2021 AWARD OF EXCELLENCE: ROD EL-FARAG CABLE-STAYED BRIDGE (TAHYA MASR) OVER THE RIVER NILE

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The Rod El-Farag cable-stayed bridge is a Guinness World Record holder as the widest cable-stayed bridge in the world (May 2019) (Fig. 1). The bridge has a total width of 220 ft (67 m) at midspan, housing six lanes of traffic per direction. The bridge width reaches 276 ft (84 m) at the eastern entrance. Construction of the bridge was completed in 32 months after the start of construction. The cable-stayed bridge consists of double H-shaped pylons (Fig. 2), each extending 250 ft (76 m) above the deck, 300 ft (92 m) above water level (three columns per pylon). The total length of the bridge is 1770 ft (540 m), with a 980 ft (300 m) main span. The stay cables have a semi-fan arrangement and carry the deck in four planes. There is a total of 160 stay cables of sizes ranging from 55 to 127 strands, with nearly 1700 tons (1600 metric tons) PT strand.

More than 1.3 million yd^3 (1 million m^3) of concrete were placed and more than 275,000 tons (250,000 metric tons) of steel reinforcing bar were used for the cable-stayed bridge and approaches. One of the key challenges for the bridge designers and constructors was how to achieve durability in the long term, adequately protecting the structures and the stay cables from the effects of air pollution and the moist riverine environment.

The bridge contributes to easing people lives and economic conditions. The bridge has a crucial role in alleviating traffic congestions and reducing traffic time and CO^2 emissions. In addition, the bridge has become an iconic landmark and a destination for breathtaking views of the River. The new glass walkways (Fig. 3) have become a special attraction, drawing citizens for a stroll across the bridge. At the turn of the 2021 new year, the bridge was

Fig. 1—Rod El-Farag Cable-Stayed Bridge (Tahya Masr) over the River Nile.

Fig. 2—Double H-shaped pylons.

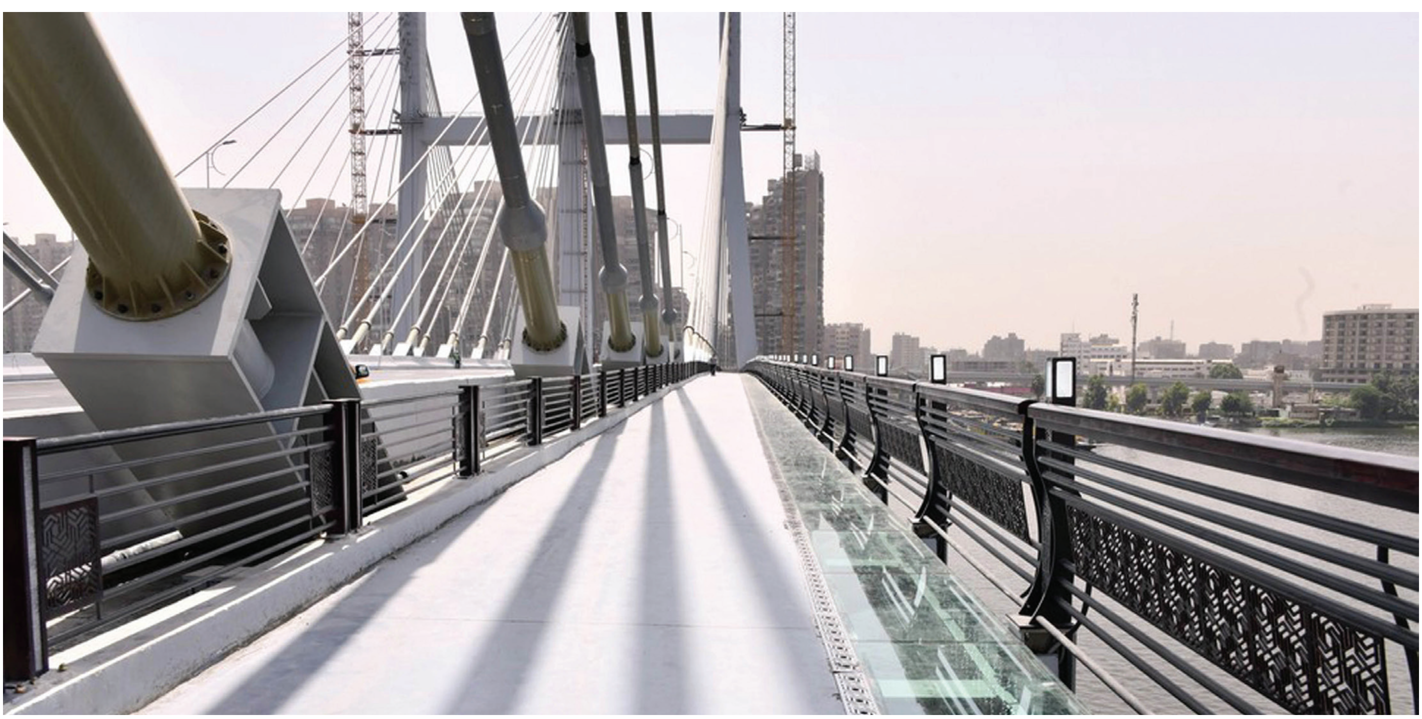

Fig. 3—Glass walkways.

home to one of largest fireworks displays in the history of the country. Four years in the making, the bridge provided work and a unique experience for over 4000 Egyptian engineers, technicians, and workers.

BRIDGE DESIGN DETAILS

Span arrangement

The main span of 980 ft (300 m) (composite steel girders and precast slab), and the continuous side spans of 6.6 x 390 ft (2 x 120 m) (concrete box section).

Stay cables

There is a total of 160 stay cables of sizes ranging from 55 strands up to 127 strands, with the adjustable stressing end at the top of the pylon. The semi-fan arrangement of the cable stays provides an optimal distribution of stresses along the pylon and practical connection details near the top of the pylons (Fig. 4). The stay cables are prefabricated seven-wire strand, providing the following technical advantages: (a) a minimum tensile strength of 257 ksi (1770 MPa) for galvanized wires; (b) high fatigue strength sockets that contain epoxy resin are used to proof a fatigue strength exceeding 36 ksi (25 kg/mm^2); and (c) no jobsite corrosion-proofing: a triple corrosion protection system, with more than 0.94 oz/ft^2 (300 g/m^2) of zinc coating for wire, waterproof filament tape, and highly weather-resistant polyethylene cover for cables are provided at shop to assure long-term durability (Fig. 5). The cable force monitoring system of the bridge uses an elastic-magnetic sensor (EM sensor) installed inside the pylon stressing anchorage—three EM sensors in each anchorage—connected with the data acquisition station in the middle leg of each pylon, from which all cable force readings can be acquired simultaneously.

PTI's "DC45.1-18:Recommendations for Stay Cable Design, Testing, and Installation" was the main document for specifying, design, testing, acceptance, and installation procedures during and after the construction, and for long-term performance of the cable-stayed bridge.

Fatigue tests were carried out on 73 strand cables up to more than 2 million cycles.

A watertightness test for an anchorage size of 55 strands was conducted.

Wind loads and wind tunnel tests

Due to the large width of the bridge, and the presence of a small gap between the North and South spans of the bridge, wind aerodynamic stability and performance is considered critical. To check the wind aerodynamic stability of the bridge, an extensive series of wind engineering studies and wind tunnel tests were carried out at Tongji University, Shanghai, China. In addition to wind effects, simulation on the cable-stayed bridge using CFD computer simulation was carried out. The wind tunnel tests included section models, pylon models, and full-scale models. Among the main parameters measured in the wind tunnel tests and studies were the critical wind speeds for vortex shedding, flutter, and buffeting. A comparison of results from CFD computer simulation and the wind tunnel test was carried out.

Cable adjustments

Cable adjustment is one of the most important procedures in the erection of cable-stayed bridges. Because cable-stayed bridges are a highly statically indeterminate structure, the cable length and/or cable

Fig. 4—Semi-fan arrangement of the cable stays.

tension affect the final profile of the girder and verticality of the pylon. Parameters to be considered for cable adjustment are described as follows:

1. Length of fabricated cable
2. Profile of girder (position of cable anchorage)
3. Height and verticality of pylon (position of cable anchorage)
4. Dead load
    a. Permanent dead load
    b. Temporary dead load
5. Structural rigidity of girder and pylon
6. Thermal effects,
7. Deviation of fabricated cable length (actually, deviations were negligible)
8. Position of cable anchorage in the girder (through the assembling stage)
9. Position of cable anchorage in the pylon (after completion of the pylon)

Bearing system

The bridge has a semi-floating bearing system. The bridge floats in the longitudinal direction, in which the wind loads and other longitudinal loads (except seismic) are carried from the deck to the cables and towers to the foundations, while the bridge is supported transversely by bearings to carry transverse loads due to seismic, wind and other transverse loads. Hydraulic dampers control the seismic movement and forces in the longitudinal direction.

Seismic dampers, bearings, and base isolation

Main reference: Design Criteria and Eurocode EN 15129:2009: Anti-seismic devices. Guide Reference: AASHTO Guide Specifications for Seismic Isolation Design, fourth edition, 2014.

Aesthetics

The semi-fan arrangement of the cable stays is especially aesthetic, as it creates an arrangement of cables that projects outwards from the tip of the pylon. Clear parallels can be drawn from the bridge's modified fan cable arrangement to the mast and rigging found in Ancient Egyptians' sailing boats, an example of which was found in Tutankhamun's tomb (Fig. 6). The sail boom that is carrying the sail is made from wood and is carried with ropes. The pylon's general configuration was selected to resemble the pylon of the old Egyptian Pharaoh's Temples in Luxor (Thebes).

Pylons

a. The pylons were constructed using self-climbing formwork with a height of 302 ft (92 m)
b. Tie beam between pylon verticals was constructed at a height of 230 ft (70 m) using heavy-duty truss supported on embedded PT bars in the pylon and lifted by heavy lifting system
c. The last 79 ft (24 m) of the pylon was designed as a composite section. A steel inner shutter was divided into 12 pieces, each approximately 28 to 33 tons (25 to 30 metric tons) to be adapted with the 330

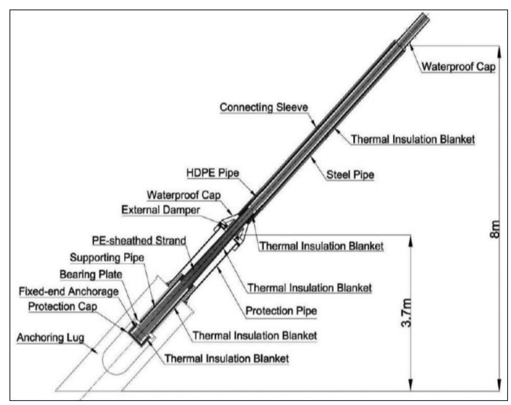

Fig. 5—Protection of stay cable at base.

Fig. 6—Bridge design tied to historical Ancient Egyptian sailing boats.

Fig. 7—Pylon construction using self-climbing formwork.

ton (300 metric ton) crawler crane, which is used for lifting the steel shutter

d. The last 9 m of the pylon contained PT bars to control and minimize crack width.

Two intermediate piers in the 394 ft (120 m) side spans were introduced at the land side of each pylon to reduce the deformations in the pylon, bending moments in the pylon, stress variations in the cables due to live loads, and improve the load distribution characteristics of the bridge. In fact, these auxiliary piers serve as anchors for the cable-stayed bridge and counterweights. They have considerable advantages on the stability during the construction stage of the main span. They allowed construction of the main span at the same time of completing the pylon.

Pylon construction

The climbing form system has several levels of working platforms. The upper platform is used for the installation of the vertical reinforcement and the placement of concrete into the distribution hoppers. The middle platform was used for fixing the reinforcement and casting and compacting the concrete. The lower platform was a hanging scaffolding used for surface finishing and curing of the concrete. The lattice girder served as a storage area and derrick crane operations as well as for stabilizing the climbing form system. The climbing form system was leveled and adjusted by semi-automatic leveling devices attached to each hydraulic jack. The geometry was checked by total station every early morning to avoid the effects of temperature. The tolerance of variations from the plumb was specified to be less than 0.1%.

USE AND ADVANTAGES OF POST-TENSIONING IN PROJECT

Post-tensioning is used in five locations of the project:

1. The largest quantity in the cable stays, where approximately 1760 tons (1600 metric tons) were used in the 160 cable-stays, with a total length of strands more than 620 miles (1000 km). Maximum/minimum number of strands per cable stay = 127/55.
2. PT tendons were used at the connection between the concrete side spans and the composite steel main span.
3. PT tendons were used for the longitudinal concrete girders and the two transverse cross girders at the East Entrance, where the total width of the bridge reaches 275 ft (84 m).
4. PT bars were used in the pylon composite concrete section at the location of the cable stay connection to limit the crack width due to large out-of-plane forces from the cable stays. PT bars were applied both in the longitudinal and transverse directions of the inner column.
5. PT bars were used to lift the scaffolding and formwork for casting the tie beams, which connect the columns of the pylons.

Location: Cairo, Egypt
Owner: Engineering Authority of the Armed Forces (EAAF), Cairo, Egypt, Project Planning and Management
Owner Consultant: Arab Consulting Engineers, ACE (Moharram – Bakhoum), Design and Construction Supervision
General Contractor: Arab Contractors (Osman A. Osman & Co.)
Contractor Consultant: Dr. Chen Dewei, Tongji University (China, Team Leader) and SICE (Egypt)
PT Supplier: Cable stays, OVM: supply cable stays, and technical support during installation; PT Bars: DYWIDAG-Systems International, Inc.
Other Contributors: Wind tunnel testing, Tongji University Civil Engineering Department, State Key Laboratory, Shanghai, China; Cable Fatigue Testing, CTLGroup, Inc.; Bearings, Arsan Industries, Dampers in Longitudinal Direction for Seismic Actions: Maurer