Double swing rail bridge over New Suez Canal and upgrading of the existing bridge over Old Suez Canal at El Ferdan, Ismailia (Egypt)

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ABSTRACT

The second Suez Canal branch opened in 2015 in Ismailia (Egypt), had as consequence that El Ferdan swing bridge built in 2001 became out of service. At the end of 2018, the Government of Egypt (GOE), committed to Chinese group CDI-Sinoma the Construction of a second swing bridge, twin in geometry of the existing one, providing two freight rail tracks. Besides, the existing bridge provided service to one railway track and two carriageway lane, being necessary updating the bridge platform. This requires upgrading the existing structure and the mechanical and electrical parts for the new service scenario. Arenas & Asociados was hired by Dorsch DCA as expert consultants in order to review the design.

KEYWORDS: Consultancy services, movable bridge, El Ferdan, swing bridge.

1. Reason for Independent Checking

The aim of the independent design check is to ensure a level of quality of the project by gaining confidence and reducing the risks through a sufficiently competent reviewing process.

It is responsibility of Engineers to guarantee public safety by preventing not only the risks of collapse but also the consequences of a design error which can lead to a lack of performance in Public Works. The costs of a mistake would extent from additional time and money expenses to fatal effects caused by the failure of the structure. These fatal effects are not only human casualties but also breaking human ties, as it could be a bridge collapse in some remote areas. The four-eye-principle constitutes basic procedure to ensure the accuracy of calculations and technical decisions that will guarantee the design, which will not lead to accidents, damages, or a reduced life span.

The origin of the independent checking is the collapse of the River Cleddau steel box girder bridge in Milford Haven (Wales) in 1970 when the Merrison Committee of Inquiry started new design rules for steel box girders which soon resulted in include all major bridges and those of unusual or complex behaviour [1].

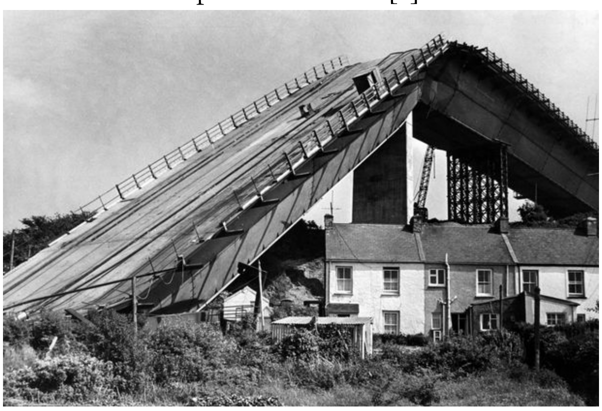


Figure 1. Cleddau bridge collapse. June 2, 1970

The extent of the independent check process could comprise a full numerical calculation of the structure or just a check carried out by another member of the design team, as a typical quality control system of a design office.

According to BS 5975:2008, depending on the category of the structure, different levels of independence of checker are required, as can be seen in Figure 3.

Figure 2. Truck stuck at Santander's Harbour bridge

The independent check process, besides providing improvements to the design itself, is positive for designers and checkers and at the end for the society, who will be the user. Lessons learned through sharing experiences and opinions between expert engineers allow to improve current and future designs.

According to the International Federation of Consultant Engineers (FIDIC) the Reviewer, having a general view of the Project, should objectively advise the designer who is further involved in the development of details. Being this collaborative work a consequence of the engagement of both subjects.

The typical scope of an independent checker is to certify that Contractor's work fulfils the Client's requirements in terms of design and construction in compliance with the Contract and regulations, guaranteeing the correctness and completeness of the final design.

The independence of the checking process is guaranteed by technical and commercial independency [1].

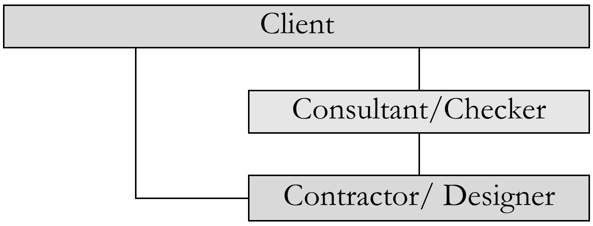
The technical independence implies that the independent checker does not have access to the designer's calculations. Verifications should be performed following their own hypothesis, calculations, software, spreadsheets, etc, so no concatenated error occurs.

Through this procedure, verification of the design is made if equivalent results are obtained.

The Commercial Independence should ensure that no conflicts of interests influence the process. The checker should not depend on the designer so as not being influenced by designer's interests. It is advisable that the checker is independent of the designer depending directly on the Client [1].

Category	Scope	Comment	Independence of Checker
0	Restricted to standard solutions only, to ensure the site conditions do not conflict with the scope or limitations of the chosen standard solution.	This applies to the use of standard solutions and **not** the original design, which will require both structural calculation and checking to category 1,2 or 3, as appropriate.	Because this is a site issue, the check may be carried out by another member of the site or design team.
1	For simple designs. These may include: formwork; falsework (where top restraint is not assumed); needling and propping to brickwork openings in single storey construction	Such designs would be undertaken using simple methods of analysis and be in accordance with the relevant standards, supplier's technical literature or other reference publications.	The check may be carried out by another member of the design team.
2	On more complex or involved designs. Designs for excavations, for foundations, for structural steelwork connections, for reinforced concrete.	Category 2 checks would include designs where a considerable degree of interpretation of loading of soils' information is required before the design of the foundation or excavation support or slope.	The check should be carried out by an individual not involved in the design and not consulted by the designer.
3	For complex or innovative designs, which result in complex sequences of moving and/or construction of either the temporary works or permanent works.	These designs include unusual designs or where significant departures from standards, novel methods of analysis or considerable exercise of engineering judgement are involved.	The check should be carried out by another organization.

Figure 3. BS 5975:2008 Categories of design check



In a Design & Build Contract the Checker could be employed by the Contractor. However, being Client's Consultant guarantees the independency allowing the Client to profit directly from the Consultant expertise.

2. El Ferdan consultancy services

2.1 El Ferdan bridges. History

Along its history Egypt has had the need of linking Africa and Asia across the Suez Canal. One of the historical crossing points in Africa is El Ferdan close to the city of Ismailia. From there, railway links have been maintained with Qantara, in Asia, from early 20th Century.

Figure 4. El Ferdan Bridge Location

The first El Ferdan Railway Bridge over the Suez Canal was completed in April 1918 for the Palestine Military Railway. It was considered a hindrance to shipping so after the WWI it was removed. A steel swing bridge was built in 1942, but this was damaged by a steamship and removed in 1947.

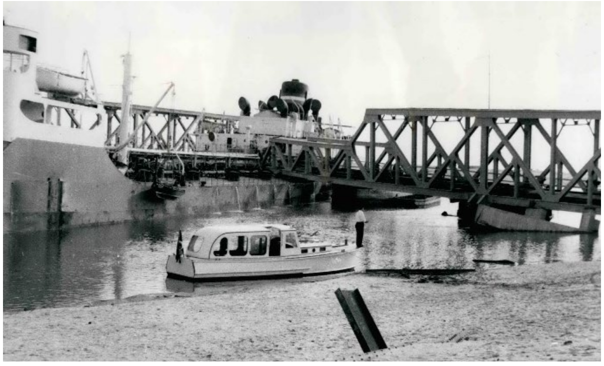


Figure 5. Ship collision in 1947

A double swing bridge was completed in 1954 but the 1956 Anglo-Franco-Israeli war with Egypt severed rail traffic across the canal for a third time. A replacement bridge was completed in 1963 which was destroyed in 1967 in the Six-Day War by the Egyptian engineering General Ahmed Hamdy.

Figure 6. Removing of bridge in January 1957

In July 1996, Egyptian Government awarded Krupp-Besix-Orascom Consortium the construction of the 4th swing railway El Ferdan Bridge, becoming in 2001 the largest swing bridge in the world with its 340 m main span.

Figure 7. El Ferdan Bridge. 1966

However, in 2015 the bridge lost its functionality, remaining opened, due to the expansion of the Suez Canal, being built a parallel Canal branch, and again, El Ferdan bridge came out of service.

Figure 8. El Ferdan Bridge built in 2001

2.2 Contractor's scope

2.2.1. Existing Bridge

In December 2018, the Government of Egypt (GOE) decided to face the challenge of recovering the railway communication between the African and Asian sides of the country. This Enterprise was awarded after a tendering process to CDI (Chengdu Design & Research Institute of Building Materials Industry Co. LTD/SRBG (Sichuan Road and Bridge Group) – Sinoma. The commitment was the construction of a new bridge above the new branch of the Suez Canal built in 2015 (see figure 4), and upgrading the existing bridge. The need for upgrading the existing bridge, built in 2001, came from the constraints introduced by other stakeholders in the Project, like the Egyptian National Railway (ENR) and the Suez Canal Authority (SCA). These agencies required duplicating the railway crossing capacity from one track to two and minimizing the affection of the bridge in the vessels traffic along the Suez Canal, one of the main incomes for Egypt, besides the tourism.

The new bridge that was required to be built and the existing one had to be designed and verified under the current standards, updating the load demand.

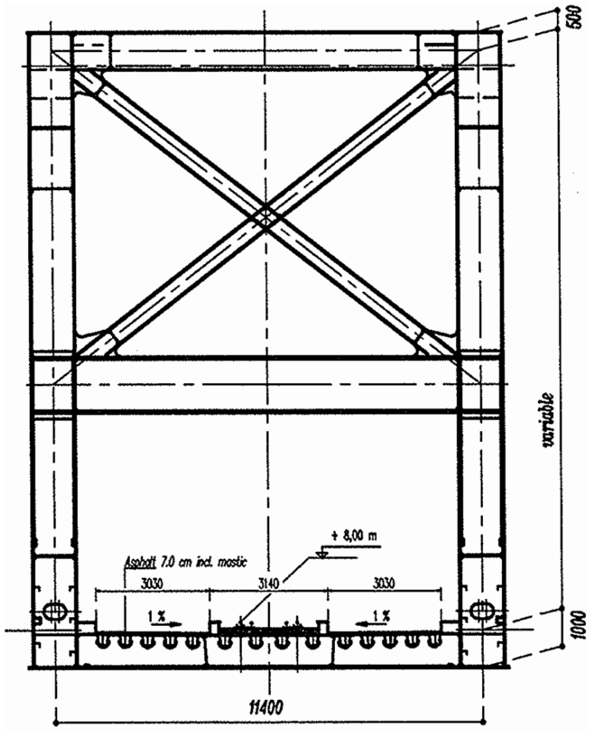


Figure 9. Existing Bridge. Cross Section

El Ferdan Existing Bridge prior to its upgrade was designed with a deck that provided service to one railway track with standard gauge (1435 mm) and one road lane at each side. This bridge crosses Suez Canal at the km 68, near ENR milestone 123.350 of the Benha-Port Said Line, between Ismailia and Qantara East Station.

El Ferdan Bridge is the longest double swing bridge in the world, composed by two identical leaves of 150 m + 170 m. Closed it provides 150+340+150 three spans bridge, but without axial continuity at mid span. The short span (150 m) is counterweighted balancing the

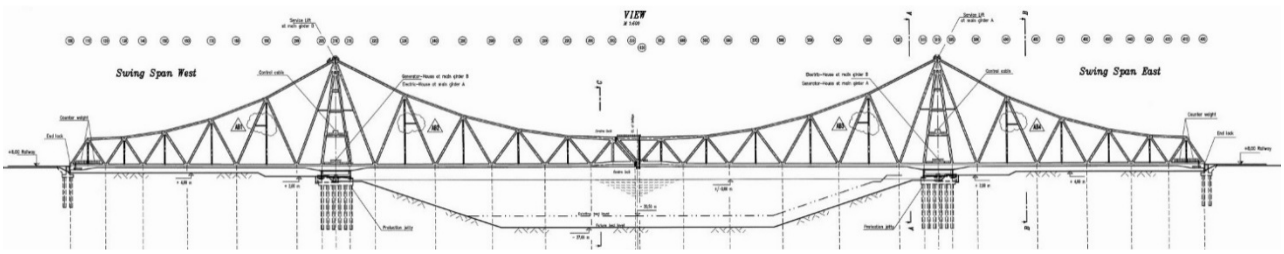


Figure 10. Existing bridge elevation

170 m main span. This allows centring the dead load reactions in the swing piers. The main span 340 m comes from the need of providing a navigable clearance in the Suez Canal of 316 m, it is to say, fully navigable.

Structurally speaking, the bridge is composed by two steel parallel lattice trusses with the deck between the lower chords, while the top chords are wind-braced by a X arrangement. The bridge depth gradually varies from 15 m at mid span and end span to 60 m at the top of the pylon. Transversally, the two lattice trusses are separated 11.4 m, excepting in the pylon area, where the deck is widened to 15.8 m in order to fit the pier and the rim girder. The deck consists in an orthotropic steel slab, with 2 stringers 800 mm height below the track rails and cross-girders at each 4.0 meters approximately.

The bridge rotates 90º from the parked position to the closed one, performing this operation around the concrete piers placed at the Suez Canal embankments. Superstructure and substructure are linked by the steel rim-girder which bears on 112 m rollers which ease the bridge rotation thanks to their low friction. The rim girder diameter is 17.1 m avoiding the uplift of the rollers from the rim girder track under live load scenarios. However, under dead loads the reaction is centred, and all the rollers are under equal loading. Furthermore, the superstructure bears on the rim girder by means of 8 pot bearings, arranged in a way that the fixed point is in the swing-pier, allowing free displacements under thermal effects. The swing-pier is founded in a dense sand soil by 38 concrete driven piles, 30 m length and 1.5 m diameter.

The structure is completed by the abutments, where the bridge is locked when it is closed; the locking heads, used for parking the bridge when it is open; and the jetties, used as protective elements against vessel impacts.

Mechanically, the bridge swings thanks to a pair of electrical motors placed at the bottom of each rim girder, acting a pinion coupled to the gear in such a rim girder.

In addition, it was provided a manual actuation by a handle in case of an emergency scenario of electrical blackout. Besides, the mid span and end span locking are operated also by electrical motors and, handled actuated manually under emergency scenarios. The locking pins were wedged to compensate the thermal deflections and fit the roller casing provided in the abutments, mid span and locking heads. Finally, the last mechanical element corresponds to the rail locking devices which were also operated by electrical motors with an auxiliary handle for manual actuation.

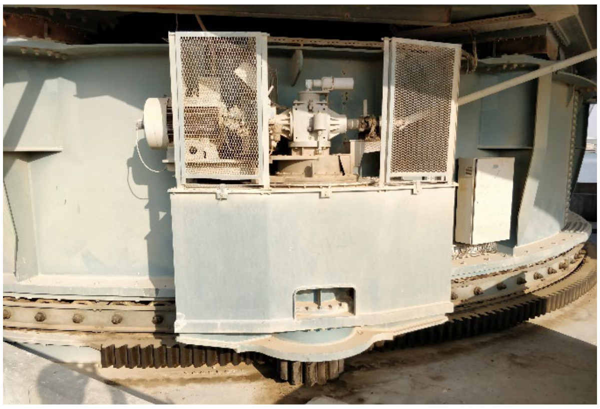


Figure 11. Electrical motor, swing drive, manual operation crank, pinion and gear at pier.

2.2.2. New Bridge

Once introduced how the existing bridge was arranged and prior to descript the requirements to its upgrading, it is necessary to outline the new bridge design.

The new bridge architecturally matches the existing one. However, painted weathering steel S355 is used, while the existing bridge was built in painted carbon steel S355. Notwithstanding the above, the new bridge has been designed to deal with the loads required by the Egyptian Code of Practice (ECP) and General Specifications by ENR, replacing the train load Type D by the Eurocode LM-71 one. The functional cross section provides service to two railway tracks, as ENR requirement to speed up the Canal crossing minimizing the number of bridge operations, which are estimated in 8 per day, with a duration below 30', considering opening, train passage and bridge closing.

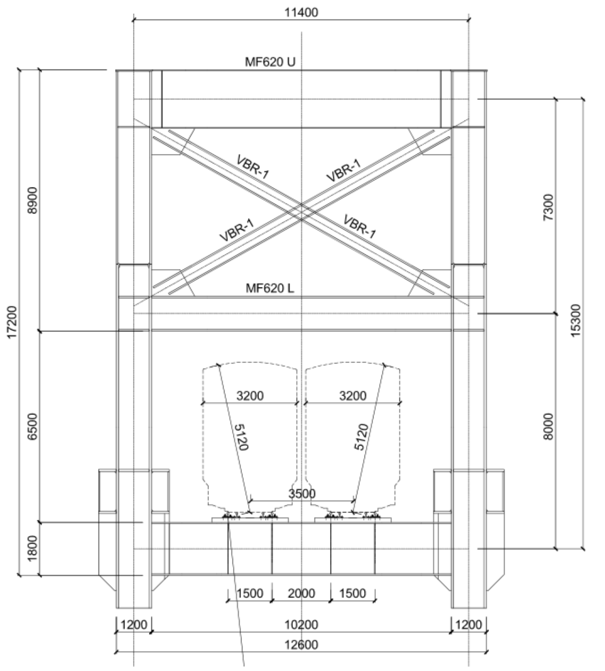


Figure 12. New Bridge Functional Cross Section

It was a contractual requirement by GOE speeding up the bridge operational time while guaranteeing the robustness, thus it was required:

- MAIN SYSTEM
  - Swing System: Two electrical motors per swing-pier acting a swing drive provided with a pinion that rotates the bridge in conjunction with the gear. The bridge can be operated by one motor at half speed.
  - Locking System: At end span and mid span locking pins are actuated by hydraulic cylinders which allows a smooth drive.
- ALTERNATIVE SYSTEM
  - Swing System: a special vehicle shall be used to rotate the bridge by pulling and pushing it if the main and secondary power supply are not operative; or the pinion or the gear are out of service
  - Locking System: a portable Hydraulic Power Unit HPU provided with a diesel generator can be used if malfunctions are detected in the hydraulic locking cylinder.
- HAND OPERATION
  - Swing System: the bridge can be operated manually by means of a handle linked to an auxiliary gear box.
  - Locking System: hydraulic cylinders can be operated manually also with the help of a handle.

Regarding the locking system the new bridge enhances the one in the existing bridge thanks to include a vertical alignment system in addition to wedging the pin to control the bridge deflections due to thermal variations.

Each bridge leaf is electrically fed by a dedicated 500 kVA Ring Main Unit (RMU). In case of electrical blackout 2x250 kW diesel generators installed in the bridge Diesel Room are ready to substitute the main power supply.

Finally, it must be mentioned that the bridge alignment during the opening and closing operations is controlled by means of laser sensors and an auxiliary CCTV system. A climate station is place on top of the pylons which mission is allowing the bridge rotation.

2.2.2. Existing Bridge Upgrade

Due to the new service conditions requiring two parallel rail tracks instead of one in the Existing Bridge its structure was reinforced adding steel plates in the most demanded truss and deck elements as well as post-tensioning tendons in the truss top chords. The main reason behind this reinforcement was controlling the deflections for railway running comfort.

To improve the bridge operability, as locking issues were reported, the end span and mid span truss cells were replaced with those designed for the new bridge. The electromechanical linear locking drives were substituted with hydraulic ones. Regarding the bridge rotation it is worth noting that the electrical motor power had to be increased to be able to swing the bridge due to the weight increase as result of the reinforcement.

In addition, all the automation systems were upgraded to the one provided in the new bridge to standardize the bridges operation control.

Figure 13. Bridge panel control in the EB

2.3 Consultancy Services

2.3.1. Client Organization

El Ferdan New Bridge and Upgrade of the Exiting Bridge is an EPC (Engineering, Procurement and Construction) Contract. The GOE committed it to the best bidding quotation, provided by Chinese group CDI/SRBG-Sinoma. The GOE also requested Consultancy Service for reviewing the technical documents (drawings and technical material submittals) as well as Site Supervision during the construction stage. The Consultancy Service Contract was awarded to Dorsch Gruppe. Furthermore, the GOE had to deal with two important Stakeholders like ENR and SCA, which require their serviceability conditions for railway and vessels traffic respectively.

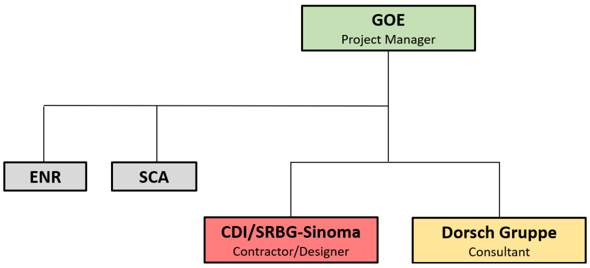


Figure 14. Client's main chart

It is worth noting that the GOE is composed by Engineers who performed their own design checks and involved in the Site Supervision of the construction activities. In singular projects like this one, as many Engineers review the design better will be the final outcome, especially when several disciplines (civil, structural, electromechanical and telecom) are involved.

2.3.2. Supervision Team

El Ferdan Bridges project required a supervision team covering different disciplines. Thus, Dorsch Gruppe Abu Dhabi hired Arenas & Asociados to collaborate with them as consultant to perform the Project reviews. The disciplines to be covered were:

DESIGN

Geotechnics:
- Geotechnical Interpretation Report.
- Pile-soil interaction.

Structural:
- Foundation design.
- Substructure elements (swing pier, locking head, abutment and damping pier)
- Jetties.
- Vessel impact on jetties.
- New Bridge superstructure.
- Existing Bridge superstructure upgrading.
- Wind Tunnel Test review.
- Method Statements.

Mechanical:
- Electrical motor torque demand.
- Hydraulic cylinders.
- Locking Pin resistance.
- Rollers' resistance.
- Gear and Pinion resistance.
- Mechanical Drives redundancy.
- Method Statements.

Electrical:
- Power supply demand.
- Single Line Diagrams.
- LV layouts and protective devices.
- Lightning, Earthing and Bonding.
- Auxiliary power supply.
- Method Statements.

Automation:
- Bridge Controls.
- Alignment sensors.
- Health Monitoring Plan.
- Bridge operation and coordination with stakeholders (ENR and SCA).

Railway design:
- Check of the 2.5 km new railway tracks.
- Tracks rail locking devices.

Civil Works:

- Earthworks and dewatering.
- Roads.
- ENR and Master Control buildings.
- Fencing.

PROCUREMENT

All the Project materials and equipment has to be reviewed and approved according to Contract Clauses.

CONSTRUCTION ON SITE

DCA Egypt team will support GOE during the construction tasks related in the design project scope.

Further to the different disciplines' reviews, the most challenging task required along the review process was the coordination of all those engineering disciplines, as the Contractor had several engineering Consultant firms for those specialised engineering field that were necessary in the Project.

2.3.2. Design stages

The design of the El Ferdan bridges, new and upgraded one, was divided by the GOE into two consecutive stages:

BASIC DESIGN

The first step before proceeding with the Basic Design was requiring to the Contractor the issuance of Design Criteria Reports for all the disciplines determining the design basis which the Project was going to be developed in. Codes and design scenarios were agreed upon. The mentioned Design Criteria Reports are a common practice in International Projects, being advisable to be introduced in Spain, as they are very clarifying for all the parts involved in the design since the Project kick-off.

Once the Design Criteria Reports were approved, the Contractor was allowed to proceed with the submittal of the Basic Design Packages.

The Basic Design constitutes an intermediate step in the design process that allows the approval of the master lines of the Project Design allowing to proceed with the Detailed Design and avoiding abortive works in later stages.

DETAILED DESIGN

The Detailed Design stage is the final step in the complete definition of the works that are necessary for the construction and operation of El Ferdan Bridges. As well as in the case of the Basic Design, each discipline was submitted in different packages for its review and approval.

Further to the Detailed Design, all the elements involved in the construction required the procurement approval, being all the materials subjected to international quality standards.

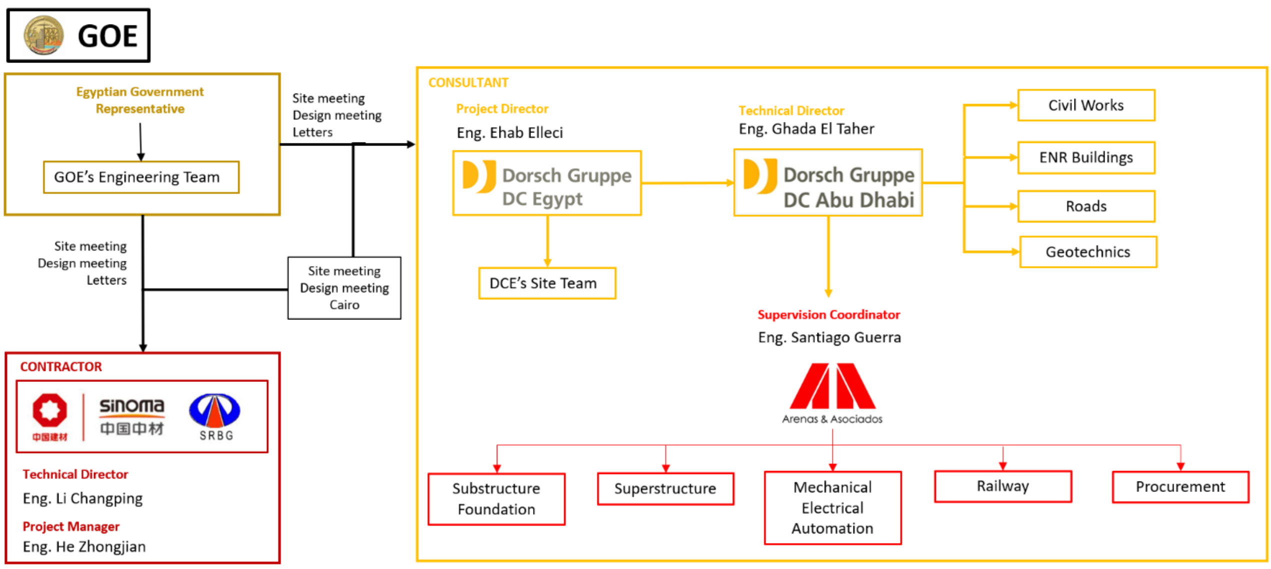


Figure 15. Consultancy Services Organization Chart

2.3.3. The Approval Process

The Contractor's design was done by:

- Maffeis Engineering SPA as structural and mechanical designers
- SGAI as Geotechnical Designers
- The electrical design was carried out by the Contractor's home office.

The design was reviewed by:

- GOE's Technical Team.
- A&A Consultants and Misr Raymond in charge of Geotechnical Engineering Interpretation.
- Cosmos Engineering as Contractor's firm in order to assure that the designs were according to Egyptian practices.
- Dorsch Consult Asia. Branch Abu (DCA) as independent Consultant reviewing the documentation issued by the Contractor.

All the documentation, submittals and check reports flowed through the GOE. The format chosen for checking submittals was by CRS (comment response sheets) and comments in design drawings. Three review status were provided: approved, approved as noted or revise and resubmit. Review cycles were carried out until the design was approved. In addition, presential coordination meetings were performed periodically in Cairo, at the GOE's facilities and on site, in Ismailia.

3. Conclusions

Arenas & Asociados feels pleasured of having been involved in El Ferdan Bridge Project, and we honestly believe that the formula chosen by the GOE has been a complete success.

The GOE created a collaborative environment involving other Stakeholders, like ENR and SCA, the Contractor and its designers, and the GOE's Consultant DCA configuring a real one team. All the team worked in the same direction, listening ones to others and always performing in the direction to provide the best product for Egyptian people.

Finally, we would like to stand out the compromise by Arenas & Asociados with the quality of our products, a heritage from Professor Juan José Arenas. We firmly believe on it, performing internal checks along our designs, based on the ethics of giving back the society reliable structures to enhance the people's life. All of us, Architects and Engineers, should have in mind and apply the words by Egyptian Architect Hassan Fathy in his book "Architecture for the Poor": *'We are so extremely poor that we have no other choice than providing good architecture'.* [2].

Figure 16. Bridge closure operation seen from Africa bank side

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- Adel A. Hameed, Architect. *Road and Construction Director.* DCA. adel.hameed@dorsch.com

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Finally, we wouldn't like to forget CDI/SRBG-Sinoma Contractor's team, being always receptive and collaborative with the GOE and DCA/Arenas & Asociados.

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Figure 17. Existing bridge, prior to be upgraded, parked at the West side