will be confronted with reservoir sedimentation problems. It also predicted that semi-arid regions are also generally more susceptible for reservoir sedimentation problems as they often have relatively larger reservoir capacities and hence higher trapping efficiencies (TE) as seen in China and Tanzania with relative high sedimentation rates at 2.9% and 3.27% respectively. Many other countries in semi-arid regions such as Morocco, Pakistan, Sudan and Tunisia, have sedimentation rates above the world average. Malaysia is generally grouped within the Southeast Asia region where the sedimentation rate is observed at 0.3% [6]. The average annual reservoir sedimentation rate shown in table 2 is 0.003% which is lower than the estimates for Southeast Asia [7]. In this study, Jor reservoir is selected at Batang Padang Hydroelectric Scheme to evaluation of contribution of sedimentation. The two
successive surveys performed in 2007 and 2010 and the result is discussed with historical data in 1968.

![Figure 1. Reservoir sedimentation rates in various other countries [5]](image)

| Country          | Annual Sedimentation Rate (%) | Source                          |
|------------------|-------------------------------|---------------------------------|
| China            | 2.30                          | Hu, 1995                        |
| India            | 0.46                          | White, 2001                     |
| Japan            | 0.15                          | NISA, 2001; ANRE, 1984-2000     |
| Southeast Asia   | 0.30                          | White, 2001                     |
| South Africa     | 0.34                          | White, 2001                     |
| Turkey           | 1.50                          | White, 2001                     |
| UK               | 0.10                          | White, 2001                     |
| USA              | 0.22                          | Morris & Fan, 1987              |
| World            | 1.00                          | White, 2001                     |

Table 1. Reservoir sedimentation rates by various researchers

| Name                          | Years in Operation | Storage (m$^3$) | Deposited Sediment Volume (m$^3$) | Annual Sedimentation Rate (%) |
|-------------------------------|--------------------|-----------------|----------------------------------|-------------------------------|
| Pedas Reservoir (PWD)         | 1932 (56 years)    | 49 x 10$^6$     | 36,000                           | 0.05                          |
| Klang Gates Reservoir (PJD/JBA/State) | 1959 (17 years)    | 32 x 10$^6$     | 740,100                          | 0.001                         |
| Bukit Merah Reservoir (DID)   | 1906 (21 years)    | 93 x 10$^6$     | 7.6 x 10$^6$                     | 0.004                         |

Table 2. Reservoir sedimentation rates in Malaysia

2. Material and methods

2.1. Case study

Jor reservoir was constructed to assure flow regulation for the downstream hydroelectric power station, as well as to provide storage for flood control [8]. The reservoir is confined by two earthfill dams namely Jor Dam and Jor Saddle Dam which forms part of the Batang Padang Hydroelectric
Scheme. The flow into Jor reservoir is contributed by the average natural inflows of Sg. Jor, Sg. Batang Padang and Sg. Sekam of 10 m$^3$/s and the tailrace discharge from Jor power station of 21 m$^3$/s [9]. Water from Jor Reservoir is fed through the Menglang intake together with other side stream intakes (Lengkok, Bot, Chenes and Tidong) to Sultan Idris II Power Station also known as Woh Power Station. The power station has a rated head of 406.8 m and has a total installed capacity of 150 MW. Jor reservoir covers a total area of 0.32 km$^2$ and has an original total storage volume of 3.17 million m$^3$ with approximately 2.33 million m$^3$ as live storage for hydropower power generation and 0.84 million m$^3$ as dead storage for sediment accumulations below the minimum operating level 480.06 m. The Batang Padang River was diverted through the diversion tunnel and spillway tunnel on October 1965 and the diversion tunnel was closed on July 1967 when the impounding of the reservoir commenced. The Batang Padang scheme was completed in 1968. Since commencing no detail study was conducted to determine the sedimentation rate and storage capacity. In order to estimate the reservoir sedimentation at Jor reservoir a bathymetric survey up to 3 m above the full supply level of the reservoir and combined with topographic survey to a boundary of 20 m from the reservoir banks was conducted.

3. Result and discussion

The two successive reservoir surveys conducted in 2007 and 2010 was compared to estimate the reservoir sedimentation and storage loss. It is estimated that in year 2007, the gross storage has reduced to 2.12 million m$^3$ (reduced by 33%) with a live storage at 1.95 million m$^3$ (reduced by 17%) and dead storage at 0.18 million m$^3$ (reduced by 79%). While the 2010 surveys show that both live and dead storage amounts have reduced further from year 2007 and the residual live and dead storage volumes at 2010 were about 1.77 (reduced by 24%) and 0.05 million m$^3$ (reduced by 94%) respectively. Overall the total storage of the reservoir surveyed in 2010 has further decreased by 43%. Table 3 shows the storage allocations between the two successive surveys. The elevation versus storage curve in figure 3 shows a leftward movement of the curve between the years surveyed which indicates a continued loss in storage. It is estimated that the annual sedimentation rate is at an alarming 3.3% which is greater than the world average of 1%.

| Storage Allocation | Original (1968) (m$^3$) | 2007 Survey (m$^3$) | 2007 Storage (%) | 2010 Survey (m$^3$) | 2010 Storage (%) |
|--------------------|-------------------------|---------------------|------------------|---------------------|------------------|
| Dead Storage       | 840,000                 | 178,418             | 21               | 49,941              | 6                |
| Live Storage       | 2,330,000               | 1,945,306           | 83               | 1,769,971           | 76               |
| Total Storage      | 3,170,000               | 2,123,724           | 67               | 1,819,912           | 57               |

Figure 3. Elevation storage curve for Jor reservoir showing continued loss in storage
3.1 Impact of sedimentation hazard on reservoir

Sediment management in reservoir is a challenging area in the field of civil engineering especially in Malaysia where the legal framework is still not clear. The continuous deposition of sediments in the reservoir may pose a hazard to the overall safety of the dam. The significant impact contributed by sedimentation includes disruptions to the hydropower generation and flood control. Among the reported hydro-mechanical problems includes frequent choking of strainers or filters with sediments, choking and puncturing of cooler tubes, damage to guide vane bushes and their cap seals, damage to seals of intake valve and main inlet valve, seating/sealing problems in hydro-mechanical gates, intake as well as draft tubes and restriction of flows into intake gates and debris accumulation. The capability of the reservoir to contain the probable maximum floods may also be affected should the reservoir continues to loss it storage to sedimentation.

4. Conclusion

The study has shown that Jor reservoir has lost almost half its storage capacity to sedimentation. The data analysed in the study is used to develop a revised elevation-storage curve which is crucial for dam operators to plan for the future power generation and flood control. The revised data is also expected to be used for future dam safety study and flood studies. Since the sediments are deposited vastly throughout the reservoir, the data also enables the engineers to accurately determine the storage volume available at various elevations. Sedimentation in reservoir contributes to serious hazard to the overall safety of the dam especially in area of mountainous terrain. Periodic reservoir survey has shown that the deposited sediment volume has increased many folds since construction contributed mainly by the uncontrolled activities upstream. The operator of the dam is working tirelessly to address the issue by carrying out continued reservoir survey and immediate mitigation such as dredging and plant live extension works.

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