Mosul Dam between the threats of imminent collapse

Maha Rasheed Abdul Hameed1 and Ali Laftah Abbas2

Civil Engineering Department, College of Dijla, Iraq
University of Diyala, College of Engineering, Diyala, Iraq

Email: mahaalzidi@yahoo.com

Abstract. This research deals with the state of Mosul Dam since first filling of the reservoir, studying the salt measurements and quantity of grouting materials consumption against drilling bore holes lengths. Based on those measurements, the conclusion made that, the state of the dam had been passed prior periods more dangerous cases than it is now, specially before fixing 319m level as threshold level in which the Reservoir level not admitted it be higher. The conclusion made that the state of the dam currently is not the worst case as claimed by USA side the research also explained the most important methods of maintenance and controlling which needs to follow according to design and guidance of treatment. The most important conclusion that this research raise is the necessity of construction of the Diaphragm Wall as a permanent solution which can be considered as a unique solution to solve the Mosul Dam problems permanently.

1. Introduction
1.1. History of the dam
Project was planned since 1950 under the name of (Askikalak Dam) by the Iraqi Development Board. Mosul dam was designed by a Swiss consultant (a group of Swiss consultants) and implemented by (GIMOD) (German Italian Mosul Dam JV). Start construction at 1980 and Tigris River was closed in 1984 while filling the reservoir started in spring of 1985 until completion in 1985. The grouting Gallery was constructed during the implementation of the dam to be ensure the dam foundation grouting and constructed according to design, and start grouting of the foundation before the main structure was built, No negative signs have been reported concerning the dam body and its function construction within more than 30 years. Dam construction has been completed in 1986 [1].

1.2. The main purposed to be constructed Mosul dam
The main purposed to be constructed Mosul dam are Flood control, to prevent the areas located south of it from the danger Water Regulation of the irrigation uses provide drinking water to the urban dwellers. The dam also serves to generate hydroelectricity with maximum 1050 MW Environmental improvement and developing fish resources. Also, the collect water during the time when the resources is available and release it during the dry period, in order to provide a cost-effective method of storing larger volumes of water for livestock or irrigation [1].

2. Basic Data
2.1. Location
Mosul Dam is located on the Tigris River 50 km north of Mosul city in Nineveh governorate [1].
2.2. Dam Specification

2.2.1. Dam – Body

a. The Mosul Dam is a homogeneous earth-fill embankment type mainly consisting a clay core protected by filters at the upstream and downstream and connects by the horizontal filter at the D/S of the dam [2].

b. The length of main dam is = 3.650 km, maximum height = 113 m Side Slope for U/S and D/S = 2.5 Vertical: 1 Horizontal, The top width of the crest is 10 m, Crest Level of the dam = 343.2 m.

c. Operational level = 330 m, Minimum operational level of the dam = 300 meters.

d. Total storage of the reservoir 11.1 * 10^9 m^3.

e. Spillway structure constructed on the right side of the dam with discharge amount (2111.5 m^3/sec).

2.2.2. Spillway

- Spillway structure constructed on the east side of the dam, controlled by five Radial gates (13.50m x 13.50 m), with maximum discharge: 13000 m^3/s.

- To the east is a fuse-plug which is emergency ungated spillway with Maximum discharge: 4000 m^3/s.

2.2.3. Irrigation opening

- Number of irrigation openings: Two gates, and total maximum design discharge of the openings 2440 m^3/s.

2.2.4. Hydroelectric power generation

- Location: at the toe of the dam on its west side, the main hydroelectric power station, It contains four Francis turbine generators for an installed capacity of 750 MW. Also from downstream of the main dam Mosul regulation dam which generate electricity as well. The hydroelectric plant has an installed capacity of 60 MW with four 15.5 MW Kaplan turbine generators. Also, from the lake, upstream of the dam is the 240 MW. [2].

Figure 1. Location of Mosul Dam - Nineveh governorate

Figure 2. Cross Section of Mosul Dam - Nineveh governorate
3. Site Geology

- Changed several times, and several geological investigations and preliminary designs were conducted and not decided until 1974 [3].
- At 1978 the location of current site of the dam axis were subjected to a new of extensive and detailed geological investigations.
- All the consultants who worked on that investigations and designs agreed on the difficulty and complexity of the foundation in all the investigated sites because of the presence of high-solubility gypsum rocks in the water.

![Diagram of geology zones](image)

- The foundations of the dam consists weak and complex sedimentary rock and sand mix each other and contain layers of gypsum and anhydrite that is soluble under the effect of the pressure resulting from water storage and its movement.

4. Beginning of the Problem

a) The beginning of problem starts since the construction of the dam and its operations, it has been shown that dam was constructed on a foundation of soluble gypsum, and that require continuous treatment by grouting deep [4].

b) The Seepage from the foundations of the dam appeared during the first storage in 1985.

c) In 1986, also, the Seepage appears near the spillway and increased more than 800 liters / Sec.

d) It was recommended to start grouting within the foundation before the superstructure was built.

Blanket-grouted 25 m deep around the foundation and a curtain 150 m directly below the dam.

e) The Grouting was carried out several times to reduce the seepage which still at this point, and its quantity changes with the changes of storage level. This seepage does not represent the leakage through the body of the dam, or the total leakage of the dam foundation.

f) Grouting started with beginning of storage and implemented by a secondary contractor (Keller-Rokem Radio).

![Figure 3. Foundation of the project area](image)

g) Several parts of the dam such foundations, D/S the dam and spillway which grouted had been well-considered and conform to design requirements according to depth of water storage [4].

h) A hole was discovered in a curtain in one of the areas that take so long time to be closed by grouting, in 1987, a decision was made to deepen the curtain and change the grouting mixture with the injection and changing pressures with it.

i) In 1988 the Iraqi staff began receiving all grouting work of the injection, filling, mixing and operating and maintaining of the machines. [4].
5. Analysis of the large loss that appeared in the tourist city in 2003:
   - Feb 2003: Big sink holes appeared in the tourist area and was closed by earth fill material but was developed and a settlement of buried material noticed. Continuity of settlement led to concentrate the grouting work [5].
   - To prevent the continuity of settlement development, the drilling and grouting machine Shifted from the left side to the right side were the sink hall appeared. Because of less efficiency's and shortage of the machineries and with shortage of grouting material, the efficiency of grouting work as a total has been affected negatively.
   - In July 2005, another land settlement in the downstream of the dam between the area main spillway and the Fuse block 60m from the edge of the dam are take place and was treated by increasing the grouting work effort.

6. Actions taken after 2003
   The measures below have contributed significantly to the monitoring and maintenance and development of injections and grouting and then the safety of the dam up to date:
   In the first years after 2003, many important steps taken:
   - Provide the grouting materials and repair the idle machines and provide spare parts.
   - Import machines and its spare parts, so the number of machines working in the dam reached 28, instead of three machines in 2003.
   - Establishment Board of experts from foreign specialists contributed with the Iraqi experts in the study and control of the case of dam Mosul:
   - In 2007 Board of experts fixed the maximum storage level be319 m.
- With the US side the process of monitoring and the establishment of the enhanced grouting program.
- Establishment of advanced communication system between the management and teams of grouting and contribute to the change and determine the mix of the inspection as needed for each case of injection
- Renew the monitoring system of grouting observation and the piezometers net
- Conduct additional geophysical and geodetic investigations of the site of the dam and the surrounding area to define the channels of melting channels, cavitation, and find treatment procedures
- The treatment of the stilling basin erosion by construction concrete beams on the bottom and sides and filling with big rocks between these beams to stop continuous erosion in the stilling basin area.
- A conference was held on the Mosul Dam in Istanbul, attended by dam’s experts, specialists companies in the treatment of dams where it was decided to proceed with the procedures for permanent treatments and the study of the construction of a concrete wall (Diaphragm) penetrates the foundation of the dam and prevents seepage and Continue with the grouting

7. Dam Break Scenario for foundation:
The Mosul dam was geometrically represented by the available topographic data and the level – volume curve. The total (storage volume was (13) billion m3 at level (335) m above sea level. The expected discharge, time of peak, and Max water level along the stream of Tigris Level during the collapse of the dam is (326) m3 / sec .Based on the results of analysis all data from Mosul dam to downstream of Baghdad shown on the longitudinal section For the case of complete collapse [7].

![Figure 6. Longitudinal Variation of Discharge for the case of dam Collapse at level (335 m).](image)

![Figure 7. Level Curve - Volume of the Lake of Mosul Dam](image)
8. **Evaluate the efficiency of the Grouting**

It is concluded that the geological nature of the foundations of the dam is complex and contains layers of gypsum and anhydrite with a high solubility in water. Therefore, in order to strengthen the foundations, it is necessary to create a deep curtain and install a wide network on both sides of the curtain for the purpose of monitoring and evaluation, to take necessary actions for its restoration and maintenance to ensure dam safety.

Method of evaluation according to the following equation:

\[
EFF = \frac{(USP - DSP)}{(R.L - T.L)} \times 100\%
\]  

\[(1)\]

![Figure 8. Law and Instrument of Evaluation.](image)

Note: Mainly if the degree of efficiency is less than 50% means the curtain needs to be treated and re-injected, the above evaluation has helped greatly in continuing to carry out the treatments in a timely manner and in order to ensure the safety of the foundation of the dam and thus the safety of the dam.

9. **Discussion - Analysis of the results of measurements for Seepage and soluble Salts:**

The table below shows the quantities of grouting material injected into foundation for sections points (1, 3, and grouting tunnel) shown on the image below, which representing from year 1986 until 2005, the information of which is also included in the final report submitted in 2005 by the (Washington international .inc) group [2].

![Figure 9. Location of injected points at Dam and the table show the quantities of grouting material injected.](image)

- In calculation the quantity of salt in water of reservoir was neglected which consider very little comparing with quantity of soluble salts from rock foundation.
- The total weight of grouting material used in that time was 91822 ton
Note: Figures 10, 11, and 12 below explain the relation between the period (month), with the seepage (l/sec), quantity of soluble salt (mm/l), and the weight of the soluble salt (ton/month) for (20 years).

9.1. For the First Three Years of the Project:

a) Point (1), Figure 10: below shown:

![Figure 10. The real action between level-seep age and solube salts.](image)

b) Entrance of Grouting Gallery, Figure 11: below Shows:

![Figure 11. The relation between water level seepage and soluble salts (point 2)](image)

c) Point (3), Figure 12 below Shows:

![Figure 12. The relation between water level seepage and soluble salts (point 3)](image)

d) Noted for this selected point that the weight of soluble salts during the measurement period was 183600 tons, while the weight of the fill during this period was 91778 tons. This means that the blank and cavities are up to 4500 m³. These spaces are not concentrated in one place but rather in several places along the sections of the reservoir.
The total consumption of grouting material (ton/m) of drilling during the period (1986-2015) indicates that the cavities for 2015 are lower than in previous years, whereas in 1998 it was the largest consumption of grouted material from all other years. This shows that the dam is currently not in the most dangerous cases as pointed out in the report of the American side, and even more serious cases in previous years have been overcome by treatment with grouting materials injection [5].

9.2. Discussion of the U/S ideas about the collapse of the Mosul Dam and Comparison of the status of the dam for the years (2015, 2014, 2013):
The US side reviewed the latest technical report which was updated on 30/1/2016 (which was submitted to the Iraqi government in addition to previous reports on the status of the dam). The American side confirmed that according to their monitoring of the dam during period from February 2015 by using the remote monitoring system by sensitive monitoring devices, the data set observed that the dam is in a very critical condition and is close to the imminent collapse compared to a situation before the year of 2003. Diagnosis in increasing the volume of cavities and sinkholes during the past year and not know the effects of non-continuation of the grouting during the period of "ISIS" occupied the area which resulted in unprecedented levels of untreated voids in dam foundations over the past year.

![Figure 13. The percentages of the (fill / Excavation) at the dam site from 1986 to 2015](image)

- It can be deducted from available data and charts which available, that the years (2015, 2014, and 2013) founded the greatest consumption of grouting material and then the more dangerous than the current material even that the continuous grouting overcome the risk.
- In order to study the consummation in relation with drilling quantities:
  - If the drilling is equal to or less than the consumption means there are few cavities.
  - If the drilling is equal to or more to the consumption means there are more cavities.
Figure 14. Quantities of drilling/grouting during years (2015, 2014, 2013)

From above quantities we can concluded when the risk was greater and when the dam threatened the possibility of collapse.

- By studying the charts and using the relation mentioned above, it deduces when the dam has a high probability of collapse.
- Also noted from the above charts that the grouting work during in 2014 as was relatively reduce by 42% of the 2013 excavation and 33% of the excavation work for 2015.
- The percentage of consumption of consumption materials / quantities of drilling (0.081931) ton / meter drilling for the year 2014, Compared to the year 2013 (0.05896) tons / m drilling, and amounted to 2015 (0.033) tons / m drilling.
- We conclude from this that the grouting materials consumption after 2014 does not indicated large cavities compared to the years before 2014.
- If the quantities of drilling consumption of year 2014 were compared with the results of the period 2000-2004, the situation was similar to that in 2014 before and during the regime change, the risk was greater at that time there was only one active drilling machine with a clear difference In the number of machines working in 2014, which is up to 25 machines capable of working to cover the required drilling and grouting activity and direct action needed at any emergency situation to avoid critical situations or dangers case.
10. Conclusion and Recommendation

1. Accelerating the implementation of Badoush Dam on the Upper Zub, Badoush dam Which designed for main purpose is to provide protection from a failure of the unstable Mosul Dam upstream and control to the flow of flow during collapse. At on the area of D/S Mosul Dam in order to close the curtain on the storage capacity about 400 million m\(^3\) that can reduce the water pressure problem of the expected collapse of the Mosul Dam.

2. Each a large dam should has monitoring system, including Cameras, geological investigation drilling, permeability test for grouting holes, grouting consumption visual inspection, seepage measurement in addition to chemical mater test. All these test and monitoring measurements can give impression on state degree of any emergency alerted by measurements of these devices and thus indicate the need for immediate treatment by the grouting and this is what happened and happens since the beginning of operation and so far and can't collapse suddenly without prior indications.

3. The presence of experts and special machines for drilling grouting and pumps is necessary to implement the program of grouting and overcame the emergency situations. Continuous grouting is necessary to avoid accumulation of cavities and the occurrence of irregular settlement in the dam as a result of the occurrence of the collapse. The grouting does not represent a permanent solution to avoid the risk situation, but the implementation of a concrete cut-off (Diaphragm) required with depth till end of gypsum layers (About 180m depth).

4. Minister of Water Rescuers Signed a contract with a foreign company to construct the grouting work because of the lack of financial possibility to implement the concrete (Diaphragm), which represents a permanent solution to the Problem.

5. The construction of the concrete diaphragm represents permanent solution which will finish all Mosul dam problems.

6. Till the starting of construction of diaphragm requires the following must be done
   a. Assess and identify risks and set standards for this.
   b. Evaluate the reduction of the reservoir level and the action diaphragm taken previously.
   c. Increase monitoring and inspection based on the operation and maintenance manual and the instructions of the designer and consultant.
   d. Update the emergence plan of Mosul dam.

7. Important phenomena that require focusing and considering their appearance require an immediate response, whether need reduction of the level, as well as an emergency grouting process:
   a. The sudden changes in the reading of measurement of the piezometers and the monitoring of advises and also check the chemical analyzes of the water of the reservoir and the piezometers and taking periodic, all these will indicate geodetic. Survey and gives indications of the development of a state of cases.
b. The appearance of new Sink holes or their development and in homogenous settlement in the body of the dam.
c. During Muddy Flow.
d. Sliding down stream slope the body of the dam
e. A clear and significant increase of wet areas downstream of the dam.

8. It is very important to establish standards and limits for the readings of the monitoring devices and piezometers and the types of the required response when exceeding the limits. These standards are based on the design standards of the dam and accumulated experience and upon the experiments in other dams suffered from the similar problem.

9. Reducing the storage levels of Mosul reservoir below (319 m) and that decision was taken by MOWR to reduce the water level in the dam basin which reduce the water pressure on the base layers and body of the dam (expected discharge during the collapse of the dam at level (319) m is (200) m³/sec. The maintenance of the 319 m level is with a capacity of 7.34 billion cubic meters will be operating the basin Tigris with (good flow and good water quality covering human consumption and irrigation and other different purposes.

References:
[1] Hussein, Ghanem Mohammed (2006). Report on Mosul Dam. Report submitted to the General Directorate of Dams and Reservoirs on 13/6/2006.
[2] Washington International Inc. (2005). Task Order 8 Mosul Dam Study. Final Report.
[3] Dr. Ali, Abdel Wahab Ahmed (2007). Engineering Geology. During the attendance meeting on 18/8/2007.
[4] Ayoub, Abdul Khaliq Danoun (2000). Correction method for gasket curtain efficiency values from readings of some of the piezometers installed in the foundation of Mosul Dam. Fifth Scientific Conference of Dams and Water Resources Research Centre. University of Al Mosul.
[5] Terzaghi, k. and R. B. peck (1967). Soil Mechanics in Engineering practice. 2nd ed., New York, John Wiley and Sonc , pp.590-595.
[6] Ayoub, Abdul Khaliq Thanoon (2002). Development of mathematical equations to evaluate the e
[7] Fread, D.L. (1982). The NEW Dam – Break Flood Casting Mode efficiency of the gasket curtain, a study submitted to the Ministry of Irrigation (gift day meeting.