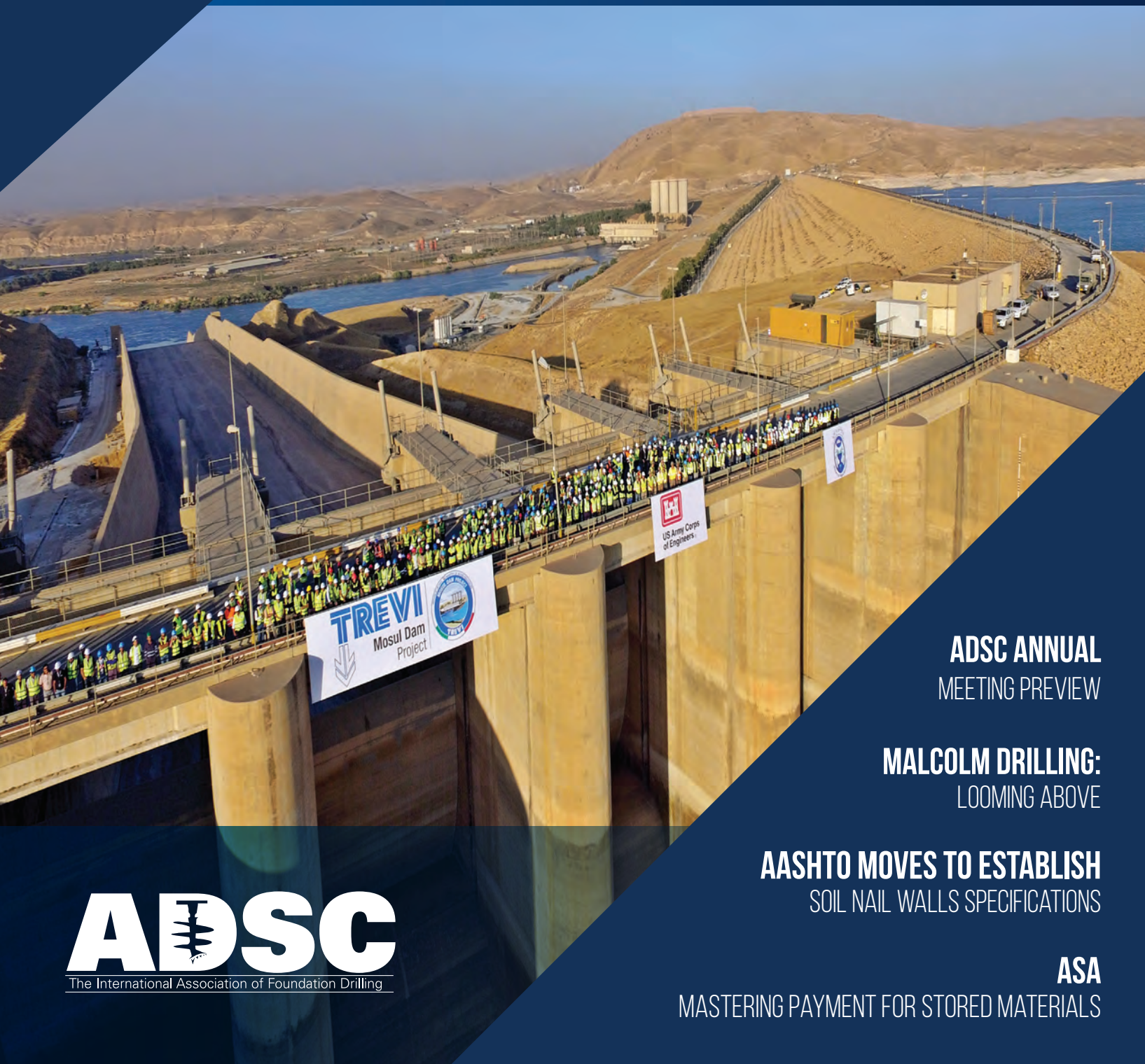
TREVI'S CHALLENGE IN IRAQ: MOSUL DAM

FOUNDATION DRILLING

OCTOBER 2018



ADSC ANNUAL
MEETING PREVIEW

MALCOLM DRILLING:
LOOMING ABOVE

AASHTO MOVES TO ESTABLISH
SOIL NAIL WALLS SPECIFICATIONS

ASA
MASTERING PAYMENT FOR STORED MATERIALS

ADSC
The International Association of Foundation Drilling

COVER STORY

TREVI'S CHALLENGE IN IRAQ:

MOSUL DAM

BY TREVI PROJECT TEAM, MOSUL DAM PROJECT

PROJECT OVERVIEW

Mosul Dam is the largest dam in Iraq, located on the Tigris River in the Governorate of Nineveh, a land rich in history on the northwestern side of the country. The dam was constructed in the 80's under Saddam Hussein's rule. Its former name was Saddam's dam. It's an earth-fill embankment-type with a clay-core dam, constructed for hydropower, flood control, water supply and irrigation purposes. Through its 370.73ft height and 2.3mi (113m height and 3.65Km) length, the reservoir has a storage capacity of 392 billion ft^3 (11.1 billion cu. m) of water. The main hydroelectric power station has an installed capacity of 750MW.

"Mosul Dam is the largest dam in Iraq, located on the Tigris River in the Governorate of Nineveh, a land rich in history on the northwestern side of the country."

The discharge system foresees two bottom outlet tunnels, a main concrete spillway with five radial gates and an emergency fuse-plug spillway, for a total capacity of 5,124,938US gal lqd (19,400 cms)

Mosul Dam was constructed by a German-Italian consortium from 1981 to 1986 under the ownership of the Ministry of Water Resources (MoWR) of Iraq. Since its construction phase the engineers were aware of the weak rock characteristics of the foundation, mainly consisting of marls and limestones, with soluble gypsum and anhydrite layers. Many cavities were found during the excavation works. Due to political pressure on location and schedule, the work moved forward. Despite the executed blanket grouting and deep grout curtain, the water seepages began immediately after the dam's commissioning and impounding.

The geological condition of the dam's foundation, is subject to potential continued deterioration due to dissolution, forming voids and networks of seepage pathways beneath the embankment that could threaten the stability of the foundation, and drove the engineers to envision a long-term constant grouting treatment. Hence, a specific 9.8x12.14ft (3.00x3.70m) grouting gallery, running along the longitudinal axis of the dam for 7086.61ft (2,160m), was designed and constructed before placing the embankment. A section 984.25ft-long (300m) beneath the main spillway (left bank) was excavated through the rock. The grouting gallery is mainly accessible through the access galleries located at both left and right banks.

DAM'S POST-CONSTRUCTION GROUTING ACTIVITIES

The Ministry of Water Resources was engaged in a rehabilitation effort through a continuous maintenance grouting program that was in place since the dam construction was completed. The owner utilized the drilling and grouting equipment and techniques left by the German-Italian Consortium. In recent history, a deteriorated political situation and the war conflict with ISIS resulted in a period when grouting was not performed as required. This increased the risk of foundation instability. The MoWR terminated its grouting works after awarding the current contract to TREVI.

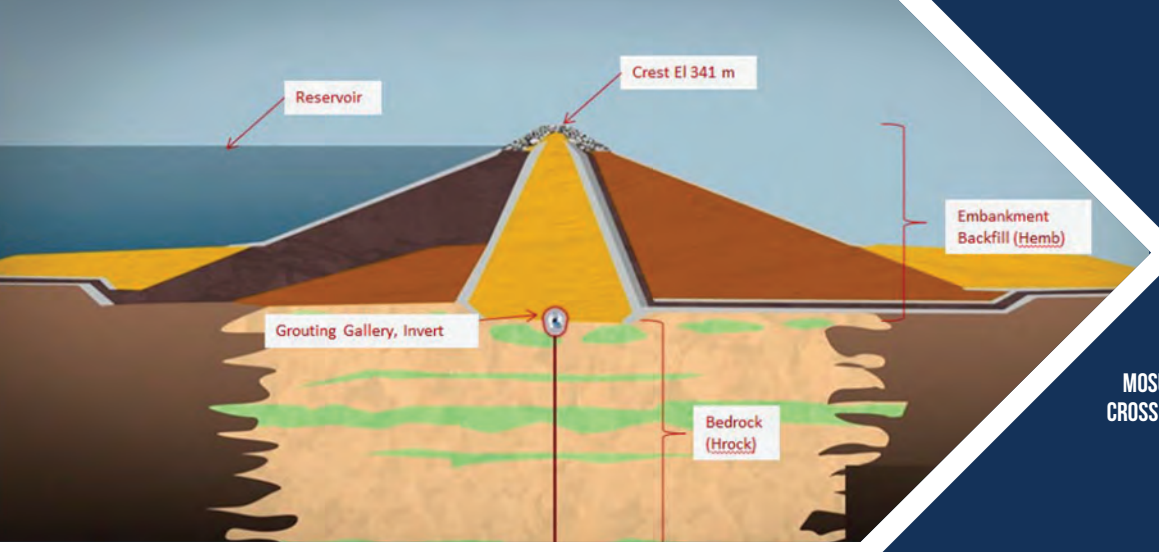
CURRENT MAINTENANCE GROUTING CONTRACT – SCOPE OF WORKS AND PARTIES

In October 2015, the current maintenance grouting contract was awarded to the Italian firm TREVI S.p.A. (TREVI GROUP), through an international bid launched by the Government of Iraq (GoI). The contract between the owner and TREVI was signed in early March 2016.

The GoI assigned the roles of engineer and Contract Administrator to the U.S. Army Corps of Engineers (USACE). USACE had been monitoring Mosul Dam since May 2015. USACE hired the A-E firm AECOM as field support and extension. To accomplish its tasks approximately 70 engineers were deployed from the USA.

The contract awarded to TREVI, amounting to Euro 273M, envisioned six months for mobilization-site installation and twelve months of drilling and grouting works. Along with the

AERIAL LANDSCAPE OF MOSUL DAM.



MOSUL DAM
CROSS SECTION.

maintenance grouting, TREVI was awarded with the training of the owner's personnel and rehabilitation of the bottom outlet tunnels (i.e. guard gates and intake bulkheads) through electromechanical works and diving operations.

GEOLOGICAL CONDITIONS

The Mosul Dam area is characterized by the presence of Fatha Formation, composed of alternating beds of limestone, marl and gypsum.

The seepages are mainly due to karsts phenomena, gypsum/anhydrite rock formations alternating with soft marl layers and weathered limestone, combined with an extensive ground water aquifer that considerably affects the ground water regime in the dam foundation. Karstification is a major problem in gypsum and limestone, with their erosion and dissolution rates mainly related to the seepage velocities and hydraulic gradient.

Relevant dissolution occurs at the "karstic line," or the inferred boundary where anhydrite converts to gypsum and then dissolved and eroded by seepage. The karst development extends to a depth of 328.08ft (100m) below the dam's foundation. The said dynamics caused the collapsing of clayey marls layers into the underneath cavities, forming beds of brecciated gypsum particles and anhydrite blocks, embedded into loose clayey matrix.

The presence of cracking and groundwater fluctuation give rise to the development of sinkholes.

DRILLING & GROUTING SCOPE OF WORKS

The Maintenance Grouting works are directed by

SOILMEC SM-16G
WORKING NIGHT SHIFT.

the USACE in accordance to their “Mosul Dam Risk Assessment Findings” released in June 2016. Through their monitoring, analysis and studies, the dam’s foundation was divided in “Critical Areas” according to rock deterioration and grouting priorities.

The grouting works foresee the execution of a double grout curtain line along the dam axis, from both the grouting gallery and the crest (between spillway and fuse plug), and a single grout curtain line along the eastern side of the spillway (from grout lines on the crest to river).

As far as the grouting pattern is concerned, the grout curtain alignment is being divided in 118.11ft-long (36m) sections, with Primary 39.37ft (12m)-spaced, Secondary 39.37ft (12m)-spaced and Tertiary 19.68ft (6m)-spaced holes. Quaternary 9.84ft (3m)-spaced and Quinary 4.92ft (1.5m)-spaced holes may be added according to the grouting results.

DRILLING WORKS – EQUIPMENT & TECHNIQUES

Multipurpose drilling rigs for specific drilling techniques and space constraints were deployed. Two units of diesel crawler-mounted SOILMEC SM-16 and six units of electric crawler-mounted SOILMEC SM-5 were selected and mobilized for the drilling works in the crest and grouting gallery, respectively. SOILMEC (TREVI Group – Italy) supported TREVI in customizing the machines with special features. Both machines are capable to execute boreholes up to 984.25ft (300m) by means of percussion and rotary drilling methods.

In the Mosul Dam Project, both the SOILMEC SM-16 and SOILMEC SM-5 executed boreholes down to 656.17ft (200m) with the rotary method, by means of PDC drilling bits, tricones (from the surface only) or core barrels with core recovery.

The grout holes executed from the crest/surface required drilling through the dam’s embankment and clay core. For this specific scope, the SOILMEC SM-16 was equipped with a powerful double rotary, allowing the dry encasement of the embankment, while advancing the borehole with auger strings down to the bedrock.

The boreholes completed through the core down to the bedrock, are permanently cased with PVC pipes, cemented with plastic grout mixture, allowing access for the rock drilling.

For drilling and packer installation operations from the grouting gallery, a significant quantity of water under pressure (artesian condition) was anticipated; hence, blow-out preventers are connected to the stand-pipes.

Direct water circulation method is implemented for the drilling through rock.

For drilling from the grouting gallery, the boreholes were executed from the ramps - with slopes at 42% maximum grade making the operations more difficult.

SOILMEC SM-16G ON THE DAM CREST.


BOREHOLE EXECUTION.

DRILLING AND GROUT INJECTION.


SOILMEC SM-5 INSIDE THE GROUTING GALLERY.


THE DAM CREST.

GROUTING WORKS – EQUIPMENT & TECHNIQUES

For the production and delivery of the base grout mixture, TREVI deployed three Main Mixing Plants (MMP), installed outdoor and strategically located to feed the new grout pipelines placed along the grouting gallery and crest. Automated plants SOILMEC SGM45, capable of producing 7925.16 US gal lqd (30 cu.m) of grout per hour, equipped with four horizontal piston pumps SOILMEC SGP-20.12, were installed. Each MMP is provided with twelve silo 11,887.74 US gal lqd (45 cu.m)/ each, to store cement, water, dry and hydrated bentonite.

The pumps SOILMEC SGP-20.12 deliver the fresh grout mixture from the MMP's to the grouting points, while keeping it in circulation through a 20 Km long closed circuit split in six pipelines.

The pumping stations deployed by TREVI are twenty automated batching grouting units (BGU) SOILMEC SGP-9.12M equipped with vertical piston pump and dosing-dilution system, to change the base mix as needed in accordance with the approved methodology.

Generally, grouting is executed applying the "upstage" method, while the "downstage" method is adopted when unstable rock layers are encountered.
The holes located in the lower part of the gallery have been drilled and grouted in challenging conditions due to the very high reservoir level. The artesian pressure and water flow required significant efforts to execute the grout curtain.

GROUTING WORKS – GROUT MIXES AND PARAMETERS

Stable grout mixes, characterized by cement content, viscosity and setting time were studied, tested and used to stabilize the deteriorated rock masses, made of large voids and/or wide and extensive fine cracks and fissures.

Generally, the grouting operations commence with thin grout mix, and continue, as required, with thicker mixtures with higher cement content and setting fastener.

The major technical concerns addressed with the designed grout suspensions were mainly two: a) their properties to penetrate through the rock fissures, and b) their plastic viscosity, cohesion and filtration rates inducing quick clogging even with low grouting pressures.

The grouting pressures were designed to enable the grout mixes to penetrate the rock joints, traveling through the fissures; and preventing the hydro-fracturing.

Grouting operations and stage closing criteria are governed by the relationship between grouting pressure and grout take. The grouting operations proceed by injecting a specified grout mix until the pressure reaches a minimum value indicating a significant trend towards the


MAIN MIXING PLANTS WITH THE DAM SPILLWAY IN THE BACKGROUND.


AUTOMATED PLANTS SOILMEC SGM-45 FOR GROUT PRODUCTION AND MIXING.


ONE OF THE THREE MAIN MIXING PLANTS.


AUTOMATED BATCHING GROUTING UNITS INSIDE THE DRILLING TUNNEL.


AUTOMATED BATCHING GROUTING UNITS INSIDE THE DRILLING TUNNEL.

CONTROL ROOM.

GROUTING SUPERINTENDENT USING THE T-GROUT SYSTEM APP.

TRAINING CLASSROOM FOR THE IRAQI PERSONNEL HELD BY TREVI EXPERTS.

closure; or by switching to a thicker mix if the pressure remains low.

For the closing criteria, the effective refusal pressure is kept stable for a fixed interval of time under a specified flow rate.

GROUTING WORKS – T-GROUT SYSTEM

For the grouting works of Mosul Dam Project, Trevi developed the T-Grout system. T-Grout, where "T" stands for "Trevi", is a computer-automated web application allowing the remote management of grouting activities. It is a stand-alone software; hence, it allows offline management as well.

Along with the already known features of the common grouting recorders, T-Grout is able to remotely manage/operate the grouting pumps from a Control Room. Moreover, it allows the calculation of the effective grouting pressure of the stage by taking into account the water table level, the head losses discounted along the injection pipeline and the specific gravity of the grout mix. The system guarantees a strict control of the pump's parameters, with a uniform pressure buildup, with the sole operator's oversight.

The T-Grout system is being managed from the Control Room and grouting stations. The Control Room's operators log into the application with a PC; while, the grouting superintendents do so through a tablet. The parties communicate with an internal on/off line chat system. Every second of grouting operations, the T-Grout system stores raw data into a relational database. This storage flow represents the start point for both data analyses and reports production.

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The first activity is fully automated, as T-Grout provides daily charts, information about stages and boreholes completed, volumes and solid takes, pressures and more. SQL Code skilled operators are able to query the database to receive and combine any kind of information for further analyses. More than 500,000,000 of data were already recorded and stored. This huge amount of data allows deep analysis and study regarding the effective behavior of the grout and the response of the rock.

TRAINING & TRANSFER OF KNOW-HOW

To engage the owner's personnel in a learning process in the use and application of the modern equipment and techniques imported, TREVI held specific and exhaustive training courses.

Theoretical classes and field activities were organized for different work categories (e.g. engineers, geologists, drilling and grouting operators, mechanics, electricians, IT, etc.), to familiarize the Iraqi personnel with the equipment, methodologies and technologies being used for the maintenance grouting works, and lastly to acquire com-

petence and confidence to continue with the operations after the completion of TREVI contract.

ICT NETWORK

Trevi constructed a state-of-the-art enterprise network to serve the drilling and grouting works, covering a working area of 2.5 Km^2. The dam's area has two data centers that are redundant to each other with more than 20 Km of fiber optic cable system.

The networking infrastructure is based on Cisco Systems equipment, with core and access switches, 4 Wireless LAN Controllers, around 200 Access Points, more than 200 IP phones, etc. The network also includes 4 Virtual Machine servers by Cisco Systems and NetApp storage system.

The network is designed and capable of serving thousands of users and right now is in a stable and operational condition.

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TREVI WORKFORCE, CURRENT QHSE AND PRODUCTION ACHIEVEMENTS

The Trevi workforce reached a peak of more than 700 units, with Italian management and supervision, third country national staff and local personnel.

With the Resident Management System - Quality Control System (RMS-QCS) implemented by the USACE, Trevi submitted approximately 1,000 submittals (e.g. methodologies, drawings, technical notes, etc.). Through June 2018, with 24/6 operations, Trevi completed 967,847.8 linear foot (295,000 linear meters) of grouted boreholes, injecting 8,981,850US gal lqd of grout – equivalent to 25,353 short ton of solids - into the ground.

5.3 million man-hours were worked ***without*** recordable incidents.

CONCLUSION

Trevi commenced the works with the war conflict against ISIS at 13Km from the dam. The presence of the Coalition Forces, together with the Italian Army, guaranteed the required security of the Project Area. Notwithstanding the strict security procedures the work proceeded expeditiously with no delays.

Further to such remarkable achievements in terms of production, quality and safety, Trevi was awarded by the Government of Iraq an additional 11 months of maintenance grouting works.

Trevi couldn't neglect the social engagement of the Project. As part of the "Social Value" corporate programme, Trevi is currently renovating the schools of the Mosul Dam Village, helping the less fortunate children to get a better future.

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The stringent technical, quality and HSE standards set forth by the U.S. Army Corps of Engineers, along with the security and climate difficulties, made the Mosul Dam Project a challenging and unique model in the worldwide field of underground engineering.

5.3 million man-hours were worked without recordable incidents.

Project Team

Owner: Ministry of Water Resources of Iraq (IRAQ)

Engineer: US Army Corps of Engineers (USA)

Contractor: Trevi S.p.A. (ITALY)