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Sharing Water: Multi-Purpose of Reservoirs and Innovations

Dez Dam Rehabilitation Project Role in Flood Damage Reduction

Rôle du projet de réhabilitation du barrage Dez dans la réduction des dommages dus aux inondations

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Abstract. As a result of climate change, extreme precipitation events from mid-March to April 2019 in southwest Iran generated catastrophic floods taken 78 lives and left $4.1 billion financial damages. The extent of damages could have been even worse without the existence of upstream flood control dams including Dez dam. Dez Dam is the only large dam in its basin which play a significant role in flood control. A multi-purpose rehabilitation project including new power intakes, flushing tunnels and dam heightening with required investment of $350 million is defined in this dam to compensate reservoir live volume losses through 57 years of sedimentation. In this paper, the effect of dam heightening and the flushing tunnels will be evaluated by their roles in flood damage reduction. Assuming that the actual magnitude of a flood cannot be predicted beforehand, a flexible multi-stage routing method considering operator judgment during flood operations is proposed to produce an optimized flood routing policy. The related operation rule is derived for existing and rehabilitated dam and the expected annual damage (EAD) compared in both conditions. The results show that the dam heightening could be considered as an effective way to improve the dam role in flood damage reduction. Keywords: Flood damage, Multi-purpose rehabilitation project, Dez Dam Heightening, Expected annual damage (EAD), Optimized flood routing policy (OFRP)

Résumé. En raison du changement climatique, les événements de précipitations extrêmes de la mi-Mars à Avril 2019 dans le sud-ouest de l'Iran ont provoqué des inondations catastrophiques qui ont fait 78 morts et causé 4.1 milliards de dollars de dommages financiers. L'ampleur des dommages aurait pu être encore pire sans l'existence de barrages de protection contre les crues en amont, y compris le barrage de Dez. Le barrage de Dez est le seul grand barrage de son bassin à jouer un rôle important dans le contrôle des crues. Un projet de réhabilitation polyvalent comprenant de nouvelles prises d'eau usiniéres, des tunnels de chasse et la suréléveation du barrage avec un investissement requis de 350 millions de dollars est défini pour ce barrage pour compenser les pertes de volume utile du réservoir au cours de 57 ans de sédimentation. Dans cet article, l'effet de la surélévation du barrage et des tunnels de chasse sera évalué en fonction de leur rôle dans la réduction des dommages dus aux inondations. En supposant que l'ampleur réelle d'une crue ne puisse pas être prédite à l'avance, une méthode de passage des crues flexible à plusieurs étages prenant en compte le jugement de l'opérateur pendant les opérations de crue est proposé pour produire une politique de passage de crue optimisée. La règle d'exploitation associée en est déduite pour le barrage existant et réhabilité et les dommages annuels prévus (EAD) sont comparés dans les deux conditions. Les résultats montrent que l'élévation du barrage pourrait être considérée comme un moyen efficace d'améliorer le rôle du barrage dans la réduction des dommages dus aux inondations. Mots clés: les dus dommages aux inondations, Projet de réhabilitation polyvalent, Surélévation du barrage Dez, Dommages annuels attendus (EAD), Politique de routage de crue optimisée (OFRP).

1 Introduction

Based on experienced flood damage in Iran and especially the recent 2019 flood, a new object has emerged in consultants and authorities to review and optimize dam's role in flood control. This role is influenced by many factors such as flood hydrograph magnitude, reservoir operating rule curve during flood season, real time flood control approach, flood forecasting system accuracy, available retention volume in reservoir during the flood event and the downstream flow constraints (D/S safe flood). Moreover in chain dams in a basin, an integrated management of the reservoirs must be considered.

Dez Dam is a 203 m high double curvature concrete arch dam which is located on a narrow gorge of Dez River, in Khuzestan Province in Iran, about 150 km upstream of the provincial capital Ahvaz. The dam has the only large reservoir in its basin and with a 720 MW power plant regulate the overall power distribution in the whole country. Beside the energy generation (hydropower), flood damage reduction and supplying agricultural demands were defined in the project originally. Drinking water supply is also added to its purposes recently.

The dam was commissioned in 1963 and after about 57 years, sediments accumulated in the reservoir up to an elevation of approximately 5 m below the intake of the power plant tunnel. A multi-purpose rehabilitation project is defined by the respected authority (Khuzestan Water and Power Authority; KWPA) to compensate reservoir live volume losses through 57 years of sedimentation. This rehabilitation package consists of three main components as follows:

a) Construction of a new power plant with an installed capacity of 720 MW along with two penstocks
b) Heightening of the dam body by 8 meters
c) Construction of new bottom outlet (two flushing tunnels)

After dam heightening the total reservoir capacity will be increased from 2650 to 3200 million m3 in which will increase flood retention volume up to 50%, consequently [6&8]. Two new flushing tunnels with the capacity of around 1000 cms is also studied to transfer turbidity current to the downstream during flood season. These tunnels would pass the fine sediments around the existing and new power plant intakes which is essential (vital) to extend the dam service life.

In this study the role of dam heightening as well as new flushing tunnels will be evaluated in flood damage reduction. To compare the amount of flood damage before and after the projects, same criteria in gate operation needs to be considered. So a multi-stage routing method for all expected incoming flood is produced considering engineering judgment. For the particular available flood retention volume the total allowable discharge will be determined in each reservoir level with the objective of minimizing downstream flood damages along with consideration of the dam safety criteria.

However the actual magnitude of a flood cannot be predicted beforehand, but in large and important dam some real-time evaluation of incoming flood is done by the operators. So in absence of flood forecasting and to take into account this evaluation (judgment) a flexible multi-stage routing method considering operator judgment during flood operations is proposed in this study to produce an optimized flood routing policy (OFRP). The model could produce some grades of flood routing policy related to the reservoir water level. Through the flood event and based on real time evaluation of incoming flood, the best grade would be selected by the operator.

The time frame for decision-making during flood events is very short (in the order of a few hours), the information available is generally scarce, and the predictability of the hydro-meteorological situation is very limited. Considering these conditions and in order to avoid complexity two grades (high/low level) of flood routing policy is proposed in this research. The flood of 100 years of return period is defined as the border of high and low level of output. The incoming flood discharge must be measured by operators in certain time intervals (every 4 hrs) and the measured values must be compared by pre-calculated hydrographs to select regarded flood routing grade (high/low level). In Dez dam there are some hydrometric station upstream of the reservoir which could help the operators for this evaluation. For the other case which this evaluation could not be achieved as simple as the Dez dam, the EFD Hydro Engineering Center proposed a new algorithm after 2016 (called as Linear Trajectory©EDF 2016) which is based on water level variations during the last 60 minutes of incoming flood [4].

Fig.1. Khuzestan inundation area; Iran 2019 Flood event

2 Methodology

The operation policy during flood event refers to many parameters. As it is stated by some researchers it was done traditionally on the basis of the judgment of the project engineer (Sakakima and Linsley, 1992). Since the advancement of optimization methods, many versions of them have been suggested for spillway gate operation during floods. Most of these method require the incoming flood hydrographs to be forecast (Windsor (1973), Chuntian (1999), Needham (2000), Karaboga (2008), Choudhury (2010), Malekmohammadi et al. (2010)).

Acanal and Haktanir (1999), Acanal et al. (2000), Haktanir and Kisi (2001) and Haktanir et al. (2013) developed a flood control operation policy which is applicable for all flood hydrographs of any magnitude (from Small to the PMF) in the absence of flood forecast [1&2]. Zargar and Samani (2016) developed a simulation–optimization model based on a continuous genetic algorithm which minimizes the damages downstream of a multi-reservoir system. To estimation of the flood damage cost MIKE11 model is utilized by these researchers [7].

Considering the proposed method by Haktanir and Acanal a multi-stage method is selected in this study to define an optimized flood routing rule curve. The reservoir's flood retention storage was divided to various critical levels and the total allowable discharge at each level step of reservoir were determined by trial and error. The operation rules will be defines with the objective of minimizing downstream expected annual damage (EAD) beside of considering dam safety.

Figures 2 depict the first main loop of multi-stage routing model and the main steps of the proposed procedure, respectively. For the lesser hydrograph, the total allowable discharge of the reservoir is determined for each step of water raising between initial level and the first critical level (Hcr1). Considering the minimum flood damage object, the allowable discharge (Q allow i) for each elevation step (El i) would be initially accepted if the maximum water level did not exceed the first critical level (Hcr1). At the end of this first sub-loop, a set of allowable discharge value (Q allow i) is produced for each step of elevation increment between Eli and Hcr1. The second sub-loop is repeated with the same procedure between again the initial level (Eli) and the Hcr2. For this sub-loop, allowable discharge for new steps of elevation between Hcr1 and Hcr2 must be determined while the maximum water level during the second flood routing does not exceed Hcr2. If the previous set of allowable discharge needs some modification, the related sub-loop should be repeated consequently. This procedure is repeated for all decision hydrographs up to PMF considering the critical level constraints in each hydrographs and the minimum flood damage.

At the end of the last sub-loop (For the largest decision flood), the first main loop is ended and a set of allowable discharge value (Q allow i) as the initial Flood Routing Policy (FRP) is produced for every elevation steps of the reservoir between Eli up to Hcr max. Then the Optimized Flood Routing Policy (OFRP) will be defined by minimizing the respected value of expected annual damage (EAD) by trial and error.

To have a flexible flood routing policy, the decision hydrographs must be put into certain grades which allows the model to select regarded value of critical levels (Hcr) for each grades. Each grades is introduced by a "limit hydrograph" to the model. Detailed procedure is explained in the next sections of this paper.

3 Flexible Flood Routing Policies; Necessitates and proposed methodology

Through the initial times of flood entering a reservoir and especially in large reservoir, reaching an appropriate decision for the amount of the released flow from the reservoir is a challengeable issue. The proposed rule curve by some researchers (Haktanir et al (2013)) have constant (unique) values of discharge (or gate opening) for any magnitude of flood in which actually ignored any engineering judgment based on the real time available data (not forecasting data) of incoming flood.

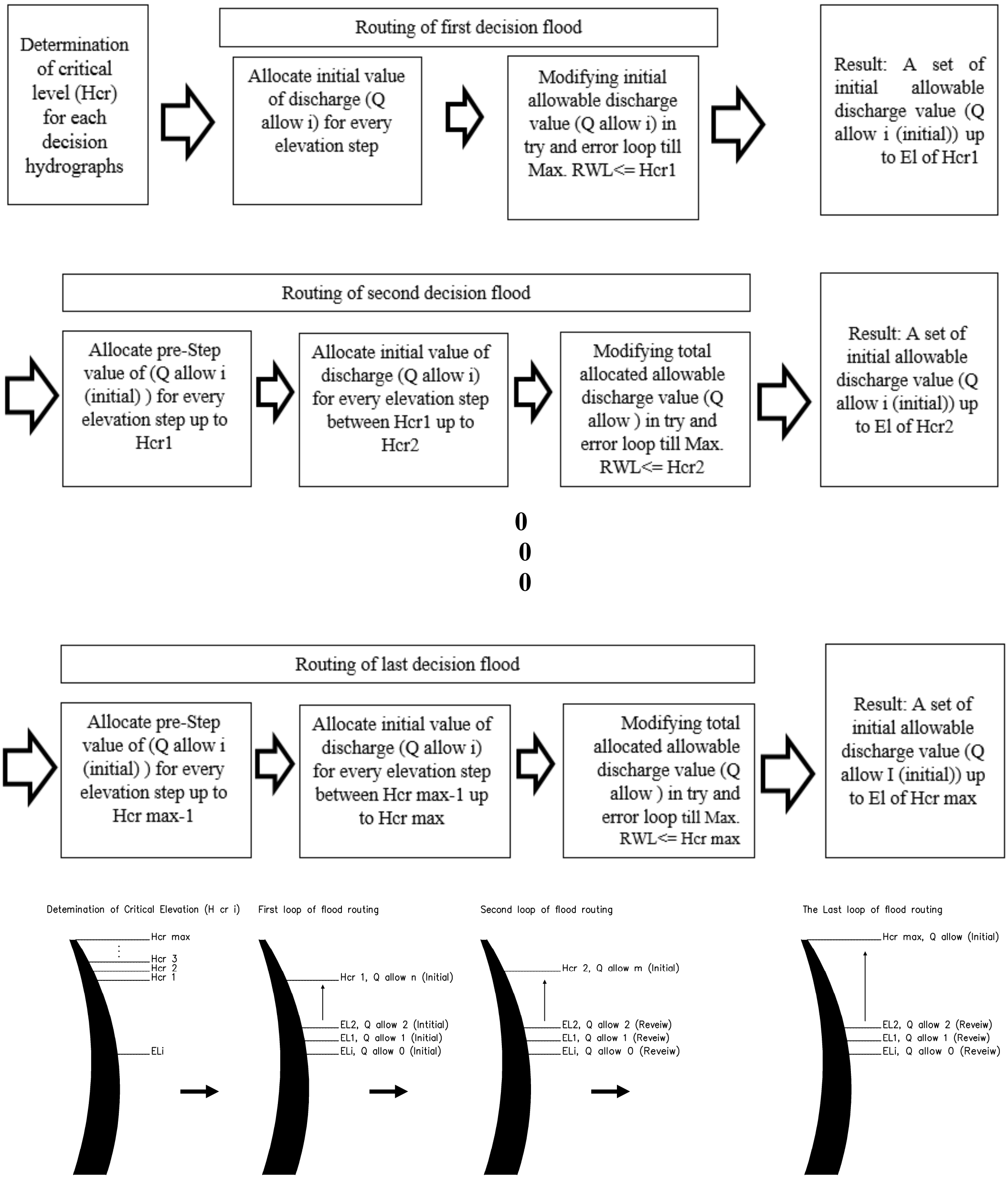

Fig. 2. Multi-Stage Routing Method Main Scheme and Flowchart: First Main Loop

In this regard and without having any flood forecasting, two general policies in flood damping which could be selected by dam operators is presented in table 1. In large reservoir, the flood retention storage may be lost rapidly if very small release flow in initial times of flood was selected by the operators (Policy-A).As it is stated in below table, selection of this policy however maybe useful for small flood, but will cause severe damage in medium to large ones. In contrary at Policy B, the damage will increase in lower hydrographs and will be decrease for larger flood.

Table 1. Main applicable routing policies for dam reservoir operator during flood event

Title	Allowable discharge amount		Expected Flood Damage		
	lower level of Reservoir	upper level of Reservoir	For small flood	For medium flood	For Large flood
Policy A	Very small	Very large	Negligible	huge	Very huge
Policy B	Small	Large	low	Almost huge	huge

To have the advantages of two policies having a flexible policy is necessary which allows to release smaller value for lower hydrographs. In this method, the allowable discharge has a reasonable relation to the value of incoming hydrographs. To address this issue a "real-time-factor" (Named as J-Factor) is considered to take into account more or less the engineering judgment for the incoming flood. A modified allowable discharge is obtained by contributing this factor if the incoming flood changes dramatically. Therefore the rule curve shifts to higher value for higher level of flood hydrographs. According to this method two sets of value is determined as optimum rule curve including base and modified value of allowable discharge at each level of reservoir. So through the above-explained loops of try and error during the rising limb, for lower hydrographs, higher level of reservoir could be select as critical level (Hcri) without concerning of passing the critical level for larger hydrographs.

4 Case study: Dez Dam (Existing and rehabilitated)

A schematic layout of Dez dam appurtenant structures is shown in Fig. 3. The dam has two gated spillways in left bank and two power intakes in right one. Three sluiceways are also located in dam body for supply agricultural demand which were replaced by newer ones four years ago.

Two new power intakes along with two intakes for flushing tunnels are considered in rehabilitation project. The flushing tunnels (FT) intakes are located near old and new power intakes and designed to transfer turbidity current during flood time with the capacity of about 1000 cms at NWL (352 m.a.s.l.).

Based on heightening study result the spillways crest level will be raised about 2.7 m and the gate original height is reduced respectively [6].

The 17500 km2 catchment area of Dez dam is consisted of two main sub-catchments area (Bakhtiary (with around 40%) and Sezar (with around 60%)). The calculated hydrographs along with two recent experienced floods (for 2016 and 2019 flood) are shown below. Some characteristics of these hydrographs are presented in Table 2[5].

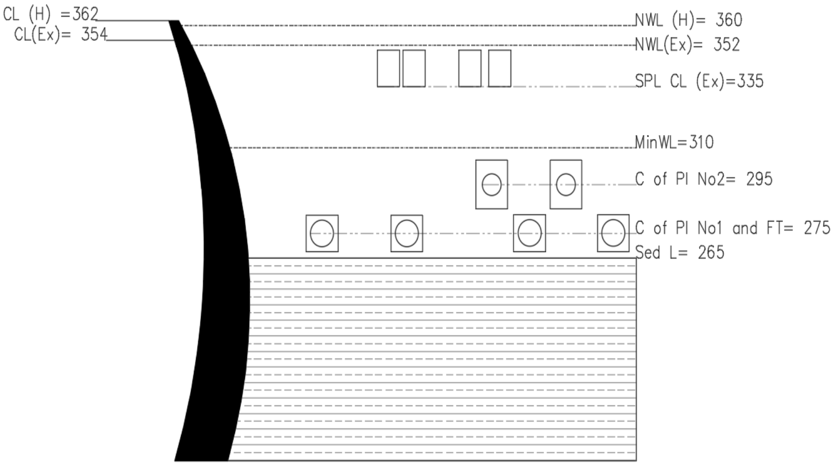

Fig. 3. Dam and appurtenant Structures schematic layout

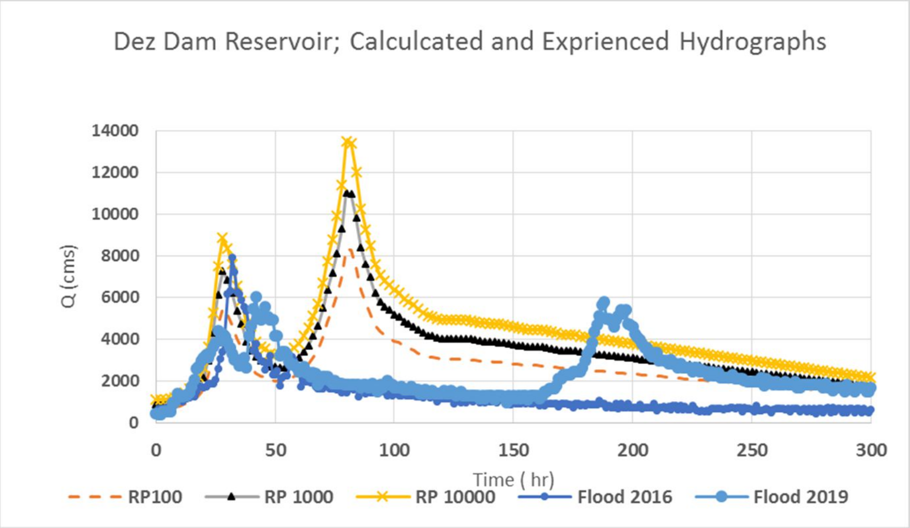

Fig.4. Dez Dam Hydrographs (Calculated and Experienced)

Table 2. Dez dam hydrographs characteristics

Return Period	RP 50	RP100	RP 1000	RP 10000	Flood 2016	Flood 2019
Peak value(cms): First tip	4,907	5,480	7,257	8,876	7,916	6,009
Peak value(cms): Second tip	7,465	8,336	11,040	13,503	0	5,807
Flood Volume(1000 MCM)	2.9	3.2	4.2	5.2	1.6	3.0

Considering the previous experience and the reservoir characteristics the following criteria and limits are defined in dam outlets operating:

- Considering of turbidity current issues in downstream, the sluicegates are operated when the reservoir level is greater than spillways gate sill elevation+10 m.
- Flushing tunnels is operate with 50% of their capacity below El. 345 m.a.s.l..

- Power tunnel capacities are considered in flood routing for upper level than NWL-3 m.
- Total discharge of all outlets is limited to allowable discharge value.

Initial reservoir water level (Eli) is set to 335 (15 m below NWL) as it is considered usually during flood season. Stepwise routing simulations at time increment of 1 h, for each of the 5 decision hydrographs including 50,100,1000,10000 years return period flood and PMF are repeated as many times as required. For each decision hydrographs, a critical level (Hcri) is selected and the large loop of routing computations begins (see below table).
Referring to Iranian Ministry of Power guideline, Dez dam is put into category 1 (highest level) and the 10000 return period hydrograph is selected as safety control flood. The maximum reservoir water level for this flood is limited to 30 cm below crest elevation.
The elevation increment step is considered 1 m in this study so the allowable discharge values is determined for every 1 meter (Qallow i) of level between initial and the maximum reservoir water level. So three sets of operational rules are defined for existing condition (as base scenario (Ex. Dam)), existing condition within flushing tunnels (Ex Dam+FT) and the heightened dam with flushing tunnels (DH+FT).

Table 3. Dez dam selected critical level in multi-Stage flood routing method

Title	**Flood Retention Storage Between El. 335 up to NWL**		**Flood Hydrographs Volume**			
	Existing Condition	After Heightening	50 years RP	100 years RP	1000 years RP	10000 years RP
Volume (1000 MCM)	0.841	1.35	2.9	3.2	4.3	5.2
Selected Critical Level (Hcr i)			NWL-3	NWL-2	NWL	CL-0.3
Selected Critical Level Value; Existing Dam			349	350	352	353.7
Selected Critical Level Value: After Dam Heightening			357	358	360	361.7

5 Flood routing Results

Using the flexible multi-stage routing method the peak discharge value of selected hydrographs is presented below for three scenarios. To compare the dam heightening condition with existing one the regarded result for 1000 return period flood is presented in fig. 5. As it is expected, the added flood retention storage in heightening dam, would let the operators to release lesser value of outflow and decrease the downstream damage especially for low and moderate-severity floods.

Table 4. Flood routing result; Scenarios comparison

Flood RP	**Max. Inflow**	**Peak discharge value**			**DH Effect (Outflow %)**
		Ex. Dam (Base Scen.)	Ex. Dam+FT	DH +FT	
50	7,465	3,300	3,080	1,750	-47%
100	8,336	4,444	3,789	2,440	-45%
1000	11,040	6,374	6,438	3,735	-41%
10000	13,503	7,526	8,321	5,429	-28%
PMF	13,908	7,550	8,561	5,865	-22%

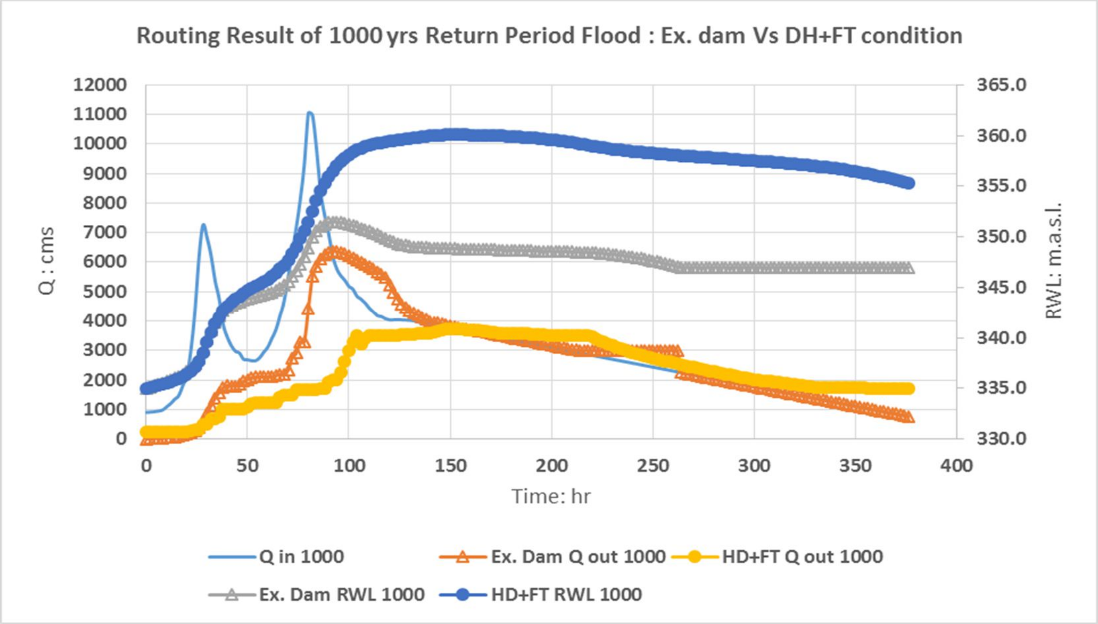

Fig. 5. Routing Result of selected scenarios; Existing dam vs. heightened dam+ flushing tunnel

6 Method of Evaluation

To evaluate the selected scenarios, the flood risk and damage must be compared. The risk assessment consists of constructing a damage-probability curve obtained by associating the damage estimated with the probability of flooding (Messner and Meyer, 2005) [3&13]. At least five floods need to be appraised to give an accurate picture of the shape of the damage-probability curves (Penning-Rowsell et al., 2005). The curve must be produced for each scenarios separately. Lastly, the related expected annual damage (EAD) value is obtained by calculation of the area below the curve. A schematic curve of damage-probability is shown below and the related result for above mentioned scenarios is presented in table 5.

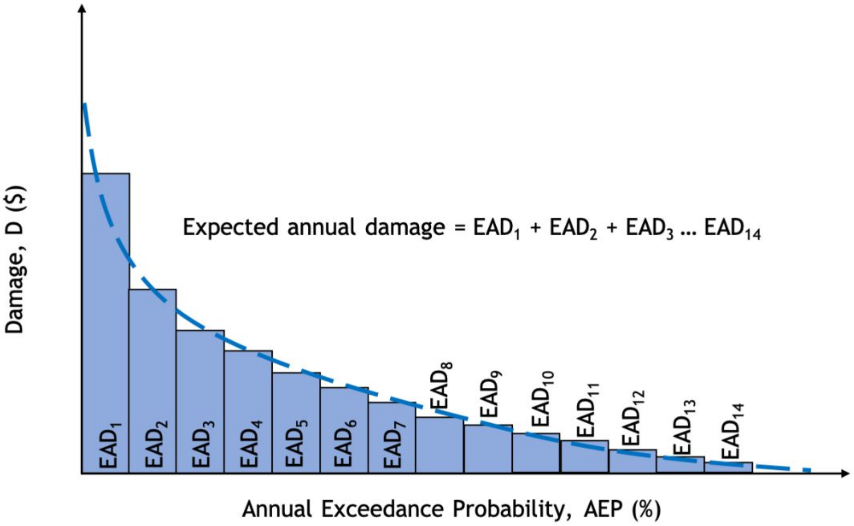

Fig. 6. Damage-Exceedance probability Curve and Expected Annual Damage.

Table 5. EAD value for selected scenarios

Return Period: Year	**Max. Avrg. Of 4 Days Outflow: cms**			**Flood Damage: Million $**			**EAD: Million $**		
	Ex. Dam (Base Scen.)	Ex. Dam+FT	DH +FT	Ex. Dam (Base Scen.)	Ex. Dam+FT	DH +FT	Ex. Dam (Base Scen.)	Ex. Dam +FT	DH +FT
10	200	200	200	0	0	0	17.2	16.0	3.5
50	2,937	2,831	1,748	177	166	14			
100	3,336	3,223	2,255	220	208	93			
1000	4,811	4,714	3,587	1,151	1,054	273			
10000	6,172	6,031	4,937	2,599	2,456	1,277			
PMF	6,365	6,248	5,161	2,796	2,676	1,525			

7 Conclusion

The defined sub-projects in Dez Dam rehabilitation project is subjected to their roles in electricity production increase, demand supply improving or extended the reservoir life. In this study the effect of the project in flood damage reduction is evaluated. An increase of 8 meter in the dam crest level, will produce the new available flood retention volume of 550 MCM to decrease the peak value of outflows up to 47%. A flexible multi-stage routing method considering operator judgment during flood operations is proposed in this study to produce an optimized flood routing policy for existing and rehabilitated dam and the expected annual damage (EAD) value compared in each scenario. The result shows that the dam heightening project could play a significant role in decreasing the flood damage up to 80% in comparison with original dam.

As a result of climate change, extreme precipitation events are expected to generate catastrophic floods in Iran. So flood management issues attract the attention of consultants and authorities recently. Using similar procedure in other cases (under operation/study dam project), improving or adding the "flood management" purpose in dams' role could be proposed. It is worth noting that the heightening of dam crest could be selected with or without the normal water level increase (which may have some restrictions because of downstream water rights, reservoir limit, etc.). Moreover the unit price of the dam body construction would decrease at upper part dramatically while the related benefit may be reasonable in some cases similar to the above mentioned project. Dez dam heightening project estimated budget is about 35 Million$ which is around 16% of the reported financial damage of recent flood in 2019 (for outflow peak value of 3300 cms the damage is reported about 220 million $!).

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