

## **Badush Dam: Controversy and Future Possibilities**

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### **Abstract**

Badush Dam is believed to be the first dam in the world which is designed to protect from the flood wave which could result from the collapse of another dam; in this case Mosul Dam. Badush Dam construction was started in 1988 but it was stopped two years later due to unexpected reasons. From that time on many attempts were made to resume construction without success. Its value was stressed in a multitude of studies and technical reports amid conflict of opinions on how to do this. The original design of the dam as a protection dam was intended to have a large part of the reservoir empty to accommodate the volume of the expected flood wave for only a few months during which time it's content are released in a controlled and safe way to the downstream. The lower part of Badush Dam which has a limited height continues before and after this event to act as a low head power generation facility. Among the later studies on the dam, there were suggestions to introduce changes to the design of the unfinished dam which covered the foundation treatment and also asked for constructing a diaphragm in the dam. A long controversy is still going on with many possibilities but with no hope to reach a final solution soon. Any rational solution must consider both Badush Dam and Mosul Dam together as the safety issue involves both of them. This paper may be seen in six paragraphs. The first three describe in brief the history, the outline design and foundation treatment of the dam, therefore, setting the background to follow the conflicting views over its purpose and future which is discussed in the following two paragraphs. The final paragraph is devoted to discussion and our conclusions.

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## 1 History of the Dam

Badush Dam located 40 kilometres south of Mosul Dam, was conceived as a protection measure against the catastrophic flood wave that could result from the failure of Mosul Dam. The idea of building such dam was circulated first within the Ministry of Irrigation (MOI) in 1987 when Mosul Dam construction had passed the non-return point. It became clear that this dam was suffering from foundation problems resulting from the unsuccessful completion of the deep grout curtain under it. This meant the possibility of dam failure due to the continuous dissolution of gypsum and the formation of sinkholes and new cavities under the dam. The fear of such catastrophe was justified by a study of the Mosul Dam flood wave which can occur due to the dam failure. This study was completed in 1985 by the Swiss Consultants Consortium who had designed the dam [1]. The concept of building a “Protection Dam” did not find complete acceptance and there were engineers and experts who argued to spend more money to fortify Mosul Dam instead of wasting it on such a dam. One member of the Mosul Dam International Board of Experts, namely the World Dams Expert the late Mr. Pierre Lond (ex. ICOLD president) even refused to take any part related to the suggested dam saying; “Nobody on earth builds a dam to protect from the failure of another dam; Why not fortify or decommission the problematic one?” [2].

The Ministry, however, went ahead with its plan and invited consulting firms to submit studies, designs and plans to construct the dam. Fast Track Method was followed by overlapping the investigation stage with the studies and design phases, while more designs were done during construction. This was done and construction started on 1st January 1988. The construction went ahead at a very fast rate but it came to a halt at the end of 1990 due to the invasion of Kuwait by Iraq and the UN economic sanctions on the country which followed. Works were not resumed up to this moment and the completed percentages of the various items then were (30%- 40%). Many attempts have been made since that time to resume construction but they did not materialize in any fruitful action so far. The chronic problems, however, in Mosul Dam continue and the need for a solution is an urgent matter.

## 2 Original Design of the Dam

The basic design considerations of Badush Dam were to have a dam which is high enough to contain the full volume of Mosul Dam wave of 10 billion cubic meters when routed through its reservoir, but to improve the economic indices of

the dam, the available head between the Mosul reregulating power station and the Badush site would be utilized to produce electric power before and after the failure of Mosul Dam [3] [4]. The final design was that of a high dam with a crest at elevation 312 m (a.s.l). The capacity of the proposed volume of the reservoir was checked by mathematical modelling and was verified on a physical model. The main characteristics and design parameter were as shown in Table (1).

The eight bottom outlets were to be used during, river diversion, normal operation and also for the passage of normal floods up to 8000 m<sup>3</sup> /sec, which is the routed maximum anticipated flood from Mosul Dam. The top ungated spillway operates only in the event of water level rising due to the flood wave and exceeding its sill level of 294.7 m (a.s.l) in which case it can pass up to 4000 m<sup>3</sup>/sec and limits the maximum water level to 307 m (a.s.l), leaving a freeboard of 5 meters without causing the danger of the dam's collapse.

The main dam was designed in two distinct parts. The first was the earthfill embankment that extends on the right bank, the left bank and part of the river channel and the second part was the concrete hollow gravity and buttress dam which was formed of two sections. The first section houses the bottom outlets and the ungated spillway at the top, while the second section contains the power penstocks that lead to the powerhouse building at the toe of the dam. More can be found on this type of dams in reference [5]. The earthfill embankment adjoins the abutments of the concrete dam from both sides. Figure (1) shows the layout of the main dam. In addition to the main dam, there were also two small saddle dams with maximum heights of 11 and 22 meters in the left bank to contain the flood wave completely and prevent it from spilling over as seen in Figure (2) [3].

The design of the earthfill dam indicates clearly the temporary nature of its use from elevation 260 m (a.s.l) upward; which is reflected in the thin inclined clay core and other embankment details as indicated in the typical cross-section of the dam in the river channel shown in Figure (3). The assumption made by the designer was that the upper part of the dam above elevation 260 m (a.s.l) was meant to function for few months only, in which time the reservoir would be emptied quickly. The same thing was also very clear in the design of the foundation treatment works, which are discussed later on in this paper. This was based on the assumption that the deep rock layers would not be affected by the very limited hydraulic head during the normal operation of the dam, and the high rise in the hydraulic head in the case of the flood wave impounding will be temporary and will not last very long. So the foundation treatment concentrated much more on the normal operation case.

Table1: General data of the proposed Badush dam.

General data of the dam	Units
Annual average discharge	667 m <sup>3</sup> /s
Maximum Probable Flood (Mosul Dam)	27000 m <sup>3</sup> /s
Flood with (0.1%) Probability at Mosul Dam	12000
Design flood during operation (Routed through Mosul Dam to be passed through Badush Dam)	8000 m <sup>3</sup> /s
Maximum reservoir level (in case of Mosul Dam failure)	307 masl
Design flood level for the normal case	250 masl
Normal operation level for the normal case	245,5 masl
Minimum reservoir level for the normal case	243,8 masl
Spillway capacity	4000 m <sup>3</sup> /s
No. of bottom outlets	8
Total bottom outlets capacity	8000 m <sup>3</sup> /s
Dam crest level	312 masl
Maximum height of the main earthfill dam	92 masl
Length of the Dam crest	3,730 km
Crest level of the Concrete Dam	294,7 masl
Maximum height of the Concrete Dam	102 m
Length of the Concrete Dam	248 m
Installed capacity of the power station	170 Mw

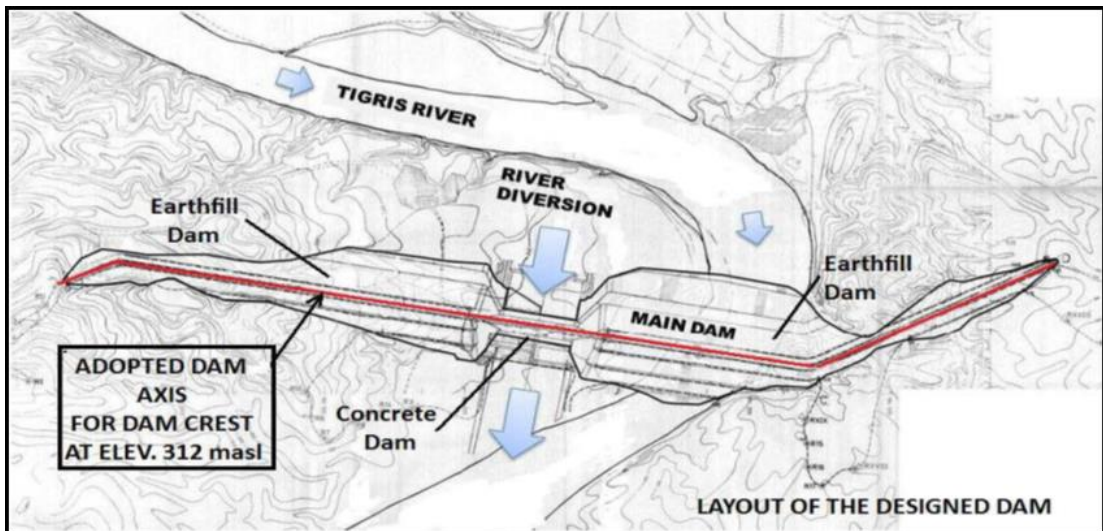


Figure 1: Main Badush dam General Layout [3].

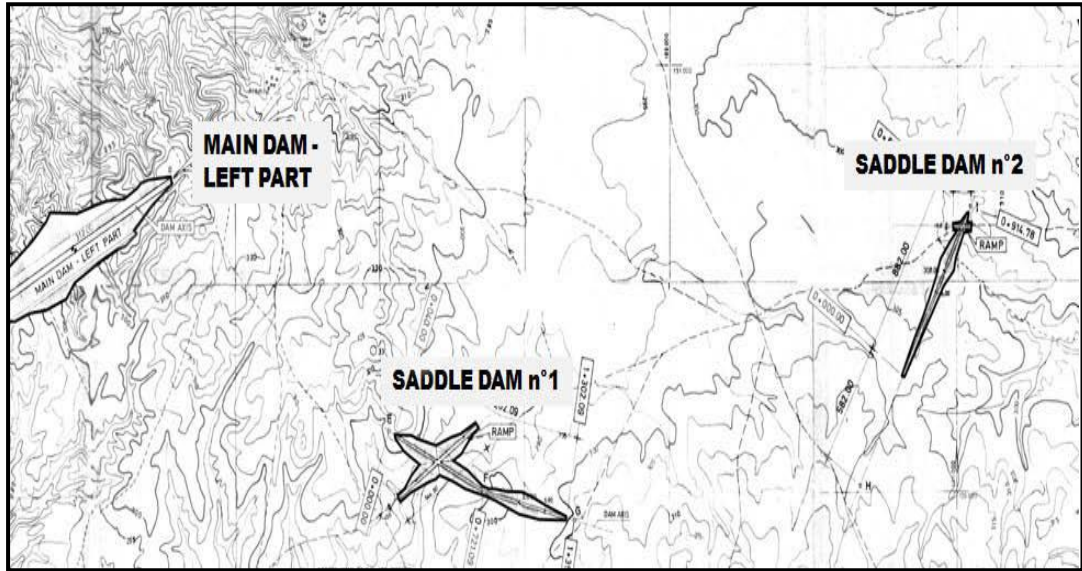


Figure 2: Badush Saddle Dams on the left bank [3].

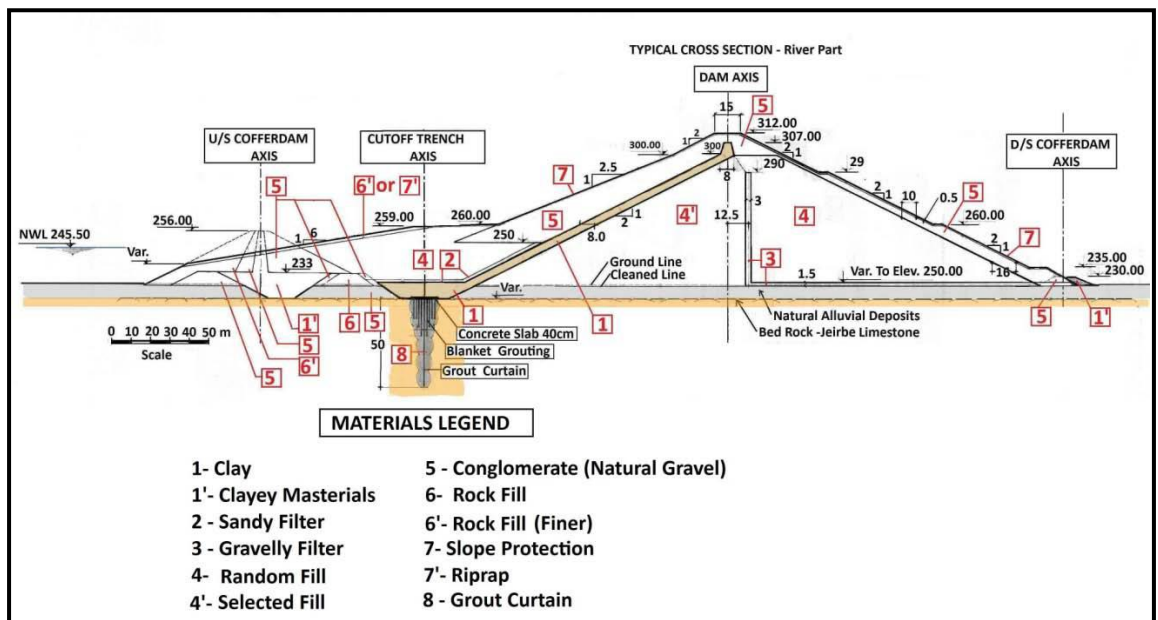


Figure 3: Typical cross section of the earthfill dam at the river channel [3].

### 3 Foundation treatment

During 1987-1988 geological investigations were carried out at the selected site which was located to have the axis of the dam coinciding with that of Alan anticline. This is a double plunging anticline extends at the right bank of the Tigris River and its eastern plunge is located at the left bank. While the dominant

geology around the site is the Fatha Formation, the foundation of the dam was to be placed mainly on the Limestone Formation (which follows the Fatha Formation) and which is exposed at the core of this anticline [6]. It is a known fact that the Fatha Formation is characterised by heavy gypsum karsts and its presence in Mosul Dam foundation is causing the safety problems of this dam today [7] [8]. The investigation campaign included geological mapping of the site, drilling 83 deep drill holes some of which exceeded 100 meters in depth and totalling 5732 meters in total length with full core recovery, testing and analysing the properties of the recovered rock samples [9,10]. In this paper, however, we call for an additional geological investigation to be completed before attempting any further work in the Badush Dam construction in order to remove any doubt on the performed foundation treatment, and the need of any modification or other special treatments if required.

The design philosophy of the foundation treatment as adopted by the designers was as follows:

- a. The effective hydraulic head in Badush dam is represented by the operation of the dam as a low dam for power generation. This head ranges between levels 245.5 m (a.s.l) and 250.0 m (a.s.l) at the upstream side and the corresponding levels of 227.7 m (a.s.l) and 233.20 m (a.s.l) at the downstream side. So the adopted value for the head was 20 meters. This is comparable to the hydraulic head at the Mosul Dam Re-Regulating Dam which is located in similar geology. The treatment works at Badush Dam need not be therefore much different if only this head is considered. This may consist of a blanket grouting with defined depth and a grout curtain of a very limited depth.
- b. The high hydraulic head which would be realized during the impounding of Mosul Dam flood wave at an elevation of 307 m (a.s.l) would be a transient case which would take place for a very short period while the reservoir is emptied. It follows in such case that the only required additional treatment is to safeguard the dam against uplift forces. At the same time no appreciable change would occur to the deep rock formations under the dam during this short period. This is reflected in the final design of the dam by adding a single row grout curtain under it.

So, the following details may be given of the foundation's treatment as indicated in the final design:

1. With respect to the earthfill embankment, a cut-off trench under the clay core would be excavated down to the limestone formation to be filled with clay after performing dental concrete treatment to its bottom and its downstream surface. This trench is placed on the limestone formation for 1280 meters measured from the right river bank, after which it would continue through the Fatha Formation for another 200 meters to the point where the grout curtain is terminated. On the left bank, the trench would be excavated down to the limestone rock for the most of its

length and only for a small part through the Fatha Formation and would finish at the end of the grout curtain approximately 250 meters from the left river bank.

2. Blanket grouting was to be applied after excavating the cut-off trench from a concrete slab 0.4 meters thick placed at the bottom. The blanket itself would be formed from 8 rows of grouting holes at 1.5 meters spacing between rows. The holes are set at 1.5 meters spacing in a staggered form and have depths of 10 meters at the edge of the blanket which increases to 20 meters at the centreline. This would bring the width of the grouted zone to 12 meters. The central row holes in the blanket are extended down another 30 meters to form the deep grout curtain which has a total depth of the 50 meters under the base of the cut-off trench.

3. With respect to the concrete dam, the foundation excavation was extended down to the sound limestone rock after removing all the cracked and badly fissured upper layer of about 10 meters in thickness, which was filled afterwards with mass concrete up to the level of the bottom of the foundation slab. Grouting works consisted of blanket consolidation grouting and a deep grout curtain. Consolidation grouting was to be applied to the whole area of the foundation slab with the grout holes drilled in a grid of 3x3 meters and depths of 10 meters and 5 meters as shown in Figure (5). The 50 meters deep grout curtain was to be constructed from a grouting gallery with a similar specification to that under the embankment.

4. Additional to these grouting works under the concrete structures, two drainage curtains were envisaged to relief uplift pressure build-up at the concrete structure foundation joints. The first one would be at a distance of 6.67 meters downstream from the grout curtain and have 30 meters depth under the foundation joint. The second would be placed at 60.9 meters behind the grout curtain with the depth of holes of 5 meters below foundation level. All holes were to be at 3 meters spacing and to have a diameter of 146 mm. Perforated plastic pipes which were to be wrapped by two layers of plastic mesh filter would be inserted in these holes and would have taps at their tops so to discharge the drainage flow into two drainage galleries as shown in the Figure (5). This drainage water would then be collected in a common sump to be pumped out by the central pumping station in the powerhouse.

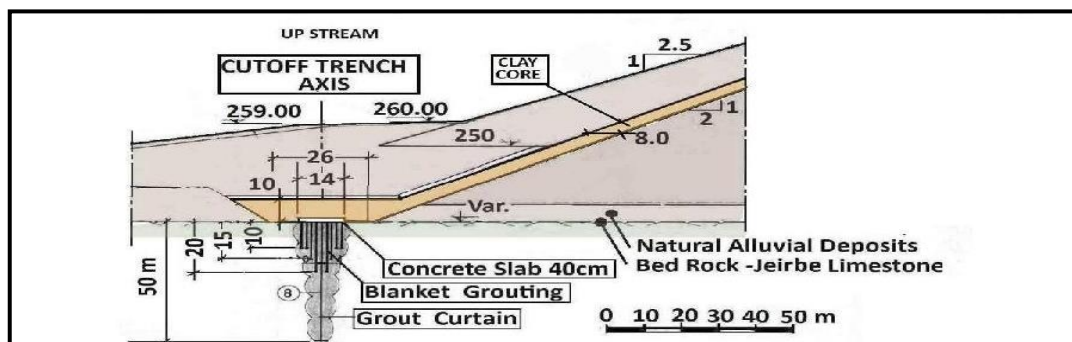


Figure 4: Details of grouting works under the embankment.



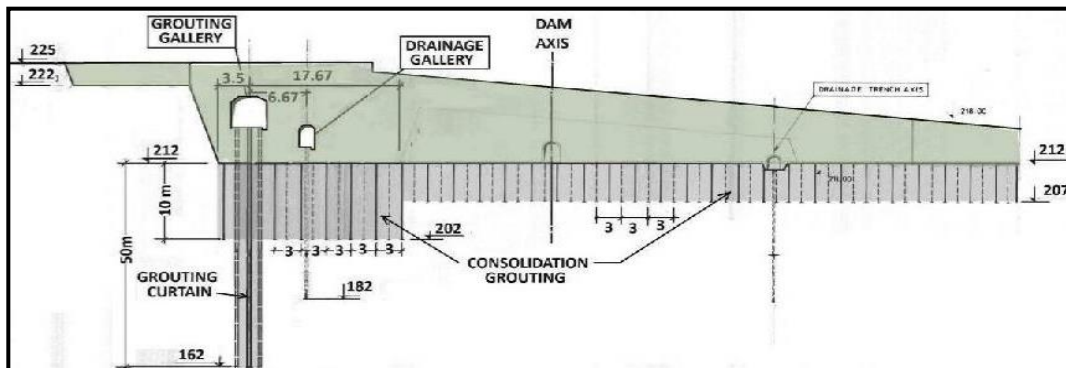


Figure 5: Details of grouting works under the concrete structure.

#### 4 Further Studies and Conflict of Opinions

In 2004 the condition of Mosul Dam was thought to have reached such critical stage that it warranted complete engineering and safety reviews. The evaluation of the worth of the ongoing grout curtain maintenance program was necessary. This maintenance grouting had started since 1987 and continued till that time without tangible results. The total quantity of grouting materials used was about (93000) tons according to the safety review report [11]. In another word, dissolution of gypsum was continuing within the grouted zone and new seepage paths were opening in the same locations or in new ones. The report was completed in 2005 by Washington Group International & Black and Veatch [11] who carried out this safety evaluation. The Panel of Experts which examined Mosul Dam within the scope of this study highlighted the need to continue the maintenance grouting in Mosul Dam as long as possible but, considered that the completion of Badush Dam was necessary to protect the downstream population from the imminent collapse of the dam sometime in the future. The panel overruled the possibility of construction of any diaphragm in Mosul dam on the grounds that such diaphragm was technologically not feasible, its construction posed dangers to the integrity of the dam, and it would be much more expensive than the completion of Badush Dam [11]. No action was taken however to resume the construction of Badush Dam.

The question of Mosul Dam safety versus Badush Dam completion was then considered again in 2006 when another Panel of Experts was commissioned by the Ministry of Water Resources (MOWR) which had replaced the (MOI) to study Mosul Dam conditions. This panel was formed mainly from specialists working with Harza Engineering Company, a principal partner of MHW Global since 2001. The panel in the report of its third meeting held in May 2007 recommended the installation of a diaphragm in Mosul Dam, in addition to transforming Badush Dam from a high protection dam to a low dam for power generation only [12].



These recommendations were the complete reverse of the previous panel recommendations. The same panel in its first report in 2006 had recommended lowering the normal water operation level at Mosul Dam from 330 m (a.s.l) to 319 m (a.s.l) to reduce the possibility of the development of dangerous sinkholes downstream of the dam as had repeatedly happened especially with the last one appearing in July 2005.

In following this matter, MOI awarded a new contract to a joint venture of consultants which was formed from Elconcord (Jordan), Paul Rizzo (USA), Energoprojekt (Serbia), and MEDINGEGNERIA (Italy) to study and present designs of a low Badush Dam for power generation only with the understanding that a diaphragm wall was to be implemented in Mosul Dam. The new consultants prepared and submitted in the following years, many reports which covered two phases, [13] [14]. The tender documents for the required works were submitted later on in 2010 and they included among other things the works for the suggested modifications on the concrete structures, earthworks and foundation treatment. One of the most striking things in these designs and documents was the unnecessary removal of 450000 m<sup>3</sup> of heavily reinforced concrete that were placed already in the dam abutments. The other matter which may be criticized strongly in these documents is the provision in the design for all the requirements as if the dam is to be raised to elevation of 312 m (a.s.l) in a second stage of work but knowing well at the same time that such second stage would not be needed if a diaphragm is to be constructed in Mosul dam which was hypothesized originally [12]. These modifications were to build the dam in two stages. The first stage was to construct the dam to elevation 260 m (a.s.l) as designed by Energoprojekt to operate the hydropower plant with a head of 18.5 meters. Then a second stage to follow was to raise the crest level of the dam to elevation 312 m (a.s.l) in order to enable the retention of the flood wave from possible failure of Mosul Dam, but no clue was given by these consultants on the proper time to start this second stage. The height increment to the final stage was designed as a Roller Compacted Concrete (RCC) dam to fit with what remains of the original concrete.

Regarding the earthfill embankment, the consultants relied upon an inner vertical core instead of the designed thin inclined core. Diaphragm wall was proposed to be implemented in the first stage under the dam foreseeing that it would be necessary for the final stage. Grouting was anticipated under the concrete structures on the same lines as those prescribed previously by Energoprojekt. The total estimated cost to complete the dam exceeded 1.45 billion dollars. This was considered by the employer as totally unacceptable high cost for getting only 170 Mw electric power facility. In addition to the fact that the start and completion of the second stage were not defined in any time frame and this decision must rest in the owner's hands.

Following this, the feasibility of the dam itself was put to the question, and for that matter, it was referred to yet another new group of consultants formed from EDR GmbH (Germany) and Cedre Team International (Lebanon) in a new contract which was signed in the beginning of 2013. The study report was

submitted in October 2014 in which, these consultants expressed their belief that the protection from Mosul Dam flood wave should take precedence over all other considerations due to the ongoing grave threats of Mosul Dam, and treating the power generation question as a secondary matter. Economic analysis outlined in their report showed that power generation alone did not justify constructing Badush Dam [15], and they considered that the total human and material losses in case of Mosul Dam failure were beyond reckoning and this would justify giving priority to flood protection over power generation, and would also justify the high cost required in such case. The report states in a concluding remark the following:

*“Although Badush dam is not profitable project, we should focus on its second, but very important purpose (Protection from Flood Risk). Consequently, it is inhuman and even uneconomical to consider the project as just electrical plant generating 170 Mw. MOWR is the concerned party or employer to be obligated by the government to complete it”*

In May 2016 an International workshop on Mosul dam safety issue was held in Stockholm which was sponsored by Luleå technical university. A large number of leading world experts and dam engineers in addition to grouting contractors and diaphragm machines manufacturers were invited. The workshop examined Mosul Dam problems closely and came up with a wide range of recommendation with respect to the required future actions (Luleå Technical University, (2016) [16]. Three alternatives with respect to Mosul Dam future were suggested for further study, analysis and evaluation; these were:

1. To study the question of installing diaphragm wall through Mosul Dam,
2. To complete the construction of Badush Dam as a protection dam and, in the meantime continue grouting at Mosul dam.
3. Use a “hybrid approach” by which Badush Dam would be completed and used as a protection and storage dam.

The third alternative means to complete Badush Dam according to a new design and not wait for the Mosul Dam to fail. The Mosul Dam storage can be then released in a controlled manner into Badush Dam reservoir which will act then as storage dam replacing Mosul Dam and completely decommission it.

## **5 Evaluation of the suggested options: their Pros and Cons**

From the proceedings, it is clear that many options for Badush Dam future were suggested and discussed. All of these options were considered in the context of providing safety to the population and infrastructure downstream from the threatened Mosul Dam and the protection from the catastrophic consequences of the expected flood wave that could result from Mosul Dam failure. In the following, these options may be summarized and investigated for their value, reliability, required scope of work and economic and technical feasibility;

**Option (0):** This option is to do nothing more than what is being done so far. That is to keep grouting in Mosul Dam and do nothing on Badush Dam. This option does not recognize the continuous deteriorating conditions in the foundations of Mosul Dam which was not so clear in 1989 [17], but which became evident after carrying maintenance grouting for so many years afterwards. It was evident during all these years, however, that not much improvement on the foundation conditions could be obtained by this maintenance grouting, which is only sustaining the dam for unknown more years. The possible collapse without previous warning is still a scare up to now [18]. We may say, therefore, that this solution by itself is of temporary nature and cannot be relied upon to save the dam or secure the downstream reach of the river. It should be noted also that this option was adopted in (1987) after the submittal to the Mosul Dam Board of Expert of a report by the main contractor of the dam construction works (GIMOD) which was prepared by his consultants Binne and Partners [19] at a time when Badush Dam construction was under discussion within (MOI) and the idea of building it was not fully crystallised.

**Option (1):** This option required the continuation of the maintenance grouting in Mosul Dam by using the improved intelligrout techniques, but at the same time to resume the construction of Badush Dam as per the original design as a protective dam [11]. It was argued that continued grouting undoubtedly would elongate the service life of Mosul Dam and produce the intended benefits for more years, but it would not save the dam itself in the long run. It follows that the only possible way to protect the population and infrastructures downstream would be the completion of Badush Dam.

In formulating this option the Panel of Experts was not in favour of constructing a diaphragm wall through the dam body down to reach the required depth on the ground that no hydromill machine was manufactured at that time which can excavate to the required depth of 240 meters as the work had to be done from the crest of the dam, and even if such machines were available then there was no guarantee that the diaphragm wall panels would have the exact vertical alignments and so there will be wide open gaps in the wall at depth.

**Option (2):** This suggested option can be seen in terms of two intrinsically related and interconnected parts. Part (a) calls for stopping grouting in Mosul Dam foundation and constructing instead a diaphragm wall from the crest of Mosul Dam reversing the previous panel's recommendation, and; Part (b) to construct Badush Dam as a low dam with a maximum height at level 260 m (a.s.l), therefore, stripping it from the protection function and only to use it as a power facility [12]. This was again in complete contrast to the previous panel's recommendations.

As regarding Part (a), the construction of diaphragm, in fact, faces many more technical problems than just the required depth or keeping the wall panel

alignments vertical; these two problems however, may have been solved today. As seen from recent technological progress such depths are attainable now as indicated from the following website which claims the ability to reach a depth of 250 meters and keeping all panels to the true vertical with no deviation.

<http://www.soilmec.com/en/soilmecworldrecord250meterdeephydromilltechnologydiaphragmwallslurrywall>

But the real problem which remains as seen by us is in the karstic nature of the soft rock in the foundation which would result in slow progress of the hydromill machine and the need for a large number of such machines adding up to the total cost.

Additionally, the karstic and cavernous nature of the foundation poses also the possibility of losing the excavating slurry and the collapse of the excavated trench. In the simplest case this means the loss of the hydromill itself but in the worst scenario, the collapse of the trench could endanger the dam integrity and stability of the dam especially at high water levels of the reservoir. A possibility of pre-grouting ahead of excavating the trench may be considered as a solution, or even emptying the reservoir may be another one. These solutions, even if they prove their usefulness they add up to the total cost of the work, either as direct costs in the case of pre-grouting or indirect cost in the form of lost benefits for many years in case of reservoir emptying. Moreover, the diaphragm construction raises many other technical problems that may need serious attention and solution, such as avoiding the grouting gallery below the dam base, solving the problem of crossing the power and bottom outlet tunnels.. etc.

In Part (b) of this option, which is the transformation of Badush dam to a run of the river power station as suggested [12], the appointed consultant went ahead to design a second stage of construction to raise the dam back to its original designed height without stating when such work would be required and ignoring the fact that the construction of diaphragm in Mosul Dam as contemplated in Part (a) of this option eliminates the need for such second stage.

Our judgment on this option is that it fails engineering and economic norms and lacks engineering logic in addition to its abnormally unjustified high cost.

**Option (3):** This option, while it does not spell the grouting matter clearly aims at continuing grouting in Mosul Dam and at the same time calls for resuming the construction of Badush Dam and completing it as a high protection dam. This option is very much similar to option (1) but it calls for introducing some design modifications to the original design to remove any doubt on its proper functioning or safety and it emphasizes the value of the dam as a protection dam [15]. The suggested modifications were to cover both the earthfill dam and the concrete dam. It stipulated the installation of a diaphragm wall under the dam to replace the grout curtain which may not satisfy all the requirements under the full head which was even admitted in the original design, raising the concrete sill of the water

conveyance structures by 3.5 meters to avoid clogging these conduits by debris which could accumulate due to Mosul Dam collapse, and finally limiting the removal of the old concrete to an absolute minimum while incorporate the rest in the finished structure. This option seems logical, but more detailed studies are needed to put it in a final shape.

**Option (4):** This option calls for continuing the grouting works in Mosul Dam for a limited period of time, but also to start immediately the works in Badush Dam as a Storage Dam in this case, and after completion the gradual decommissioning of Mosul Dam must be started, whereby Mosul Dam reservoir is to be released into the new Badush Dam reservoir in a controlled manner and to take Mosul Dam out of service completely. This was one of the options discussed in Stockholm World Mosul Dam Workshop (2016) [16]. In studying this option, we examined its implications on the design of Badush Dam and the far-reaching results on the other projects connected with Mosul Dam. These may be explained as follows: First; the design of Badush Dam must be changed drastically to allow using it for permanent storage and not only for the few months that were envisaged originally as a protective measure. The changes should cover the details of the earth dam cross section by enlarging the clay core and the gravel and sand filter zones from elevation 260 m.a.s.l upwards; the water outlets structures i.e. bottom outlets and the ungated spillway must be re-examined and reassessed. The question of eliminating four of the eight bottom outlets and at the same time lowering the sill of the spillway and equipping it with radial control gates should be addressed to get more flexible operation. The design of the power conduits and power plant should be changed completely to take the much higher head into consideration. The main challenge to the designer in all this is how to elaborate these changes and incorporate them into the final design together with some parts of the already completed works. The anti-seepage foundation work is the other crucial matter that should be studied carefully. A new campaign of geological investigation must be done adding much deeper drill holes, and not to be limited to the dam location but it shall cover the surroundings and the reservoir area, and must extend to include the saddle dams' foundation and the periphery of the reservoir to locate possible sinkholes and other karst phenomena. Second: The impacts on the projects related to Mosul Dam as a result of its decommissioning should be carefully studied. These may be outlined by the following:

1) the required removal of the re-regulating dam of Mosul Dam which will be flooded by the Badush high reservoir.

2) the necessary remodelling or changing of the pump storage power intake which is located about two kilometres downstream from Mosul Dam.

3) Other changes which affect the three Jazira Irrigation projects must be considered, namely; First, relocating, redesigning and refurbishing the existing pump station feeding the North Jazira irrigation project and moving it southward from its present location north of Mosul Dam to a new site making use of the new Badush reservoir; Second, relocating the intake of the East Jazira irrigation

project to be fed from Badush Reservoir instead of the Mosul Dam Reservoir, and; Third, finding an alternative location for the intake of the South Jazira irrigation project which is presently incorporated in Mosul Dam itself, and also finding a new route for the feeder canal of this project and review the need for the Jebal Sheikh Ibrahim tunnel which is part of the original route of the main canal.

Fortunately, the last two projects are planned and not implemented yet which make room for carrying out the required designs, and if needed enough time for completing.

## 6 Final Conclusions and Recommendations

The final conclusions of this study may be stated as follows:

- From all the previously performed studies it is very clear that the problem of Mosul Dam safety cannot be separated from Badush Dam construction issue. Badush Dam was suggested as a protective measure from the consequences of Mosul Dam flood Wave in case if the dam would fail. But unfortunately, the works in Badush Dam were abandoned unfinished due to the reason explained previously. The calls for its resumption have continued up to now, either as it was originally designed or by introducing some design changes, and at the same time with the inclusion of diaphragm wall in Mosul Dam. It seems that the continued interest in Badush Dam reflects its importance and value.

- It is a much-known fact that the geology of Badush dam site is very similar to Mosul Dam site. Fatha Formation is dominating the depth of foundation around the Badush Dam although the dam axis itself is located on the Alan anticline in most parts which is a favourable factor. It was known that some of the drill holes completed during the investigation stage were about 100 meters deep without reaching the lower boundary of the karstified rock. In the light of all this, any plan for the resumption of works of Badush Dam, whether, according to the original design or otherwise must take the complexity of the geology into considerations and a thorough and new campaign of geological investigations must be performed. If the decision is taken to build the Badush Dam as a high dam, then such investigation should go as deep as 400 meters or even more in order to obtain the depth of the deepest karstified gypsum and limestone beds accurately

- In the case of high Badush Dam, grouting will not work for similar reasons as in Mosul Dam case. A diaphragm wall offers then a good solution and it can be constructed from the ground surface and can, therefore, go down to much deeper levels than in Mosul Dam. Moreover, the work will be much easier in such case as there is no full reservoir to worry about. If the decision is taken to go for low Badush Dam the revision of grouting is also necessary. Such revision may result in deepening the curtain and making it wider but, the changes will not be

very extensive due to the low hydraulic head sustained by the dam. Such head is similar to the head at the re-regulating dam downstream of Mosul Dam which was constructed in similar geology without any known trouble so far.

– From the analysis of the various options available at our hands and discussed so far, it looks that all options have their pros and cons. In our opinion the more logical solutions seem either, to construct a diaphragm in Mosul dam after drawing down the reservoir so not to cause any danger to the dam stability and integrity, and at the same time convert Badush Dam to a low dam with absolutely minimum changes to the original design. Or, to decommission Mosul Dam after completion of a high Badush Dam according to a completely new design. Such design shall take care of all the requirements necessary in a high storage dam and shall include no doubt the construction of a diaphragm in this dam.

These solutions must be examined by thorough and rigorous future studies. The economic factors must not be overlooked and should be given prime considerations as the two solutions involve very large investments, in addition to such indirect costs such as the lost benefits which result from emptying the Mosul Dam reservoir which is necessary for the first solution, and the cost of relocating and constructing new feeding facilities to the three Jazira irrigation projects in the second solution.

- There seems also a strong need that the owner of Mosul and Badush Dams (MOWR) should take a more serious and firm policy towards the Mosul- Badush question. We can observe a lack of resolve to finalize this matter which is clear from the long years the discussions have taken from 2005 till now, and from the many panels of Experts appointed, and in the many consulting contracts which have been awarded during these years, only to get a lump sum of conflicting design requirements and ideas which do not help in drawing clear roadmap to resolve this matter. Another example of (MOWR) blunders is clear from signing in 2011 a letter of understanding with a major hydromill manufactures to produce many units and construct the diaphragm at a cost of 2.6 billion US dollars. This was done when the Ministry did not have the slightest clue on the technical specification and requirement of such a huge and delicate work. According to Reuter News Agency the following was reported on Nov 4, 2011;

*“Construction and engineering company Bauer said it signed a letter of understanding on a \$2.6 billion [3.1 trillion Iraqi dinar] contract to refurbish a dam in Iraq. “We expect the contract to be ready for signing within the next few months after some final details have been clarified,” Chief Executive Thomas Bauer said in a statement on Thursday. The project, the company’s biggest ever, is scheduled to take about six years to complete It will involve Bauer building a cut-off wall to seal the Mosul Dam in northern Iraq. The ground beneath the 3.6-kilometre-long dam has become increasingly water-permeable, Bauer said” [20].*



This letter of understanding (or rather misunderstanding) was shelved and no one knows what has come of it so far.

In a final statement, we can only hope that a serious action to end this controversy will be taken before it is too late. Once Mosul Dam was described as “Iraq’s Ticking Bomb” [21].

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