Geological and Engineering investigations of the most dangerous dam in the world

Mosul Dam

Mosul Dam is located on the Tigris River in north western part of Iraq; approximately 60 km northwest of Mosul city and 80 Km from Syrian and Turkish borders (Figure 1). It is a multipurpose project for irrigation, flood control and hydropower generation. It is 113 m in height, 3.4 km in length, 10 m wide in its crest and has a storage capacity of 11.11 billion cubic meters. The water surface area of the reservoir at the beginning of the dam operation was 380 km^2 with a storage capacity of 11.11 km^3 at the maximum operation level 330 m (a.s.l.) including 8.16 km^3 live storage and 2.95 km^3 dead storage. It is an earth fill dam, constructed on bedrocks of the Fatha Formation, which consists of gypsum beds alternated with marl and limestone, in cyclic nature. The thickness of the gypsum beds attains 18 m; they are intensely karstified even in foundation rocks. This has created number of problems during construction, impounding and operation of the dam.

Construction work in Mosul Dam started on January 25th, 1981. Swiss Consultants Consortium was asked to be the consultants for Mosul Dam project. A consortium of German and Italian companies (GIMOD) was asked to execute the civil and steel work of the project in 1980. While electromechanical plant of the power station was given to the Japanese company (Toshiba) on the condition that the capacity of the plant will be 750 MW. The electromechanical plant contract for the regulation dam was awarded to (Elin Union) from Austria, while the electromechanical plant for the pump storage scheme was given to (G.I.E) from Italy. The total cost of the development was estimated at 2.6 billion US$ at the prices level of 1985and the dam started operating on 24th July, 1986. After impounding in 1986, new seepage locations were recognized. Grouting operations continued and various studies were conducted to find suitable grout or technique to overcome this problem. The seepage due to the dissolution of gypsum and anhydrite beds raised a big concern about the safety of the dam and its possible failure. This problem was kept in a small closed circle within the Iraqi Ministry of Water Resources (previously Ministry of Irrigation) till the US Army Corps of Engineers conducted a study on Mosul Dam for the period June, 2004 to July, 2006 and highlighted the possibility of the dam failure (Wakeley et al., 2007). News media had highlighted this concern in 2014 when ISIS occupied the dam site area. It was reported that about 500,000 will lose their lives in case of Mosul Dam failure. Loses of property and destruction of the infrastructure of the main cities downstream the dam will be enormous and it will reach the capital city Baghdad.

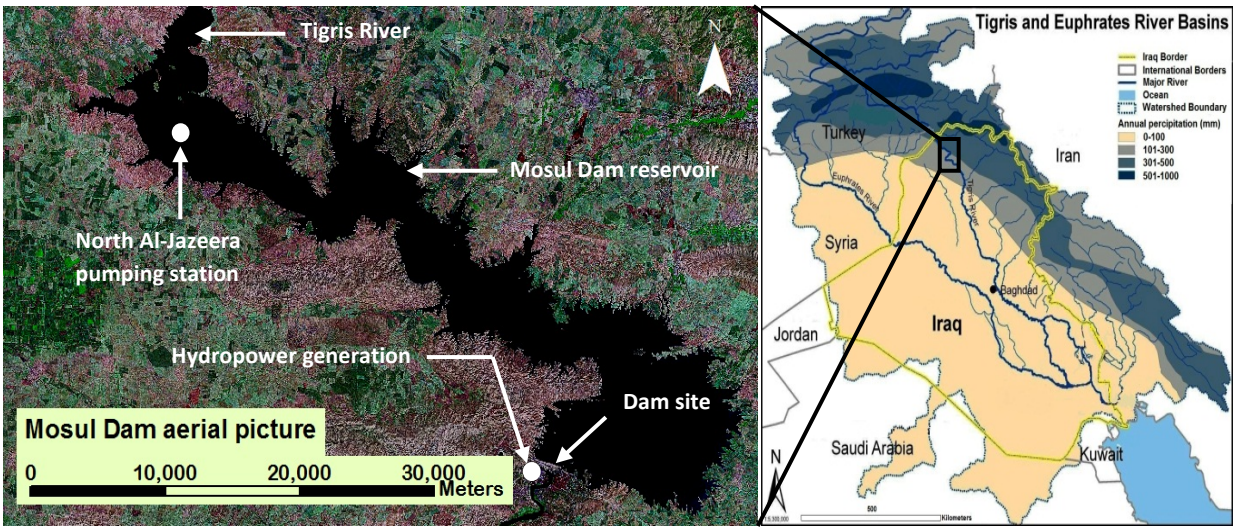

Figure 1: Location of Mosul Dam with main facilities.

Consequences of Mosul Dam Failure

The seepage problem during the construction and operation periods in Mosul Dam due to the dissolution of gypsum and anhydrite beds raised high concern about the safety of the dam. In view of the situation, the Iraqi Government asked the Swiss Consultants to perform a study about this matter (Swiss Consultants, 1984). This study was checked again by BV in 2004 (Wheeler, et al., 2004). Despite the fact that the above studies used different mathematical models, they got the same results. To overcome the problem, grouting operations were the main solution. Later in 2007, the US Corps of Engineers raised high concerns about the safety of the dam and it was reported that in case of the dam failure, it could wipe out whole cities, and was considered to be "the most dangerous dam in the world (Wakeley et al., 2007; RT, 2014). When ISIS occupied the dam site in 2014, there were fears that they might use explosives to destroy the dam. Numbers of articles were written in this context (RT, 2014; Roulo, 2014; The Independent, 2014; Bender, 2014; Tomkiw, 2014). As an example, RT (2014) wrote “the dam has been suffering a critical lack of maintenance and repair work. And under Islamic State management, a similar situation has been happening to other major dams located on the Euphrates (which still haven’t been freed).

The problem is that when it was built in the mid - 80's, little thought was given to the location. David Petraeus, the former commanding general of the US Army in Iraq, wrote a letter to Prime Minister Nouri Al-Maliki in 2007, indicating the dangers of the soluble soil located underneath the dam, which warrant constant attention and repair work. *“Extraordinary engineering measures” to fill soil gaps and “maintain structural integrity and operating capability of the dam” are a must, according to the US Army Corps of Engineers (USACE) report sent out in the same year. Another report by USACE in 2011 indicated that a failure of the Mosul Dam could cost 500,000 civilian lives in the immediate aftermath”*.

Swiss Consultant (1984) report had traced the wave caused by the dam failure. They calculated the discharges and water levels from the dam site downstream to Baghdad (Table 1 and figure 2). The highest discharges and wave heights are expected to be noticed in the first 122 km downstream the dam. The discharge is expected to be 551000 $m^3.sec^{-1}$ at the start and attenuates to 320 000 $m^3.sec^{-1}$ at the confluence of Tigris- Greater Zab Rivers, which will be reached after 7 hours. The wave height is expected to be 55 m and decreases to 45 m the first

20 km. Mosul city will be affected by the flood after 4 hours of the dam breaching where the maximum water level is expected to be 243 m (a.s.l.) (see Fig. 3). The wave height will be 24 m and it will inundate 74.044 km^2 of the area of Mosul city (Fig. 3). Downstream the confluence with Greater Zab River the discharge of the Tigris River will be reduced to 310 000 $m^3.sec^{-1}$. The water wave will reach Fatha after 16 hours and the discharge of the Tigris River after its confluence with the Lesser Zab River will be 210000 $m^3.sec^{-1}$. The wave height is expected to be 25 m at Fatha and since the water has to pass through the narrow gap between Hemrin and Makhul Mountains, backwater effect will be noticed and the water velocity at the gap will reach 10 m/s.

Downstream Fatha, the Tigris River valley widens from 1 km to 5 km and the discharge will decrease to 185000 $m^3.sec^{-1}$. At 422 km downstream the dam, the river passes a major city called Tikrit. At that city the discharges will be 185000 $m^3.sec^{-1}$. The wave height will arrive after 22 hours and its height will be 15 m. It will inundate 68.985 km^2 (Table 1, Figures 2 and 3). Then the wave will reach another major city called Samara which is 479 km downstream the dam. The wave time of arrival at this city is 25 hours and height of the wave reaches 10m. The river discharge will be reduced to162000 $m^3.sec^{-1}$. It will inundate 30.100 $km^2$of the city (Table 1, Figures 2 and 3). Further downstream, at a distance of 638 km from the dam, the wave reaches north Baghdad with a height of 4m. The time expected for the wave to reach Bagdad is 38hours. The discharge of the river at this point will be about 46, 000 $m^3.sec^{-1}$. It will take the wave about 10 hours to pass Baghdad and it will inundate an area of about 216.934 km^2 (Table 1, Figures 2 and 3).

Table 1: Discharges, time of arrival and wave height of the wave generated due to Mosul Dam failure (modified after Swiss Consultants, 1984).

Location	Discharge $m^3.sec^{-1}$	Time of Arrival hr.	Wave Height m	Distance km	Flood area Km^2
Dam site	551,000		54	0	
Regulating Dam	545,000	1.3	48	9	
Eski Mosul	481.000	1.6	45	17	
Mosul City	405,000	4	24	69	74.044
Hamam Ali	370,000	5	18	97	
Tikrit	185,000	22	15	422	68.985
Sammara	162,000	25	10	479	30.100
Balad	115,000	28	9	516	
Khalis	81,000	31	6	566	
Tarmiya	72,000	33	4	597	
Baghdad (North)	46,000	38	4	638	
Baghdad (Center)	35,000	44	4	653	216.934
Baghdad (South)	34,000	48	3.5	674	
Diyala Confluence	34,000	>48	3	685	
Salman Pak	31,000	>48	3	708	

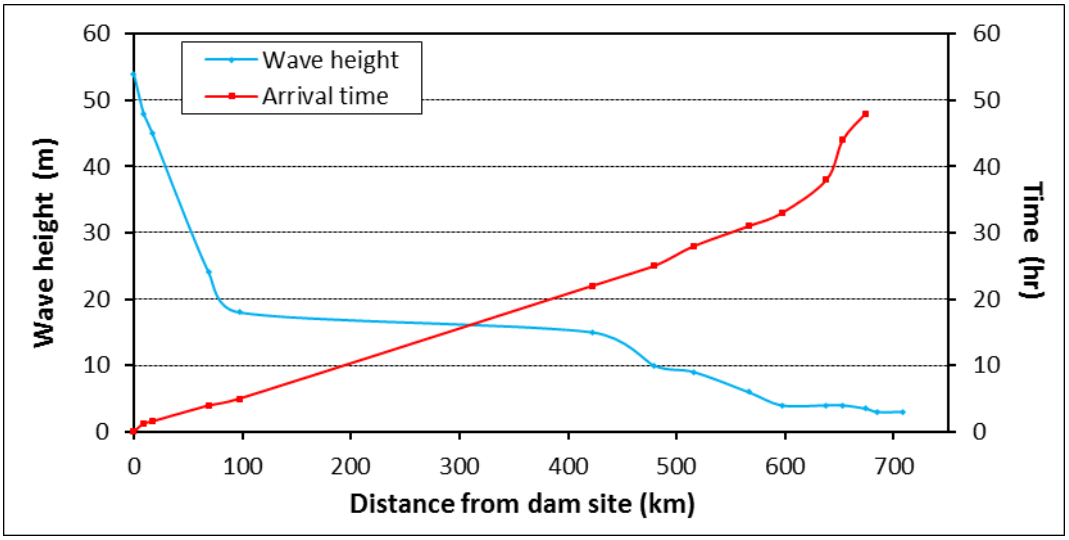

Figure2: Water wave height due to Mosul Dam failure and time of arrival from the dam site downstream.

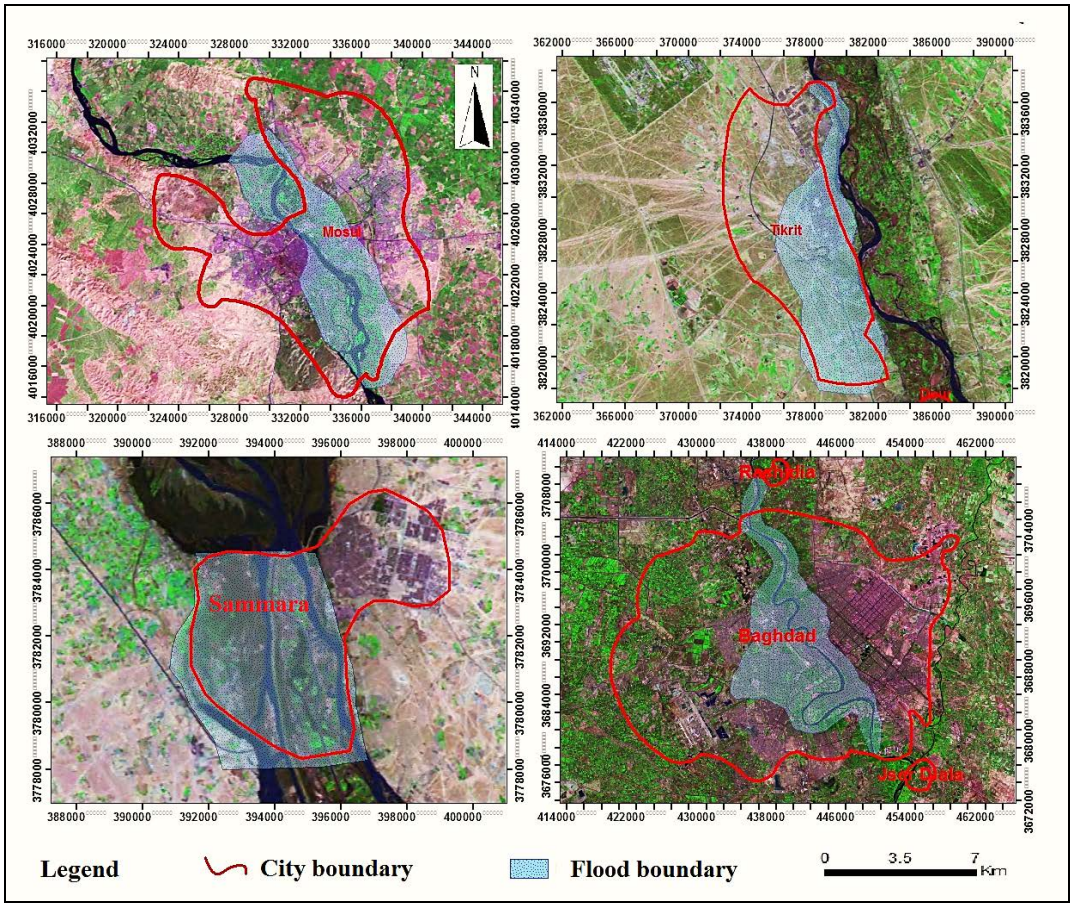

Figure 3: Expected inundation of major cities on the Tigris River due to Mosul Dam failure.

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