

# **Mystery of Mosul Dam the most Dangerous Dam in the World: General Geology**

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## **Abstract**

Mosul Dam project is the most important water resources project in Iraq. It is located on the River Tigris in northwestern part of Iraq, about 60 km north of Mosul city. This project is multipurpose project; to provide water for three irrigation projects in the north of Iraq and many other projects in the middle and south of the country, flood control and hydropower generation. Its storage capacity is 11.11 km<sup>3</sup>. The oldest exposed rocks in the reservoir area belong to the Pila Spi Formation of Late Eocene age, while at the dam site; the oldest exposed rocks belong to the Fatha Formation (ex-Lower Fars) of Middle Miocene age. The topography of the Mosul Dam and reservoir area is characterized by hilly terrain that rise to low mountainous area; representing physiographically Low Mountainous Province. Tectonically, Mosul Dam site and reservoir area are located within the Cham – Chamal Subzone of the Low Folded Zone of the Outer Platform of the Arabian Plate. The project is located far from Zagros Active Seismic Zone, but still many earthquakes were recorded in areas surrounding the project area.

**Keywords:** Mosul Dam, Regional Geology, Reservoir of Mosul Dam.

## **1 Introduction**

Mosul Dam is one of the most important strategic projects in Iraq for management of its water resources. It is considered the second biggest dam in the Middle East. The project was constructed on the Tigris River in the northwestern part of Iraq, located 60 km north west of Mosul city and 80 km from the Syrian and Turkish borders at 4056066 N northing and 305356.69 E easting [1] (Fig. 1).

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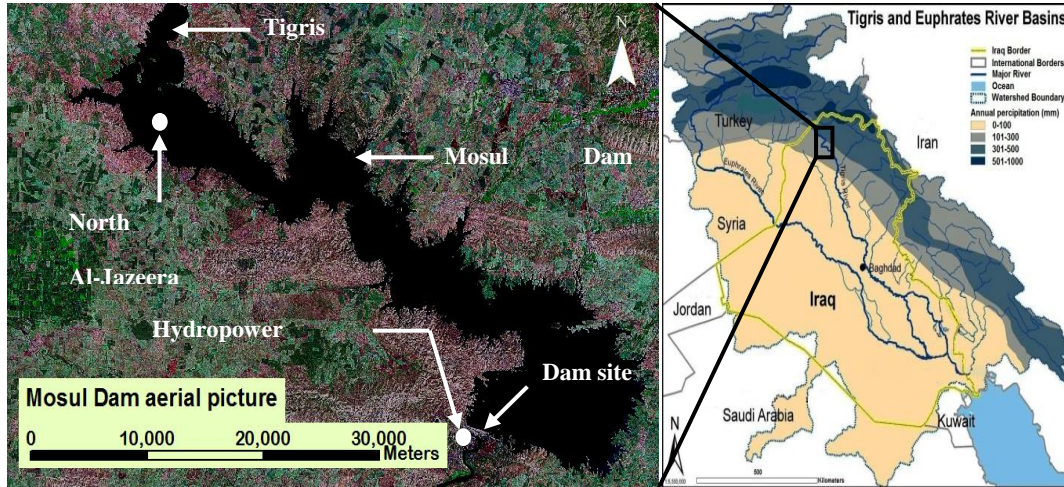


Figure 1: Location of Mosul Dam with main facilities.

Construction of Mosul Dam began on January 25<sup>th</sup>, 1981. The dam is a multipurpose project and started operating on July 7<sup>th</sup>, 1986 to provide water for three irrigation projects, flood control and hydropower generation. The dam is 113 m high and 3650 m long including the spillway. The top width is 10 m at 341m (a.s.l.) crest level. The dam is earth fill type with a mud core. The upstream side is faced with rock [1]. The maximum, normal and dead storage levels of its reservoir are 335, 330 and 300 m (a.s.l.), respectively. The dam was designed to impound 11.11 km<sup>3</sup> of water at normal operation level, including 8.16 and 2.95 km<sup>3</sup> of live and dead storages, respectively (Fig. 2).

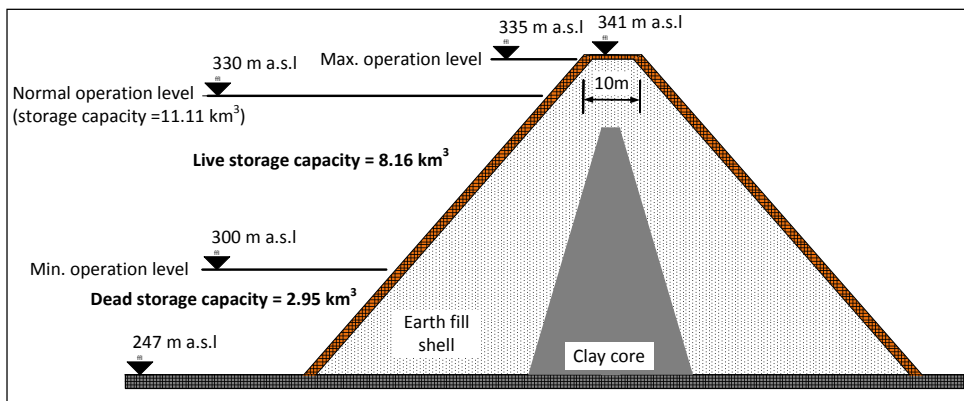


Fig. 2: Schematic diagram of Mosul dam cross section

The dam has a concrete spillway located on the left abutment. The crest elevation of the spillway is 330 m (a.s.l.) and its length is 680 m. The spillway has five radial gates measuring 13.5 m×13.5 m giving a discharge of 12600 m<sup>3</sup>.sec<sup>-1</sup> at the maximum reservoir level of 338 m (a.s.l.) [1]. In this research, the general geology of the dam project area including the reservoir is discussed.

## 2 Geomorphology

The topography of Mosul Dam and reservoir area is characterized by hilly terrain that rises to low mountainous area; representing physiographically Low Mountainous Province [2]. The mountains form anticlines, which trend mainly in NW – SE direction and changes westwards almost to E – W direction.

The main geomorphological units in the concerned area are of Structural – Denudational origin; the main units are the anticlinal ridges, which form the limbs of the existing anticlines, either formed by limestone or gypsum (Fig.3). Another geomorphological form is the flat irons formed either in limestone beds or gypsum (Fig.3); however in the outer areas of the limbs, sandstone beds form cuestas and hogbags; due to their alternation with soft claystone beds [3].

Another significant geomorphological aspect is the karstification, which is densely developed in the dam site and reservoir area (Fig.4) [3,4,5,6]. The main karst feature is the sinkholes, which are developed in limestones and gypsum beds. Those developed in limestone beds have regular forms, either with circular or elliptical apertures, the diameter ranges from (< 1 – 20) m, whereas the depth ranges from (< 1 – 15) m, whereas those developed in gypsum beds have irregular apertures with clear dissolving indications, the diameter ranges from (< 1 – 3) m, whereas the depth ranges from (< 1 – 8) m [3,5].



Figure 3: Google Earth image of the Mosul Dam site, located within Butma East anticline.  
**AR**= Anticlinal ridge, **FI**= Flat iron,



Figure 4: Enlarged Google Earth image showing many sinkholes (Dark spots encircled by red color).

### 3 Tectonics and Structural Geology

Mosul Dam site and reservoir area are located within the Cham – Chamal Subzone of the Low Folded Zone; within the Unstable Shelf of the Arabian Plate [7,8]. Fouad [9]; however, using the plate tectonics theory updated the tectonic frame work of Iraq, and consequently considered that the dam site and reservoir area are located within the Low Folded Zone, within the Outer Platform of the Arabian Plate.

The Low Folded Zone of Iraq is characterized by long anticlines and wide synclines, which are usually filled with Quaternary sediments, whereas the cores of the anticlines are occupied by Miocene rocks, mainly Middle Miocene. Mosul Dam is located within Butma East anticline, which has almost E – W trend with steeper southern limb (Fig.3).

The reservoir area of Mosul Dam includes many anticlines, which surround the limits of the reservoir; however, many others are located nearby to the reservoir and the dam site (Fig.5). Some of them exhibit strange shapes and local dislocations due to a major deep seated fault called Sasan – Bekhair Fault [10], which passes NW of the dam with clear dislocation of the axes and beds of many anticlines (Fig.6). Moreover, many other small faults of different types and different dislocations were mapped in the dam site and reservoir area [11]. It is worth mentioning that all structural disturbances have no any significant effect on the dam. Buday and Jassim and Al-Kadimi *et al.* [7, 12,]reported about deep seated fault called "Sinjar – Dohuk – AmadiyaFault" to exist in the reservoir area; however, Fouad [9] denied the presence of this fault. No surface indication is present to confirm the presence of the claimed fault.

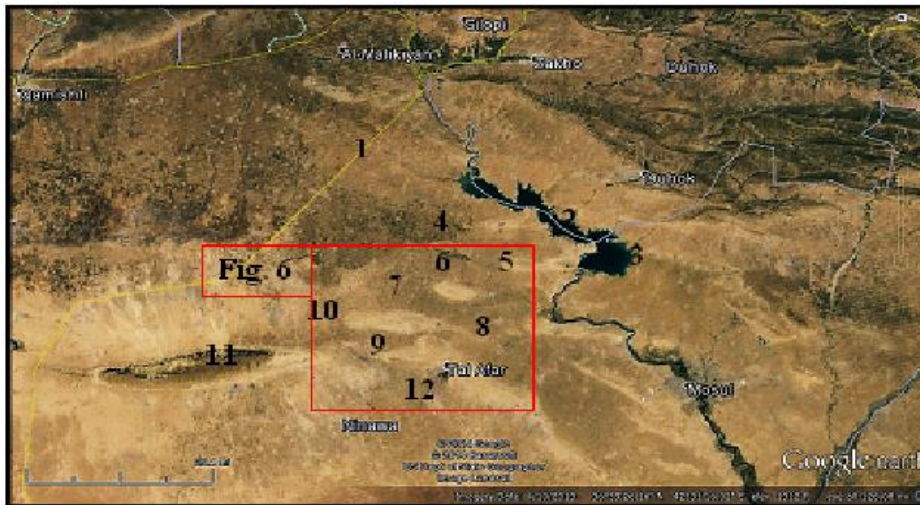


Figure 5: Google Earth image of Mosul Dam site and reservoir area showing the existing anticlines: 1: Mashoura, 2: Dahqan, 3: Qand, 4: AinZala, 5: Butma East, 6: Butma West, 7: Qusair, 8: Alan, 9: Sasan, 10: Ishkaft, 11: Sinjar and 12: Sheikh Ibrahim

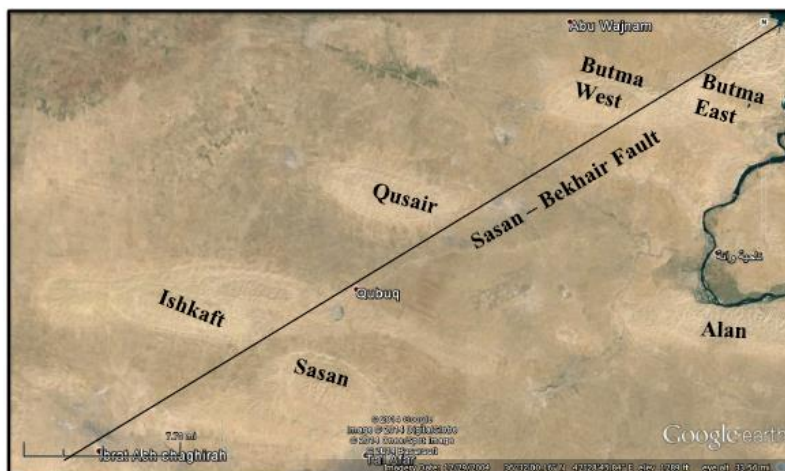


Figure 6: Google Earth image showing dislocated anticlines; along Sasan – Bekhair Fault.

#### 4 Stratigraphy

The oldest exposed rocks in the dam site belong to the Fatha Formation ex-Lower Fars) of Middle Miocene age; however, in the reservoir area, the oldest exposed rocks belong to the Pila Spi Formation of Late Eocene age [2,3,11] (Fig.7). The exposed formations in the dam site and reservoir area are described briefly hereinafter.

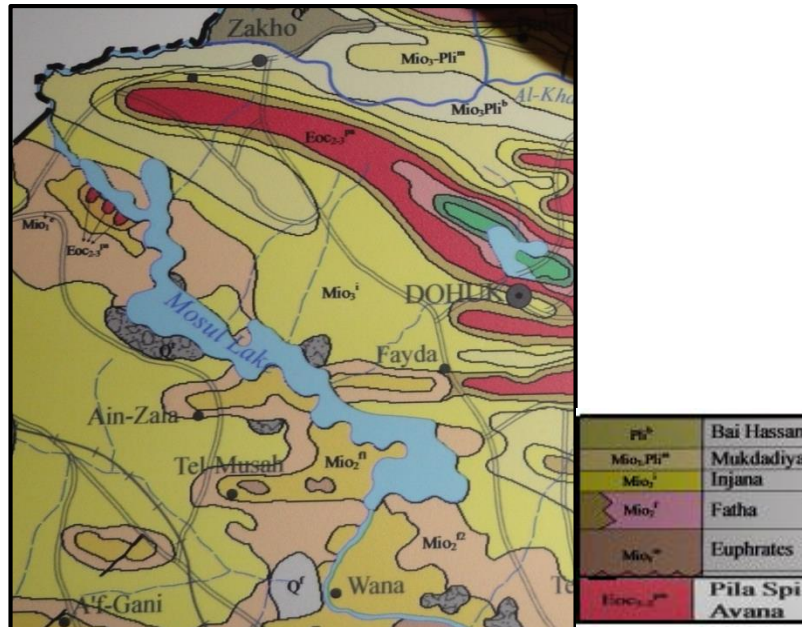


Figure 7: Geological map of Mosul Dam site and reservoir area (After [2]).

#### 4.1 Pila Spi Formation(Late Eocene)

Small outcrops of the Pila Spi Formation exist in the extreme northwestern side of the reservoir (Fig.7). The formation consists of well bedded, dolomite, dolomitic limestone, limestone and rare marl [11,13]. The exposed thickness of the formation is few meters only.

#### 4.2 Euphrates Formation (Early Miocene)

The Euphrates Formation is exposed in the core of some anticlines in the reservoir area (Fig.7), as well in the foundations of the dam. The formation consists of well bedded, hard and fossiliferous limestone, marly limestone with less abundant dolomitic limestone [11,13]. Some of the limestone beds exhibit karstification as indicated by the presence of sinkholes. The thickness of the formation in nearby areas ranges from (15 – 50) m [11,14].

#### 4.3 Jeribe Formation (Middle Miocene)

The Jeribe Formation is not recorded to be exposed in the dam site and reservoir area [2,11]. However, the formation is recorded in the foundations of the dam [6], and to be encountered in oil well Butmah 2 [15]. The formation consists of well bedded, hard and fossiliferous limestone; highly resembling to the Euphrates Formation [13]. No thickness record exists in the dam site; however, in some drilled oil wells in near surroundings is about 60 m in oil wells AinZala 22, Mushorah 1 and 33 m in Butmah 2 [15].

#### 4.4 Fatha Formation (Middle Miocene)

The Fatha Formation is widely exposed in the dam site and reservoir area (Fig.7). The formation is characterized by cyclic deposits, the thickness of the formation is variable; in

Butmah is 392 m, in Ain Zala 325, in Mashourah 320 m, in Ishkaft 350 m [16]. The formation consists of two members [2,3,11], these are:

#### **4.4.1 Lower Member**

The Lower Member of the Fatha Formation consists of cyclic deposits, each cycle consists of green marl, limestone and gypsum; however, in some cycles one of the three constituents may be absent. The abutments of the dam are located within this member. The rocks of this member are highly karstified, not only in the dam site and the reservoir area, but else-where in Iraq.

#### **4.4.2 Upper Member**

The Upper Member of the Fatha Formation consists of cyclic deposits, each cycle consists of green marl, red claystone limestone and gypsum; in the uppermost part reddish brown sandstone may be present too; however, in some cycles one of the three constituents may be absent. This member covers majority of the reservoir area.

### **4.5 Injana Formation (ex-Upper Fars) (Late Miocene)**

The Injana Formation is exposed in the eastern, northeastern and some parts of the northern banks of the reservoir (Fig.7). The formation consists of fining upwards cyclic deposits of reddish brown sandstone, siltstone and claystone. The thickness of the formation is variable ranges from (200 – 330) m [16].

### **4.6 Mukdadiya Formation (ex-Lower Bakhtiari) (Late Miocene – Pliocene)**

The Mukdadiya Formation is exposed in the eastern bank of the reservoir (Fig.7). The formation consists of fining upwards cyclic deposits of grey sandstone, siltstone and claystone; some of the sandstone beds are pebbly. The thickness of the formation is variable ranges from (100 – 230) m [16].

## **5 Seismicity**

Although Mosul Dam and near surroundings are located far from Zagros Active Seismic Zone, but still many earthquakes were recorded in areas surrounding the project area. According to [17,18], the dam area and the reservoir are located in Zones IX and VIII of Historical Isointensity Map, respectively and in Zone V of Seismic Isointensity Map, which means zone of minor damages.

The seismicity index (ST) is related to the frequency of occurrences of earthquakes magnitudes 4.0. The dam site area is located in region of  $ST = 0.1$  of Seismic Index Map, which means the area, suffers an earthquake with magnitude  $\geq 4.0$  every five to ten years in an area with diameter of 100 Km. Moreover, it is located in Zone (0.4 – 0.5) of Seismic Acceleration Map with design period of 100 years (Fig.8).

According to [7,18], there are many epicentres of (3.6 – 5.3) degrees on Richter scale nearby the dam site. Moreover, during the year 2014, many earthquakes were recorded

northwest, north and northeast of Mosul city, but all of them are within magnitudes of less than 4 degrees on Richter scale [19].

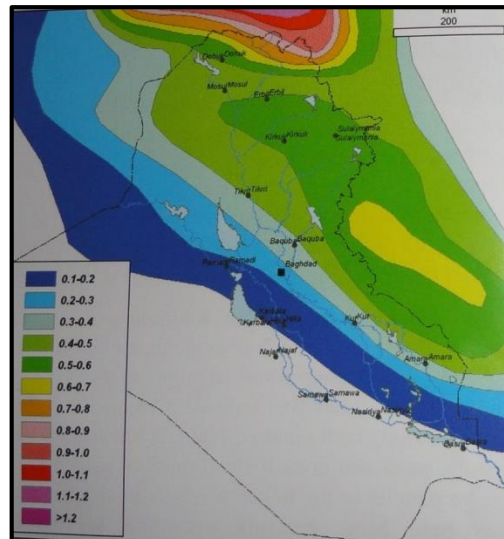


Figure 8: Seismic acceleration map with design period of 100 years (After[18]).

In addition to the above, it is noteworthy to mention that the Swiss Consultants carried out Seismicity study for Mosul Dam [20]. This report was reviewed by Washington Group International in 2005 [21]. The main remarks about the Swiss Consultant [20] report were:

I. The SC report seemed to be well prepared and contained the information available up to 1985. But, new data were generated from 1985 to 2005 with respect to plate tectonics.

II. Very little information on local and regional geology was given in SC report. (The answer to this remark is that SC had already compiled this information in the planning report and there was no need to repeat again).

III. Much of the information given was “attenuation relationships “, which were developed for the earthquake data and seismic sources areas that were researched for the project. The source zones were developed for ground motion was based on plots of earthquakes epicentres as:

1. Low seismicity zone (40 Km radius around site).
  2. Moderate seismicity zone (from 40 km to 150km radius around site).
  3. High seismicity zone of Zagros Mountains (from 150km to 250km radius around site).
- The zones were separated so that different attenuation relationships could be developed for the different data and distances involved.

On the basis of this information, a design earthquake with 280 to 450 years return period was developed with recommended ground peak acceleration (PGA) of 0.15g. The maximum credible earthquake (MCE) with a return period on the order of 10000 years was recommended to be 0.25g.

The remarkson the data by [21] in 2005 were based on the data they reviewed from the internet. These data were addressing the following topics:

**A. Regional Tectonics:** Iraq is located on the Arabian subcontinent tectonic plate which is a subduction zone under Anatolian and Iranian Plates along the Zagros-Taurus zone at



the NW boundary of the plate. So, north and north eastern parts of Iraq have the highest seismicity. Figure 9 shows most of the seismicity recorded in the Middle East.

**B. Geological Setting:** The tectonics of Iraq has been divided as follows:

1. The Stable Zone
2. The Mesopotamia Zone (between the Tigris and Euphrates rivers)
3. The Simply Folded Zone (within which the dam is located); characterized by folds and thrust faults.
4. Imbricate Zone (series of thrust zones).
5. The Thrust Zone (complex thrust structures as the Main recent fault of Iran (on the Iraq-Iran border on which major earthquakes have occurred).

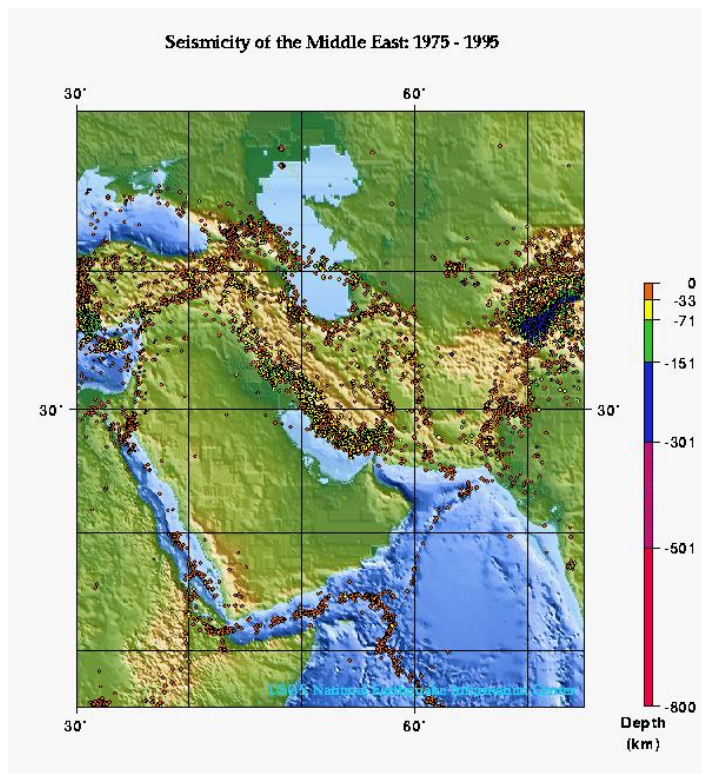


Figure 9: Seismicity of the Middle East [21].

**C. Seismicity:** Historic seismicity shows 91% of the earthquake events in Iraq are between 4 and 5.5 occurring at immediate depths from 30 to 90 km. Reviewing the earthquake records of SC report by a new review with the records of the US Geological Survey, National Earthquake Information Centre [22], shows the highest magnitude recorded within 200 km of the site is Magnitude 6+ at a distance of about 121 km. The only recent probabilistic seismic hazard map produced was by the Global Seismic Hazard Assessment Program (GSHAP), but it was possible to access only a portion of this map through USGS web site due to restriction by password (Fig.10).

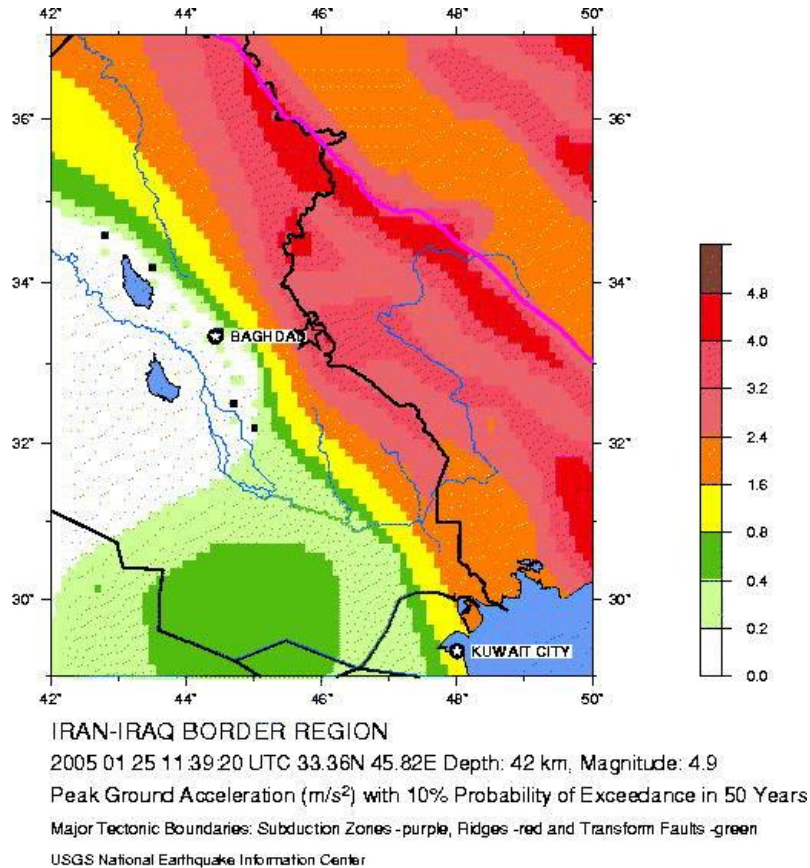


Fig. 10: Probabilistic Seismic Hazard Map for a Portion of Iraq/Iran [22].

Notes: 1. Site is located in the far northwest portion of the map, 2. Map corresponds to the 475-year return period, 3. Peak ground acceleration at the site corresponds to 1.6 to 2.4 m/s<sup>2</sup>. This value corresponds to 0.16 to 0.24g, 4. Map taken from National Earthquake Information Center (website:[http://neic.usgs.gov/neis/bulletin/neic\\_tsa3\\_w.jpg](http://neic.usgs.gov/neis/bulletin/neic_tsa3_w.jpg))

This map (Fig. 10) shows that probabilistic seismic hazard with 10% probability of being exceeded in 50 years, or about 475 years return period. The purple-pink line in the map shows location of the subduction zone. From the map the site (at northwest corner) will be subjected to peak ground acceleration of 0.16g to 0.24g for this return period, which is similar to the MCE recommendation in the SC report. The current practice in dam design is for MCE events that are closer to 2500-10000 years return period, depending on the significant hazard.

Finally, Washington Group International [21] concluded and recommended the following:

1. The SC report was well prepared, but it did not reflect current plate tectonic theory with respect to earthquakes and seismicity.
2. The site is located near the boundary of the subduction zone (Arabian Plate colliding against Iranian Plate). It should be mentioned here that the authors do not agree with this statement. It is in the simply folded zone, an area of folded rocks and thrust faults that accommodate some of the compression.

3. Based on, this the dam can be subjected to ground accelerations from two sources; one is the large earthquakes that occur in the subduction zone. The second source is related to background earthquakes close to the site (which may result from surface faults).

4. This assessment report is based on data available on the internet (on Iraq). Additional information may be obtained from more complete review of data.

5. SC report recommended PGA of 0.15g for design earthquake based on 280 to 450 years return period and recommended PGA of 0.25g with the MCE with return period of 10000year. Available current information on the internet from GSHAP shows recommended PGA for the 475 year return period 0.16g to 0.25g.

6. Recommended additional work to this project to identify all potential sources of earthquake ground motion. In view of this a probabilistic seismic hazard study of the area should be conducted for the designated return period, which reflects the hazard assessment for the dam.

It should be noted that

## **6 Conclusions**

Mosul Dam project is the most important water resources project in Iraq. It is located on the River Tigris in northwestern part of Iraq, about 60 km north of Mosul city. This project is multipurpose project to provide water for three irrigation projects, flood control and hydropower generation. Its storage capacity is 11.11 km<sup>3</sup>.

The topography of the Mosul Dam and reservoir area is characterized by hilly terrain that rises to low mountainous area; representing physiographically Low Mountainous Province. The oldest exposed rocks in the reservoir area belong to the Pila Spi Formation of Late Eocene age while at the dam site; the oldest exposed rocks belong to the Fatha Formation (ex-Lower Fars) of Middle Miocene age. The foundation of the dam lies on this formation. It is composed of alternating beds of marls, limestone, gypsum and clay. It is highly karstified. Tectonically, Mosul Dam site and reservoir area are located within the Cham – Chamal Subzone of the Low Folded Zone; within the Unstable Shelf of the Arabian Plate. The project is located far from Zagros Active Seismic Zone, but still many earthquakes were recorded in areas surrounding the project area.

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## References

- [1] Iraqi Ministry of Water Resources, Water Resources, Mosul dam. [Available at: <http://dams.mowr.gov.iq/node/11> accessed 11 May 2012]
- [2] Sissakian, V.K. and Fouad, S.F., Geological Map of Iraq, scale 1: 1000000, 4<sup>th</sup> edition. Iraq Geological Survey Publications, Baghdad, Iraq, 2012.
- [3] Sissakian, V.K., Report on the Geological Map of Mosul Quadrangle, scale 1: 250 000, Iraq Geological Survey Publications, Baghdad, Iraq, 1995.
- [4] Jassim, S.Z., Jibril, A.S. and Mouman, N.S., Gypsum karstification in the Middle Miocene Fatha Formation, Mosul area, northern Iraq. GEOMORPHOLOGY, Vol. 18, Issue 2, p. 137 – 149, 1997.
- [5] Sissakian, V.K. and Al-Mousawi, H.A., Karstification and related problems, examples from Iraq, Iraqi Bulletin of Geology and Mining, Vol.3, No.2, p.1 – 12., 2007.
- [6] Sissakian, V.K., Al-Ansari, N. and Knutson, S., 2014. Karstification problems in Mosul Dam and its assessment, North Iraq. Engineering, <http://www.scirp.org/journal/eng>.
- [7] Al-Kadhimi, J.M., Sissakian, V.K., Fattah, A.S. and Deikran D.B., Tectonic Map of Iraq, scale 1: 1000 000, 2<sup>nd</sup> edit. Iraq Geological Survey Publications, Baghdad, Iraq, 1996.
- [8] Jassim, S.Z. and Goff, J.C. (Eds.), Geology of Iraq. Published by Dolin, Pragh and Moravian Mueseum, Brno, 2006.
- [9] Fouad, S.F., Tectonic Map of Iraq, scale 1: 1000000, 3<sup>rd</sup> edition. Iraq Geological Survey Publications, Baghdad, Iraq, 2012.
- [10] Fouad, S.F., Western Zagros Fold – Thrust Belt, Part I: The Low Folded Zone. Iraqi Bulletin of Geology and Mining, Special Issue No.5, 39 – 62, 2012b.
- [11] Taufiq, J.M. and Domas, J., Report on the regional geological mapping of Duhok – AinZala Area, Iraq Geological Survey's Library report no. 837, 1977.
- [12] Buday, T. and Jassim, S.Z., Tectonic Map of Iraq, scale 1: 1000000. Iraq Geological Survey Publications, Baghdad, Iraq, 1987.
- [13] Sissakian, V.K. and Saeed, Z.B., Lithological Map of Iraq, Compiled using GIS Techniques. Iraqi Bulletin of Geology and Mining (ISSN- 1811.4539), 8, 3, 1 – 13, 2012.
- [14] Mohi Ad-Din, R.M., Sissakian, V.K., Yousif, N.S., Amin, R.M. and Rofa, S.H., Report on the regional geological mapping of Mosul – Tel Afar Area, Iraq Geological Survey Library report no. 831, 1977.
- [15] I.P.C., Geological and Production Data. Iraq Geological Survey Library report no. 130, 1964.
- [16] Sissakian, V.K. and Al-Jibouri, B.M., Stratigraphy, In: The Geology of the Low Folded Zone, Iraqi Bulletin of Geology and Mining, Special Issue No.5, 63 – 132, 2012.
- [17] Al-Sanawi, S.A. and Al-Qasrani, Z.O., Earthquake hazards considerations for Iraq. Fourth International Conference of Earthquake Engineering and Seismology.12 – 14 May, Tehran, Islamic Republic of Iran, 2003.
- [18] Al-Sanawi, S.A., Seismicity. In: Geology of Iraq, S.Z., Jassim and J.C., Goff (Eds.). Dolin, Prague and Moravian Museum, Brno, 2006.

- [19] Mohammed, J.Gh. Abdul Ahad, A.D. and Jabbo, B.R, The 11<sup>th</sup> March, 2013 Earthquake in north of Mosul vicinity, North Iraq. Iraqi Journal of Geology and Mining, 10, 1, 59 – 72, 2014.
- [20] Swiss Consultants, Mosul Dam Project, Seismic Risk Analysis, prepared for the Republic of Iraq, Ministry of Irrigation, State Organization of Dams, 1982.
- [21] Washinton Group International, Review of Seismicity Report – Mosul Dam, Ministry of Water Resources, Baghdad, Iraq, 2005.
- [22] United States Geological Survey, Earthquake Hazards Program, National Earthquake Information Center website <http://neic.usgs.gov/>.Last accessed 3 March, 2015.