

Comparative Study of Mosul and Haditha Dams in Iraq: Different Construction Materials Contribute to Different designs

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Abstract

Mosul and Haditha Dams are the two largest dams of Iraq. They were constructed in localities having completely different materials for use in the core and rip-rap. While clay for the core was abundant in Mosul Dam site it was completely missing in the other dam site. Where solid and sound limestone for the rip-rap was available in large quantities in Mosul dam only dolomitic limestone of inferior quality was there in Haditha Dam site. In Haditha Dam, the use of the only available material for the core was mealy dolomite and it was used successfully, but the addition of an asphaltic concrete diaphragm was necessary to improve impermeability of this core. The use of this material for the first time in the world was a challenging task to the engineers, who could not have done this without carrying out first comprehensive field and laboratory research. Even sand and gravel materials were available in the two sites in ways that borrowing and using them required completely different techniques in the two sites. In the shells of Mosul Dam, they were placed and compacted after minimum treatment, filter material; however, had to be sorted out and mixed in screening plants. In Haditha Dam site dredging of the materials from the river channel resulted in adopting a hydraulic filling procedure in building the shells and eliminating the filter zones. Good quality limestone was used in Mosul Dam rip-rap but the missing of such rock quality in Haditha Dam dictated the use of concrete facing protection placed by mechanical means. The different construction materials used in the two dams resulted in producing two contrasting designs which had also required different

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methods of construction and to some extent different machinery. In Mosul Dam, everything followed the standard and classical methods and specifications. In Haditha Dam new specifications were necessary for many items of the work. In both cases, the engineers were successful in producing good designs which were safe and functional.

Keywords: Mosul Dam, Haditha Dam, Clay, Mealy Dolomite, Diaphragm, Hydraulic Fill

1 Introduction

In this paper, two examples are given depicting two different dam designs. The difference is attributed to the basically different available construction materials at the two sites. Moreover, the use of these materials required; the use of completely different technologies, different completion time was needed, and to be sure resulted in a different unit cost per cubic meters of stored water. The two dams are the Mosul Dam on the Tigris River and Haditha Dam on the Euphrates River, both in Iraq.

In Mosul Dam, there were abundant quantities of clayey materials from nearby borrow areas and plenty of sandy gravel which could be easily quarried from the floodplain deposits or conglomerate from the terraces at the river banks very close to the site. This was useful in adopting a conventional design of the cross section with all that was required for a very low permeability core and more permeable sandy gravelly shells in addition to the required filter materials for the transition zones at the upstream and downstream faces of the core, and the horizontal drainage blanket at the downstream side. Good quality limestone from the Euphrates Formation outcropping at very close proximity lent itself for good use in the upstream rip-rap and downstream slope protection. Construction procedures were standard and specifications of the earthworks were very similar to those used in similar large and important earth fill dams. No new research work was needed to investigate the characteristics of the materials and only standard laboratory tests were used to identify the materials and to carry out quality control during construction.

In Haditha Dam, the case was completely different. No clays were available available at the site or at any reasonable distance from it. Sandy gravel materials were available in large quantities at the river channel and the banks of the river but at some distance at the upstream. Dolomitic limestone was available from the Euphrates Formation but the quality was questionable and could not be used for upstream rip-rap, although it was sufficient for use in the protection of the downstream slope of the dam. The extraction of these materials, transporting and placing them in the dam body required different technologies than those utilized in Mosul Dam. Mealy dolomite derived from the Euphrates Formation which was

used in the core was a completely new material in dam construction. No previous experience of using it as a major construction material in dams was known worldwide, only a small portion of few meters' height was constructed in the upper upper level of Tabqa Dam in Syria [1] Tabqa Dam was designed also by Soviet engineers the same as Haditha Dam. Even with its proved other qualities, dolomite dolomite by itself could not give the required level of low permeability and an asphaltic concrete diaphragm had to be used in conjunction with it to satisfy the anti-seepage criteria required for the core.

This paper aims at comparing the two dams from these perspectives and highlights the innovative use of dolomite. Before doing this however, an overview of the two dams must be given for illustration and to lay the ground for further discussion.

2 Mosul Dam: an overview

2.1 General

The construction of Mosul Dam was started on the 25th January 1981 and completed on 24th July 1986. Studies and investigation works were carried out by different consultants who had selected different sites and prepared different designs from 1951 until 1978. The present selected Mosul Dam site was the subject of the last investigation campaign, and the contract for preparing the planning report, the final design and tender document were awarded late in 1978 and these works were completed in 1980 only to start construction immediately afterwards. The Mosul Dam scheme, in fact, comprises three associated works which augment each other aiming at the best utilization of the water and power resources. The main earthfill dam is the main element in the scheme, the low earthfill reregulating dam at 8 kilometers downstream of the main dam was planned and constructed to reregulate the flows from the main dam power station to satisfy daily irrigation demands downstream and generate base power at the same time.

The Pump Storage power station, which is the third element in the scheme, is to generate peaking power and it was located at the core of Butma South anticline at the right abutment of the main dam; it drew its water supply from an intake in the reregulating reservoir just 2 kilometers downstream of the main dam. At the start of the planning stage borrow areas for possible construction materials were investigated. Sources for clayey materials, sand and gravel and limestone were located and this investigation showed the availability of these materials in good quantities; which lead to define the design features of the project. The designs of both the main dam and the re-regulating dam followed conventional procedures and used the accumulated experience worldwide on this type of dams. Only the main dam however, is discussed here being a large dam according to the International Commission of Large Dams (ICOLD) and comparable to Haditha Dam.

2.2 Design Features

The site of the Mosul Dam was selected as the most suitable location to serve the three Jazira irrigation projects. It also offered the largest reservoir volume from topographic considerations. The geological conditions of the site did not seem to have received enough considerations [2]. All the alternative sites that were investigated before, including the present one, suffered from the presence of soluble gypsum rock, but all consultants had thought that grouting could solve the seepage problem in the foundations and stop dissolution. The designed earthfill dam consists of two parts. The first part is the main high dam closing the Tigris river channel together with its right and left abutments. While the right abutment was located on the plunging part of Butma South anticline, the left abutment extended on the left bank till the right abutment of the spillway head structure. The second part of the dam is the low saddle dam extending from the left abutment of the spillway head structure following E-W direction toward Jebel Terra anticline. The Total length of the dam, spillway head structure and the saddle dam is about 3600 meters out of which 100 meters is the width of the spillway head structure. The emergency spillway structure is located within the saddle dam on the left bank and has a width of 400 meters. The powerhouse is constructed on the right bank downstream from the main dam. Four steel-lined tunnels deliver the water to the powerhouse below the earthfill dam. Similarly, on the same bank, two steel-lined tunnels were constructed to be integrated parts of the bottom outlet structure. This structure was intended for emptying the reservoir in emergencies and for carrying repair works on the dam. These tunnels were also used for river diversion during construction; (Figure, 1) illustrates the general layout of the Mosul Dam.

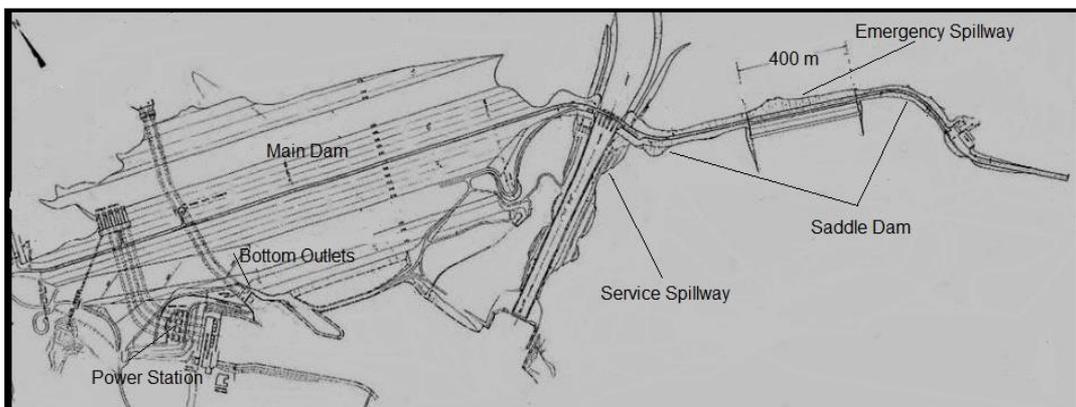


Figure1: General Layout of Mosul dam

The maximum height of the dam is 113 meters from the deepest point in the river channel; this height was obtained based on the topographical and hydrological consideration to get the maximum storage of the reservoir. Accordingly, the crest level was fixed at 341.00 meters above sea level m (a.s.l.).

To cope with future settlement, the crest was super elevated by up to 2.0 meters, depending on the height of the dam at the location of super- elevation. The maximum crest elevation at the end of construction was thus 343.20 m (a.s.l) [3], hydrological conditions at the dam site, and design water levels of the reservoir are detailed in Table (1):

Table 1: Hydrological Parameters and Reservoir Water levels of Mosul Dam

Hydrological Conditions at the Dam Site			
Description		Remarks	
Catchment Area	54400 km ²	Mosul Dam is the 2 nd largest storage dam on the Tigris. The other dam is Ilisu dam in Turkey. Other smaller dams are built on the river tributaries in Turkey also. These figures are expected to decrease considerably after the Ilisu Dam operation and the full development of the (GAP) irrigation project in Turkey	
Total Annual Runoff	Billion m ³		
Maximum	43.400		
Mean	21.100		
Minimum	11.700		
Mean Annual Discharge	569 m ³ /sec	Reference [4]	
Maximum Design Discharges	m ³ /sec	Reference [3]	
PMF	27000 m ³ /sec		
P = 0.01%	15000 m ³ /sec		
P = 0.1%	12000 m ³ /sec		
Storage and Operation Water Levels			
Description	Water level m (a.s.l.)	Storage m ³	Remarks
Normal Operation Water level	330	11.11 × 10 ⁹	This level was reduced in 2006 to 319 in order to reduce gypsum dissolution and formation of sinkholes downstream of the dam [5]
Maximum Operation Water	335	13.13 × 10 ⁹ Capacity for flood routing between level 330 m (a.s.l.) and 335 m (a.s.l.) is 2.03 × 10 ⁹	This level is reached in routing the 0.1% design flood.
Maximum Flood Water Level	338		At this level, the earthfill part of the Emergency Spillway collapses and its operation will be initiated.
Lowest Operation Water Level	300	2.95 × 10 ⁹	This is the minimum water level required for Power Generation. A lower level of 270 m (a.s.l.) can still be attained by using the bottom outlets. This level is the top level for sediments accumulation.

The design and construction of the earthfill dam followed classical methods and specifications based on the current worldwide practices. The dam profile is traditional; provided with central core supported by massive shells. On both the upstream and downstream sides wide berms were placed to provide additional stability to the profile, due to the presence of very thin and weak clay layers in the foundation rock. The core is separated from the downstream shell by two filter layers, one is a coarse filter zone and the second is fine filter zone, and a drainage

layer. Their purpose is to prevent erosion from the core and safely drain off any seepage quantities passing through it. As a horizontal blanket, the drain extends at the base to the downstream shell and underneath the toe weight to the downstream in order to prevent pore pressure build-up in the downstream shell. Also on the upstream side, the core is separated from the shell by a filter layer. In the case of cracks potentially forming in the core, materials from this filter will be transported into such cracks, initiating thereby self-healing processes. Because the toe weights consist of a material of low permeability fill of random nature, they have therefore a horizontal drainage blanket at the base. The upper part of the upstream shell located above the toe weight is protected by a layer of rip-rap against wave action. The downstream face of the dam and the downstream slope of the toe weight are covered by a layer of slope protection material of crushed stone in order to prevent erosion by rainwater.

The crest of the dam is covered by a thick cap consisting of large boulders of various sizes and zoning (1 to 10 tons) from elevation 330.00 m. (a.s.l) upward to protect from airstrikes and this crest has a width of 10 meters. This protection was called the “Blasting Cover”. The design of this blasting cover followed the outlines of such designs in Norway which is a unique feature in earthfill dams, and it was added due to the threats of the Iran-Iraq war at that time. The outer slopes of the shell were 1: 2.5 below elevation 330.00 m. (a.s.l) and 1: 1:73 above this level, which gave a maximum width of dam base of 650 meters in the river section. A typical cross-section of the dam at the river channel is shown in (Figure 2).

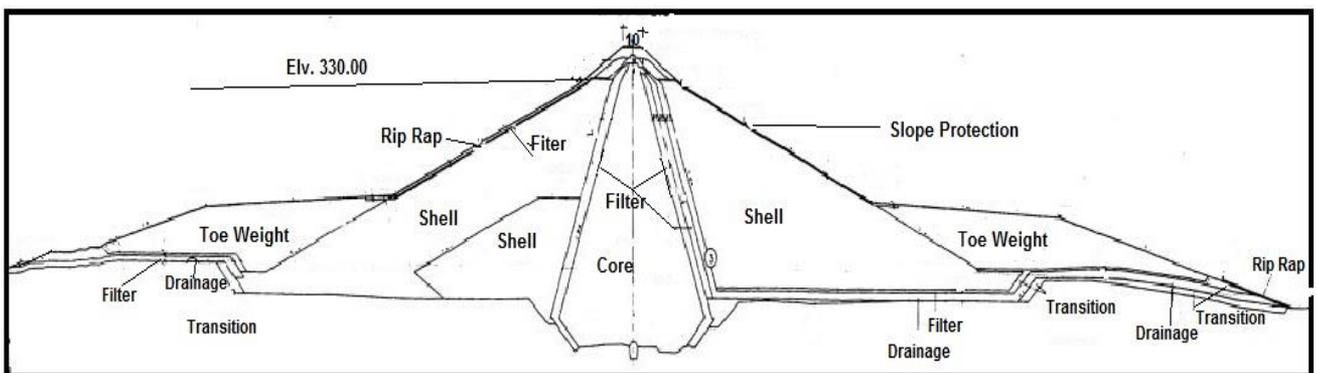


Figure 2: Typical Cross Section of the Main Dam at the River Channel (St. 2+400).

The maximum width of dam base is 650 meters and the maximum height of earthfill is 113 meters, Figure (2) does not reflect the actual dimensions of the dam as vertical and horizontal scales used are not the same, but it shows the actual disposition of materials in the cross section. The large toe berms showed in Figure (2) have their top level at elevation 290 m (a.s.l.) and were not part of the original design but they were added later on during the detailed design stage required for construction. During the foundation excavation of the grouting gallery,

the intake structure for the power tunnels and the PowerStation itself, very thin clay layers of (10 -20) cm thickness were recognized in these excavations in four horizons. These layers extend over long distances and they are parallel to the other rock layers indicating their sedimentary origin, it is clear that they were the product of successive cycles of sedimentation [3]. Moreover, they showed marked signs of slickenside especially in the right bank which indicated the occurrence of displacement along them as a consequence of faulting or past seismic activities. The excavations in the foundations were deepened to remove some of them but could not discover or remove other potential ones. A new set of stability calculation for the dam was made recognizing the presence of these layers and using the sliding block analysis and Sarma method for the stability analysis of embankments and slopes [6]. The calculation indicated critical sliding conditions under seismic loading, which required the addition of the mentioned toe berms as additional weights to ensure stability. No special specification was required for the quality of the materials in these toe weights whether on limits of compaction or permeability, as the main objective of using them was to get the extra weight. Random fill materials were mainly of surplus excavated foundation materials and other waste materials.

2.3 Construction Materials and Methods

The total volume of the used earthfill materials was 37.70 million m³, which included 6.01 million m³ of clay for the core, 19.88 million m³ gravels and sands for the u/s and d/s shells, 6.37 million m³ for the random fill in the toe weights at the upstream and downstream of the section. Another 4.45 million m³ of graded sand and gravel filters were also used in the filter zones and drainage layers. Additionally, limestone was used for the slope protections and riprap with a total quantity totaling 0.97 million m³. The detailed properties of the materials were as follows:

Core material

The core material is sandy silt, which was borrowed from flood plain deposits along the river. It was placed at optimum moisture content in layers of 25 cm and compacted by sheep foot rollers to give at least 95% of the maximum dry density. The geotechnical properties of the clay core material are shown in Table (2):

Table 2: The Geotechnical Properties of Clay Core Material.

Property	Value
Classification	CL
Liquid Limit (LL)	38.6 - 43.6 %
Plastic Limit (PL)	21.1 - 21.5 %
Plasticity Index (PI)	17.1 - 22.5 %
Maximum Dry Density (γ_d)	17.0 kN/m ³ (average)
Moisture Content, as placed	19.7 % (average)
Permeability coefficient (k)	1.8 x 10 ⁻⁶ cm/sec
Cohesion (C)	50-60 Kpa [7]

Shell Materials

For the shells, river alluvium and processed conglomerate from river terraces were used. The river alluvium was processed to remove excessive fines before it was used. The other material was used without treatment even with the presence of sulphate as bonding material to the matrix [2]. The materials were placed in layers of 50 cm thickness and compacted in 4 passes with vibratory smooth steel rollers. The properties of these materials are shown in Table (3):

Table 3: The Geotechnical Properties of shells Material of Mosul Dam

Material	Property	Remarks
Material from River Alluvium		
Percentages of fines after treatment	< 0.88 mm=2.5 % (average)	Treatment was done by washing excessively fine material
Coefficient of Permeability	1.5 x 10 ⁻² – 3 x 10 ⁻¹ cm/sec	Using in situ tests
Effective Angle of Internal Friction	40°- 43°	Using large-scale triaxial tests
Materials from Conglomerate		
Natural State	Cemented to various degrees	Obtained by common excavation and ripping with occasional blasting
Coefficient of Permeability	4.5 x 10 ⁻² – 2 x 10 ⁻¹	Using in situ tests
Effective Angle of Internal Friction	40°- 45°	Using large-scale triaxial tests
Other Materials		
Waste Rock From Rip Rap Production		Used in some parts instead of Alluvium and Conglomerates

Filters and Drainage Materials

These materials were obtained by processing of alluvial gravelly sand. The main filters of the dam downstream of the core were constructed as double filter,

consisting of a fine filter and a coarse filter zones. The first one adjacent to the core core was of sand and fine gravel of the size fraction (0 – 7) mm, while the next one one was a mixture of sand together with fine and medium gravel. It was a blend of 20% of the size fraction (0-7mm) and 80% of the fraction size (7 – 25) mm. The drainage material represented a medium to coarse gravel blended from 20% of the size fraction (7 – 25) mm and 80% of the size fraction (25 – 150) mm.

Toe weights, Riprap and Slope Protection

The materials placed in the toe weights were random material. Only uniform sand was excluded from being used. Most of the material used was either from excavated marl from the Fatha Formation or from waste rock from blasting operations. The riprap consisted of limestone blocks of up to 1000 kg in weight. Above elevation 300.00 m (a.s.l) the riprap was coarser than below this elevation because normal reservoir fluctuates between 300.00 m (a.s.l) and 330.00 m (a.s.l). The bigger blocks were used on the dam crest in the so-called “Blasting Cover” and they were in the range of 0.5 to 10 tons. On the downstream side the slope protection materials were the same as the rip-rap, but of smaller blocks largely in the weight range of (5- 60) kg.

3 Haditha Dam: an overview

3.1 General

The Construction of Haditha Dam was begun in 1977 and it was completed in 1988. Investigation works and preparation of the general design and specifications were made by Soviet organizations in contracts with the Iraqi Government under the Treaty of Technical and Economic Cooperation between the two governments. The All-Union Institute” Hydroprojekt” of Moscow took up the guidance of the investigations, preparation of final design, detailed design and the preparation of the detailed specification of the earth fill dam. The construction works of the earthfill dam were done by the Iraqi State Organization for Dams (SOD) with technical Soviet support. The detailed design and construction of the powerhouse were awarded by (SOD) to Energoprojekt – Hydrogradnja from the previous Yugoslavia. The preliminary design of the powerhouse was done by Hydroprojekt Institute- Moscow, excavation of the powerhouse pit by (SOD) and Soviet support. The long period of investigation and construction was in lieu of procedures of similar works carried out in the Soviet Union. The usage of mealy dolomite as a core material in this dam for the first time in the world required extensive laboratory and site testing of this material to prove its suitability. The usage of the asphaltic concrete diaphragm in conjunction with the dolomitic core required conducting additional testing. These and the performance of grouting tests meant that the detailed specification could only be issued gradually according to the progress of the works. The long period of construction was also in part due

to the volume of research work and testing programs that were necessary.

3.2 Design Features

The selected site of Haditha Dam is located in a narrow part of the Euphrates River few kilometers upstream from Haditha city. This selection was determined by the topographic and geological conditions and mode of occurrence of karstified rocks in the abutments of the dam in addition to the presence of local construction materials and the suitable conditions of performing the works. The total length of the dam is 9064 meters, which includes 8875 meters of the earthfill part and 189 meters of the hydropower station and spillway combined structure which is located at the river channel. The earthfill part is divided into 3310 meters in the right bank, 4985 meters in the left bank, and another 580 meters in the river channel. In Figure (3) the general layout of the dam is given.

The maximum height of the dam is 57 meters from the deepest point at the river channel, which was dictated by topographical and hydrological factors. The dam crest level, according to these considerations was fixed at 154.00 m (a.s.l.), and the width of crest was 20 m.

The Hydrological conditions at the dam site and design water levels of the reservoir are detailed in Table (4).

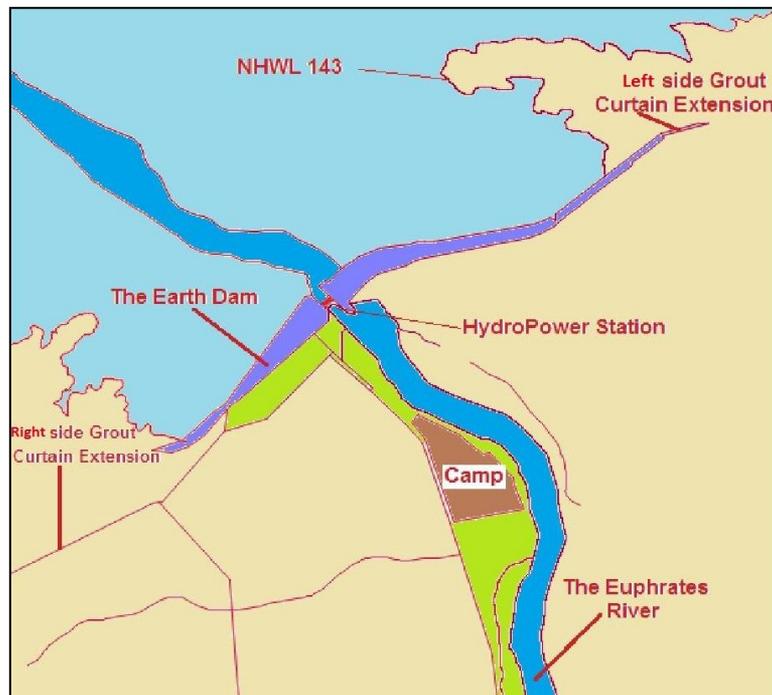


Figure 3; Haditha Dam Layout.

3.3 Materials and Methods of Construction

The design of the earth fill dam and the methods of construction used in Haditha Dam were governed by the availability of local materials at the site or close to it. The total volume of materials required for the construction of the dam was 30 million m³. Clay for the dam core was virtually nonexistent at any reasonable hauling distance from the site, which is a marked difference from Mosul Dam site. Instead, 77 million m³ of mealy dolomite was available in addition to about 36 million m³ of sandy gravel materials in the river banks, and 8.8 million m³ dolomitic limestone and dolomite rock were also available [8]. Suitable conventional type core materials were not located in sufficient quantities during preliminary stages of investigations, which lead to looking for alternative solution. The presence of large quantities of dolomite drew the attention of the engineers, who were involved in this project to this material as a possible construction material. It is believed that dolomite had never been used before in major dams as the main construction material for a vital section. In Tabqa dam in Syria; however, a portion of the dam body only of few meters high was constructed of similar material. Previous knowledge regarding the properties and behavior under different loading conditions did not exist. A challenging task was facing the engineers throughout the preparation of the planning report to determine the various properties of this new material in order to adopt it in this field of engineering, and this required the performance of extensive programs of field and laboratory investigations.

Table 4: Hydrological Conditions at Haditha Dam Site and operation parameters of the reservoir.

Hydrological Conditions at Haditha Dam Site			
Description		Remarks	
Catchment Area	235000 km ²	Haditha Dam is the last storage dam on the Euphrates River in a cascade of dams, i.e. Keban and Karakaya dams in Turkey and Tabqa and Tishrin Dams in Syria	
Total Annual Runoff	30 Billion m ³		
Mean Annual Discharge	950 m ³ /sec		
Maximum Design Discharge (P = 0.01%)	13000 m ³ /sec		
Storage and Operation Water Levels			
Description	Water level m (a.s.l.)	Corresponding Storage (Billion m ³)	Remarks
Normal Operation Water level	143	6.4	Out of this storage 0.2 Billion m ³ is dead Storage, and 6.2 Billion m ³ is live

			Storage
Maximum Operation Water	147	8.2	This is only realized in wet years
Maximum Flood Water Level	152.2		The volume between levels 147 m (a.s.l.) and 152.2 m (a.s.l.) is required to route floods up to the Maximum Design discharge of 13000 m³/se (P = 0.01%)
Annual firm water yield of Haditha and Habbainya reservoirs (P = 90 %)		10.7	

The selected dolomite material for the core is called “mealy dolomite” or what is equal of saying “powder dolomite”; the reason is due to the fact that this material is reduced to sandy powder state after excavation and treatment by mechanical means. After excavation, the material may be produced into lumps or powder. The big lumps can be then broken by mechanical means depending on the size and moisture content. Details of the mealy dolomites’ properties and the tests performed at Haditha Dam site are explained in details in a paper which was presented to the ICOLD Congress in Lausanne in 1985 by one of the Iraqi research engineers at the dam site laboratory [1].

Full description of the dominant geological formations at Haditha Dam area and their details were given by a recent paper by Sissakian et al. (2018) [9]. The source of the dolomite utilized in construction was the Euphrates Formation, which is one of the dominant formations at the site and which outcrops mainly at the right and left bank of the river. This formation has varying thickness between (13 – 26 m) [1] and it was formed in four benches. The dolomite material excavated from these benches by blasting and the use of excavators had a powder form with characteristics varied between yellowish grey chalky clayey and mealy to yellowish grey and light grey detrital and mealy[10]. Detritus is defined as small loose pieces of rock that have worn or broken off, or any debris or disintegrated material.

Read more on <http://www.yourdictionary.com/detritus#8UIDtxWjp68qs1f7.99>.

In natural state the moisture content of the used dolomite varied between (3.5% - 12.5 %) and its bulk density between (1.55 – 2.11) tones /m³. When excavated, completely vertical walls stayed in stable conditions that were excavated by ordinary bucket type excavators. In the laboratory it was found that the best temperature to dry up dolomite test samples taken from the construction site was 150 C° and drying period did not exceed three hours which helped in the fast progress in construction.

Shrinkage and swelling characteristics were investigated on fine-grained dolomite with particle size diameter less than 1 mm. The samples which were saturated in water for 9 days showed a swelling of 0.3% and no shrinkage was observed. Tests on larger diameter samples showed no indication of either

swelling or shrinkage.

Determination of grain size distribution was not possible using mechanical action of the shakers which caused continuous increasing trend of the finer fraction due to the reduction of the bond between the particles. So, wash screening of saturated samples was used as it gave more reliable results. It was found that the increase of fine particles (less than 0.1 mm) was 5.8% when sieving dry dolomites. Wash sieving of saturated dolomite after 24 hours gave an increase to 26.9% and an increase to 32.1% in wash sieving of saturated dolomite after 48 hours. An average gradation curves for dolomite samples from the main quarry on the right bank of the river are given in Figure (4) which also shows the design envelope curves required for the construction of the dam. From this Figure it may be seen that the average percentage of fine particles which is less than 0.2 millimeters is about 30% of the total material.

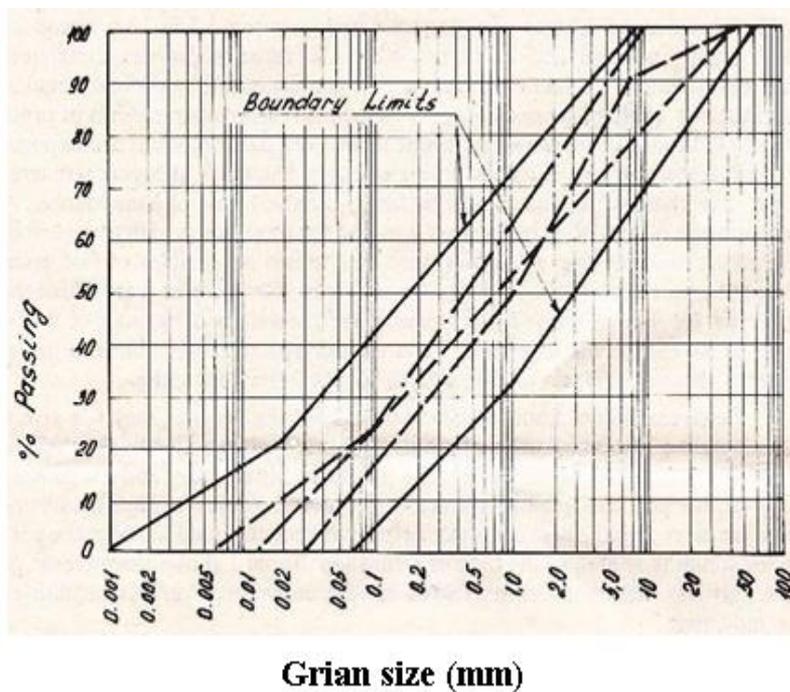


Figure 4: Average Curves of Grain Size Distribution of Dolomite material in comparison with design envelope (Boundary) curves.

Much research work was done in the field and in the laboratory to investigate the permeability and filtration characteristics of dolomite under different conditions. Special attention was also paid to study its stability against piping. Standard laboratory experiments showed that the permeability could vary between $(1.1 \times 10^{-3}$ and 3.1×10^{-5} cm/sec) depending on the dolomite bench where the samples came from and the corresponding bulk densities which varied between 1.67 ton/m^3 to 1.81 ton/m^3 . Different hydraulic heads were used for

samples coming from different benches showing different porosity characteristics. The hydraulic heads gradients corresponding to the above range of permeabilities varied between (4.00 – 1.63). Field tests were then conducted on test embankments which were constructed with controlled laid layers in order to reveal possible anisotropy. Water was poured in pits which had been dug in these test embankment to a depth not less than 3 layers. Polyethylene sheets were used to prevent water flow through the bottom of the pit. Results indicated the permeability varied between (4.3×10^{-4} – 2.1×10^{-5} cm/ sec) and the corresponding hydraulic gradients used varied between (0.58 – 0.64). Other set of tests were done to check seepage conditions at the contact of smooth concrete surface with dolomite, and also in the presence of existing seepage paths. Both sets of experiments showed that washing of dolomite particles occurred during the first 24 hours and with increasing head only, after that the water was clean. It was concluded that whatever seepage paths were there, they tend to be filled by dolomite particles due to its compaction when subjected to greater pressure in addition to the tendency of the fine washed particles to agglomerate closing these seepage paths.

In order to investigate the strength properties of the filled dolomite, standard shear tests were performed for various types of samples taken from different benches. A standard small shear ring and another larger shear ring with a diameter 305 mm and effective area 730 cm^2 were used for testing of fine and coarse fractions with samples up to 60 mm in diameter. Other samples from field test embankments were also tested in the same way. The results showed that the strength of this material was provided by internal friction. Its cohesion was very small and could be neglected; it ranged between (0.13 kg/cm^2 - 0.8 kg/cm^2). Final adopted design values were: $\tan \phi = 0.6$ and $C = 0$, $E = 10 \text{ MPa}$ and $KP = A.10^{-4} \text{ cm/sec}$ and density of $\gamma_d = 1.75$ [1, 8].

Compaction of dolomite muck in the laboratory with various moisture contents were done by the standard Proctor test procedure. Relative density tests provided practically the same results for majority of dolomite benches making it evident that the required dry density γ_d should be equal to or more than 1.8 ton/m^3 and the relative density should be equal to or more than 0.90. Relative density of more than 0.97 was also attained in all cases with the exception of one bench which had a maximum dry density of 1.73 tons/m^3 .

Dolomite preparation in the quarry involved the loosening by pre-splitting blasting using explosive charges. To raise the moisture content of the dolomite to its optimum value of (15% - 18 %) the surface of the blasted material was arranged into blocks for water saturation. The quantity of water and period of saturation was estimated according to the volume of material and the season. The color of the moistened dolomite would turn yellowish brown when it was wet but as it dried its color would become powdery white. Bucket excavators would then excavate the material from almost vertical faces in the quarry mixing together the material from different benches before loading. Another method was also tried by filling water into the drill holes and without blasting, but in such case the

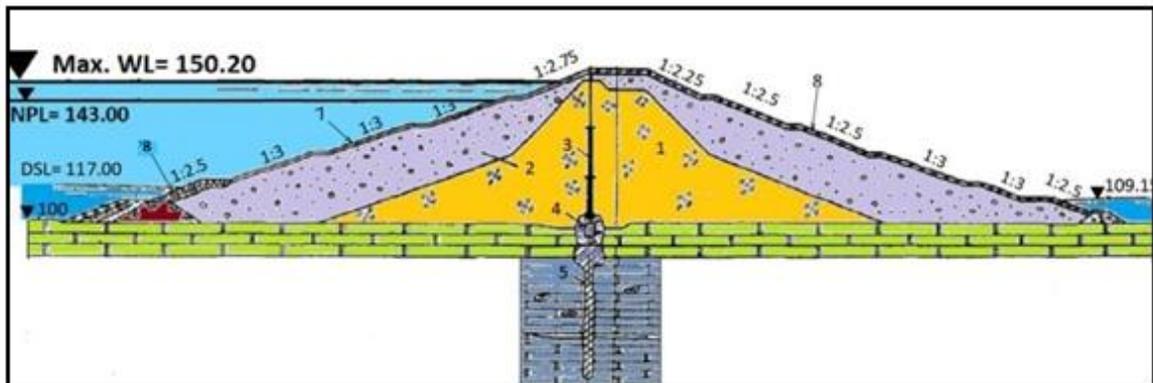
excavation became harder and big lumps should be broken down during filling by heavy machinery. Filling operations were carried out using layers of 25 cm thick and then compacted by 35 ton loaded dumpers making (8 -10) passes. The control of compaction was based on the determination of the dry density which would be judged in accordance with the above established criteria. Vibratory rollers were used later on (plain and sheep foot) which enabled the increase of layer thickness to 40 cm achieving the same values of density but with slightly higher optimum moisture content (16% - 19%).

Although testing showed that dolomite fill was stable against piping, the relatively high permeability coefficient of the dolomitic core warranted the use of asphaltic concrete diaphragm in conjunction with this core. The diaphragm was constructed as the filling progressed upwards and its centerline was located at 10 meters upstream of the centerline of the dam. It extended down to the foundation surface where it was rested on a concrete slab at the top of a short cut-off wall that formed also the grout curtain cap. The thickness of the diaphragm was 0.8 meter in the lower part, 0.6 meter in the middle part and 0.4 meters in the uppermost part. The mix design of the asphaltic concrete was obtained after a series of tests and dolomite powder was used as mineral filler. Such diaphragms were used in many dam sites in the previous USSR and much experience had been accumulated at the time of Haditha Dam planning and construction. The reader is referred for detailed information on this matter to a paper written on this subject and given as reference [11] in which Haditha Dam was cited.

A typical cross-section of the dam is shown in Figure (5). This figure indicates the details of the dolomite and asphaltic concrete diaphragm core arrangement. It shows also the upstream and downstream shells, which were constructed from the sandy gravelly materials obtained from the river banks and channel upstream of the dam by using dredgers. The material was transported by pumping using steel pipelines that were laid on the ground surface to final destination at the dam site.

The shells of the dam were constructed mainly by using hydraulic filling method, only a small portion in the left bank was constructed by placing the sand-gravel mix in dry conditions. A hydraulic fill dam is one in which the material is transported in suspension in water to the embankment where it gets placed by sedimentation and then excess water would be sluiced out by special outlet pipe. In a semi- hydraulic fill dam, the material is transported by hauling units and dumped at the edge of the embankment. It is then washed to its final position by water jets. The sorting out effect of flowing water is utilized in creating a fine-grained zone at the center of the embankment with the coarser fractions being placed at further out positions on the sides. In Haditha Dam the materials were normally deposited into blocks around the outlet pipe which sluices the water down to the collection channel after its load of material settles down. In the hydraulic filling of Haditha dam, the finer material was deposited adjacent to the dolomite core which in effect eliminated the need for the graded filter zones upstream and downstream of the core which was required in the case of Mosul

Dam.



1) Mealy Dolomite; 2) Sand- Gravel mixture; 3) Asphaltic concrete diaphragm; 4) Grouting gallery; 5) Grout curtain; 6) Stone revetment; 7) Reinforced concrete slabs protection on porous concrete drainage layer; 8) Rock mass revetment

Figure 5: Typical Cross Section of the fill dam (All levels are in m a.s.l.).

The sand-gravel materials of Haditha Dam shells were dredged from the river channel and they were characterized by considerable non uniformity. The average particle diameter varied between 0.24 to 16.7 millimeters, coefficient of uniformity ranged between 4 to 300 and higher, and the permeability coefficients of the natural mixture in the quarries were between $A \times 10^{-3}$ to $A \times 10^{+1}$ cm/sec. Examination of the particles size fractions in the natural quarries was necessary in order to ensure the required particle size distribution in the placed fill in the dam body using the hydraulic filling method. Required strength design parameters of the hydraulic fill of the shells were adopted and these were: $\tan \phi = 0.55$ and $C=0$. The dry density of the hydraulic fill was specified to be 1.85 g/cm^3 (tons/m^3) with 60% of the content being of fraction larger than 1 mm, the permeability coefficient of the fill should not be less in this case than $A \times 10^{-3}$ cm/sec. When stability analysis of the dam was performed, these design parameters provided good slope stability under conditions of the phenomenon "Liquefaction" under the dynamic effects from earthquakes and occurrence of excess pore pressure. The accepted parameters of strength of the sand-gravel soils which were being placed in dry conditions in the dam were: $\tan \phi = 0.55$ and $C=0$, permeability coefficient greater or equal than $A \times 10^{-3}$ cm/se, with the dry density of the sand -gravel mixture with 90% probability is not less than $1, 80 \text{ gm/cm}^3$ (tons/m^3) with an average value of $1, 90 \text{ gm/cm}^3$ (tons/m^3) [8].

In Haditha Dam site, good quality rock for the use of the riprap layer in the upstream face of the dam was lacking. The available rock of dolomitic limestone that was found in the Euphrates Formation did not have enough strength and abrasion resistance which was a marked difference from Mosul Dam site. These factors lead the designers to adopt the use of reinforced concrete slabs as a

replacement except for a small part of the upstream at the right bank which had to be protected by riprap after rigorous selection of the required rock.

The thickness of the slabs was 40 cm. Casting of these slabs was done in panels by lining machine which was specially manufactured in Germany and it was tailored to the required dimensions of the dam face. The required filter layer under this concrete facing was replaced by a 20 cm thick layer of specially manufactured porous concrete which could be cast in place taking advantage of the same lining machine prior to the placement of the concrete facing slab itself. The mix design of this porous concrete had to take into consideration the required porosity to allow the relief of seepage water during the drawdown of the reservoir at a reasonable rate. It also considered the possibility of clogging due to the migration of fine sand particles from the shell under it. Many trial mixes were investigated and tested before selecting the final approved mix suitable for such use and gap-graded aggregate was used to arrive at the required results.

In summary, the use of dolomite in the core of Haditha Dam was only possible after long and careful research work to discover all its properties and to prove its suitability for use in such an important work. Nevertheless, an asphaltic diaphragm had to be incorporated in conjunction with the dolomite in the dam core, which came to compensate for the relatively high permeability of dolomite itself. Generally speaking, the design and construction of the dam may be considered as unconventional with the use of this new material, and also due to the use of hydraulic filling dictated by the location of the borrow areas at the river channel and banks at some distance upstream.

4 Discussion and Conclusions

From the above proceeding, one point was made very clear; that is, the use of different construction materials may result in a completely different design of an earthfill dam and may require adding the use of different construction procedures. Local materials available at the site at an economical cost is one of the major elements in shaping design decisions, although it may not be the only element as seen from the case of adding huge toe weights in Mosul Dam. The examples of Mosul Dam and Haditha Dam however, are very good examples of the importance of local materials available in shaping the final design. In Mosul Dam site; good quality clay, sand and gravel were present at the site in abundant quantities, together with the availability of high-quality limestone. These materials were put to good use in producing a fine, classical and functional design of the cross section. In Haditha Dam site, the case was exactly the reverse. With the exception of sandy gravelly materials at the banks and river channel, no clay was to be found anywhere at a reasonable distance from the site. Even the exposed rocks at the site were not competent enough for any sort of rip-rap works. The engineers faced the possibility of using of what was available of local materials, which were dolomite or not to build the dam at all, at a time when Rolled

Compacted Concrete (RCC) dams were not developed to the standards we know of today. Such a dam could have been built as an RCC dam after thorough treatment of the foundation with consolidation grouting to the required necessary depth under the whole base of the dam. It took however, a lot of engineering ingenuity and long and patient research to use the available dolomite as the main material for the core of this dam and to finish with a good and stable design.

The available dolomite at site was therefore studied in all respects relevant to hydraulic structures such as large storage dam. Its suitability was proven, but the relatively high permeability of its fill required the engineers to take a further step by augmenting the dolomite core with the asphaltic concrete diaphragm. Standard control tests of the compacted dolomite materials were found to apply in this case and were used. Strength parameters were studied and taken into consideration in the design. The availability of sandy-gravelly deposits in the upstream river channel required the adoption of hydraulic filling procedures which eliminated the need to have graded filter zones to stop possible piping of the dolomite particles which had shown very low tendency for dispersion and to such piping.

As a final conclusion, it can be said that the designers of both dams, even with their use of different construction materials, were equally successful in producing good and stable designs as far as the embankment cross section and appurtenant structures are concerned. The design of foundation treatment however was not equally successful in the two dams. Good understanding of the geology at Haditha Dam resulted in successful treatment, but unfortunately misunderstanding the geological data for Mosul Dam foundation contributed to its current safety problems and its collapsing hazards.

In Haditha Dam, much research work was needed in order to use dolomite as core material which contributed to the long period of construction, but this has paid off in the increased knowledge of dolomite as a potential material to be used in dams. In Mosul Dam, the ample dimensions of the various elements of the designed cross-section contribute to the better stability of the dam cross section even with the known problems in its foundation due to the possibility of forming sinkholes at depth. The dam can by its present design take much more settlement, and the thick layers of filters can have very favorable effects in sealing cracks in the dam body even in the case of appreciable settlement.

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