Inspection and rehabilitation of old White Nile steel bridge substructure

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مستخلص: الإنشاء السفلي لجسر النيل الأبيض الحديدي القديم يتكون من دعامات (أغلفة فولاذية مملوءة بالخرسانة) ومسنودة بقيسونات محفورة في الحجر الرملي. تم فتح هذا الجسر الفولاذي في عام 1928م، وتم التحقيق فيه وتقييمه من أجل السلامة والأمان. وشمل التحقيق والتفتيش، الفحص البصري، والاختبارات الحقلية والاختبارات المعملية. تضمنت إختبارات ألواح الفولاذ التكوين المجهرى للصلب، وإختبار الشد، وإختبار الإنحناء، وإختبار الصلابة من أجل تحديد الخواص الكيميائية والميكانيكية، في حين أجريت إختبارات قلب الخرسانة لتحديد قوة إنضغاط مكعبات الخرسانة. كشفت إختبارات الفحص ودراسة التقييم أن معظم أغلفة الدعامات الفولاذية عانت من مشاكل صدأ وتآكل عالية. وعليه ونتيجة للتآكل، تم نقصان سمك لوحة الغلاف والتي كانت في الأصل 5 مم للدعامات الثابتة و 7 مم لدعامة الفضة المتحركة، بشدة إلى حوالي 1.5 مم أو حتى في بعض الحالات إلى حوالي 0.4 مم فقط (في دعامة الفضة المتحركة). في بعض الحالات، ظهرت ثقب في ألواح الأغلفة تُشير إلى أن الفولاذ قد تآكل تماماً وفقد كل سماكته. كذلك قيسونات الأساس التي كانت تحت الماء بشكل دائم أو مدفونة بالكامل في الأرض سليمة ولا تعاني من مشكلة التآكل. لم يُلاحظ أي علامة للهبوط المتفاوت. أظهرت إختبارات المواد التي تم إجراؤها أن الفولاذ قد تجاوز عمره المتوقع وفقد قابلية اللحام. وعلاوة على ذلك فإن نظام الحماية الكاثودية الذي تم توفيره في الأصل سابقاً للحماية من التآكل قد أصابه التلف ولا يعمل. لذا، تُقدّم هذه الورقة نتائج التفتيش وإعادة التأهيل للإنشاء السفلي للجسر.

ABSTRACT The substructure of The Old White Nile Bridge consists of steel tubular piers (steel casing s filled with concrete) supported by caissons drilled into the sandstone. This steel bridge which had been completed in 1928, was investigated and assessed for integrity and safety. The inspection and investigation of the piers covered visual inspection, field tests and laboratory tests. Steel plates tests included microstructure analysis for steel, tension test, bending test and hardness test to determine the chemical and mechanical properties, whereas concrete core tests were conducted for determining cubes crushing strength of concrete. The inspection tests and assessment study revealed that most of piers steel casing suffered from high corrosion problems. Thus, due to corrosion the thickness of the casing plate, which was originally 5 mm for fixed piers and 7mm for swing span pier, was reduced severely to about 1.5 mm or even in some cases to about only 0.4 mm (in the swing span piers). In some cases holes appeared in the casing plates indicating that the steel was corroded totally and all the thickness was lost. Then, the Foundation caissons which were permanently under water or fully buried in the ground were found sound and suffer no problem of corrosion. No sign of differential settlement was observed. The material tests performed showed that the steel exceeded its expected life time and have lost their weld-ability. Moreover, cathodic protection system which had originally provided previously to protect against corrosion found damaged and not functioning. Therefore, this paper presents the results of inspection and rehabilitation of the bridge substructure.

Keywords: White Nile steel bridge, substructure, piers, steel casings, caissons, corrosion, cathodic protection, inspection and rehabilitation.

1. INTRODUCTION

The white Nile Steel Bridge crosses White Nile river near Military force Hospital in Omdurman and connects Khartoum city to Omdurman city. The overall bridge length is about 680 m the bridge is of steel truss type. The bridge was opened in 1928. The bridge has seven fixed spans and two swing spans to facilitate navigation. It consists of two lane main central carriageway and two cantilever lanes for light traffic, as shown in Fig. 1.

Fig. 1: General view of the bridge.

The bridge stands on 19 piers based upon caissons that were sunk into rock to a depth of 2.4 m. Each span of the bridge is 244' (74.37 m) except for the swing span which stretches up to 152' (46.33 m) on either side. Six piers and caissons are within water whilst the rest (including the swing span) are within land (Wad Dakin Island in the middle of the River). Four piers and caissons are within the Eastern channel (close to Khartoum) whilst two are within the Western channel (close to Omdurman).

There are three types of piers in the bridge; regular land piers, river piers and the swing span pier. The regular piers are tubular with a diameter of 3,000 mm, formerly covered with a 5.0 mm steel sheet riveted together with 7/16" rivets. The tube is internally braced with a relatively light steel frame and the whole is filled with concrete. The bottom of the pier is about 4' (1,200 mm) below the top of the caisson. Steel rails placed vertically within the pier tube reinforce the junction between pier and caisson. The top of the pier is strengthened with a circumferential steel band and the concrete fill is finished off level with the top. Each pair of piers is cross-braced, with the cross bracing connected to the internal bracing

of each pier. All the piers are about 8500 mm high from the caissons top. Currently, river sediments bury almost half the height of the piers within land. The fixed spans caissons are 4880 mm in diameter and consist of 5.0mm plate riveted to an internal steel framework and filled with concrete. The caisson plating is also riveted together using 7/16" rivets, as shown in Fig. 2.

Fig. 2: General view of bridge substructure.

The swing span pier was constructed similar to the fixed span piers, but stands solitary with a diameter of 9,100 mm. The swing span caisson was constructed similar to the fixed span caissons, but has a diameter of 10,000 mm, as shown in Fig.3.

Fig. 3: Swing Span Pier.

The plating for all the piers and the cross bracing (both forming an integral part of the construction) had been coated with bituminous paint for protection against corrosion [1].

2. CONCRETE FILLED STEEL TUBE PIER AND COLUMN (CFST) SYSTEM

The cross-section of concrete filled steel tube (CFST) which was used in piers of this bridge and the overall section can behave as composite under certain conditions. The steel tube enhances ductility capacity, stiffness, shear capacity,

flexural capacity of the section. This system of construction can also help in reducing cost and efforts during construction. Concrete filled tube sections proved to be most efficient approach for railway bridges and it has the effect of enhancing bridge service and seismic behaviour and performance [2]. A lot of research is now being carried out on the behaviour of this type of construction. There are many types of CFST in construction, for example single tube, double tube non-braced, double braced tubes, circular or non-circular. Fig. 4, shows a schematic drawing for double braced tube pier used in Blue Nile bridge connecting Khartoum to Khartoum North. The design of this bridge was accomplished in 1907 [3].

Fig. 4: Double tube pier and caisson internally braced used in Blue Nile steel Bridge1907.

3. DETERIORATION IN STEEL STRUCTURES [4]

There are five basic types of deterioration in steel structures: Corrosion, abrasion, loosening of connection, fatigue and impact. The two main causes of deterioration in bridge substructure are corrosion and impact. Corrosion may be defined as the conversion of metals by natural agencies into compound forms. It is the major maintenance problem in steel structures. The symptoms are oxidized surface with loose flakes, reddish-brown rust – colored appearance. The reduction in the section due to corrosion leads to stress

concentration and the member may snap or buckle. It is necessary to realize that corrosion does occur and to know where it is most likely to occur, how to prevent it and how to repair the condition when it develops. Steel sections are sensitive to damage for impact of moving objects much more than concrete or timber because steel section have relatively thin flanges. Impact damage is characterized by local distortion of the affected member. One should distinguish between buckling of compression member and flanges due to overstress and impact distortion. Impact damage may be repaired by strengthening the member, either plating or encasing it.

4. ASSESSMENT INVESTIGATION OF BRIDGE SUBSTRUCTURE [5].

The inspection, tests and assessment study revealed that:

1. Most of piers steel casing suffered from high corrosion problems. These corruptions start at 3.0 m from the top of the piers down to the parts which are permanently underwater. Due to corrosion the thickness of the casing plate, which was originally 5 mm for fixed piers and 7 mm for swing span pier, was reduced severely to about 1.5 mm or even in some cases to about only 0.4 mm (in the swing span piers). In some cases holes appeared in the casing plates indicating that the steel was corroded totally and all the thickness was lost. The entrance of water inside the piers initiated the corrosion from inside and made the problem of corrosion even worse, as illustrated in Fig. 5, Fig. 6 and Fig. 7 [5].

Fig. 5: Corrosion in pier casing.

Fig. 6: Deteriorated swing pier vertical stiffeners.

Fig. 7: Total loss of steel casing plates.

2. The Foundation caissons which were permanently under water or fully buried in the ground are sound and suffer no problem corrosion. Also it can be concluded that no sign of differential settlement was observed.

3. The material tests performed showed that the steel used is ST37 and has exceeded its expected life time. This fact is clear from the microstructure analysis of steel plates. Also from these results, it can be seen that the cover steel plates have lost their weldability.

4. The inspection of concrete filling pier casings indicates that the outer rings of concrete adjacent to the steel casings suffer severe disintegration to a depth of about 50 mm and some cavities were encountered which made this concrete very porous. The inner parts of concrete

are sound and intact with very good cube crushing strength for both piers body and piers head (the mix design was different for each). These cube crushing strength ranges between (23.1 to 41.7) N/mm².

5. Bituminous paint which was intended to protect pier steel casings from corrosion is in bad condition and most of it fell down and does not exist which makes the steel prone to corrosion.

6. Cathodic protection system which was originally provided to protect against corrosion was damaged and no longer performs its role, hence corrosion was enhanced, see Fig. 8.

Fig. 8: Damaged cathodic protection system.

7. The guard and protection rings around piers had fallen down due to mechanical strike by moving bodies and failure of rivets joining them to the casings due to corrosion, as shown in Fig. 9. Hence the piers, especially in the navigational channel, may be subject to collision of ships or boats.

Fig. 9: Corrosion and damage of rivets.

8. The cross-bracing members between pairs of piers suffered from deterioration due to corrosion in particular parts buried in the sedimentation soils and shall be changed during the repair process, as shown in Fig. 10.

Fig. 10: Corrosion of cross-bracing members.

9. Lubricating pins in the bearings mounted on the piers are clogged and no lubricant was provided which will result in the bearing surfaces be abraded.

5. REHABILITATION AND STRENGTHENING OF BRIDGE SUBSTRUCTURE

A. Recommendations for bridge repair

As a result of this study the following recommendations were drawn:

a) Bridge Piers:

Bridge piers need urgent and immediate strengthening and repair. The strengthening can be performed by jacketing the existing piers from the top of the foundation caisson to the head of the pier. Pier Jacketing can be done by constructing an outer ring of steel casing around the old one with a larger diameter (for example, the outer diameter can be 600 mm larger than the inner one). The gap must be filled with very dense high strength concrete.

Sand blasting of all casings shall be made and all deteriorated parts of casing shall be removed prior to repair process to prevent any transfer of corrosion in future between the old casings and the new ones. For the upper part which will not be jacketed the sand- blasting shall be followed by protection paint to protect steel from corrosion.

Proper connection between the new casing and the pier body shall be made to prevent any separation and to ensure perfect load transfer and composite behavior of the renovated pier.

New cross bracing between each two pairs of piers shall be constructed and protected against corrosion according to specifications.

b) Protection against collision of ships and boats:

Protection system for piers that lie in the navigational channel shall be constructed to protect against collision of ships and boats.

c) Cathodic Protection:

Cathodic protection system against corrosion shall be reinstalled for all piers to help protecting steel casing from corrosion (this system was originally provided but was damaged and was not maintained again).

d) Scour Protection:

No Scouring hazard was detected hence there is no need for any measures to be taken in this regard.

e) Foundation caissons:

No measures or strengthening were needed to be taken for foundation caissons since they are sound and in good condition.

f) Bridge bearings and swing span device:

Bridge bearing was found to be frozen because of not being maintained for long time and also the swinging device is out of order. It was decided by the client not to change this device because no need for opening bridge for the navigation by swinging.

B. Strengthening performed for the piers [1],[5]:

The piers which require rehabilitation were strengthened by outside jacketing using larger diameter 10 mm thick steel casings of 600 mm larger than original one and the gap was filled with very dense high strength concrete grade C40. Because of the limited height of working space between bridge deck and river level, the temporary steel cofferdam was constructed in courses welded together around the pier and allowed to penetrate the soil under its own weight. The steel used is type ST 37. A floating platform was used for this purpose, as shown in Fig. 11. Piers on central island was excavated around to the level of the top of the caisson and jacketing was constructed without cofferdam, see Fig. (8-c).

The jacketing casing was also welded in courses and connected together around the piers and fixed to the base plates welded to the top of the caisson, a total weight of about 167 ton of steel was used. Horizontal and vertical shear connectors were fixed to ensure complete transfer of forces between old and new structures and composite behavior of the renovated pier.

(a) Steel plate cofferdam a round pier.

(b) Steel plate cofferdam a round pair of piers.

(c) Excavation to the top level of caisson for land piers.

Fig. 11. Construction of steel plate cofferdam.

A total of 825 pieces of M20×600 mm horizontal shear connectors and 204 pieces of M24×1000 mm of vertical shear connectors were installed and fixed in position [see Figs. 13 and 14].

Cross bracings between pairs of piers were replaced by HE-B 300 steel sections, all new and old steel members were sandblasted and painted. Cavities and gaps in pier old concrete were filled with approved slurry mix before connecting new members for strengthening, see Fig. 12.

Fig. 12. Pier strengthening drawing [5]

Fig. 13. Points for grout injections inside pier.

Fig. 14. Vertical and horizontal shear connectors.

Protection against collision of ships and boats system was constructed. Four rows of polyurethane rubber rings was fixed to the six piers in the navigation channel, as shown in Fig. 15.

Cathodic protection system against corrosion was reinstalled for all piers. The design of this system considered all protected surfaces as bare

because river will carry a lot of sand, rocks and natural debris which will damage coating by time. Solar panels is used to provide current for the system, as shown in Fig. 15. The anodes are buried in the central island in the Nile, as illustrated in Fig. 16. The design life time of the system is 20 years and should be inspected and maintained periodically. A central monitoring room was provided to inspect and evaluate the system.

Fig. 15. Erection of protection against ship and boat collision [7].

Fig. 16. Solar panels to provide electricity for Cathodic protection.

6. CONCLUSIONS

We can conclude that:

- (1) The rehabilitation of substructure can be accomplished without much disturbance of traffic, if suitable methodology is selected.
- (2) Inspection of bridges according to international standards plays important factor in discovering early deterioration of bridge elements, which give suitable decision to avoid progress of deterioration that may result in costly repair.
- (3) Sacrificial member thickness in original design is an important factor in the structures prone to corrosion and can help in protection of structures and increase its lifetime.

Fig. 17-a. Installation of Cathodic protection around swing span pier.

Fig. 17-b. Installation of Cathodic protection anodes.

Fig. 17. Installed of new cathodic protection system.

(4) Maintenance and lubrication of bearings and swinging devices must be carried periodically.

(5) Cathodic protection system, when installed must be inspected and maintained according to standards and reinstalled when it exceed its lifetime.

(6) Rehabilitation and upgrading of old bridges can help in increasing remaining lifetime and save a lot of time and money for the facility to continue being used.

(7) The lifetime of the bridge is increased to more than 50 years and load carrying capacity of the bridge is enhanced.

REFERENCES

- [1] PGM & SPAN, "Bridge Substructure Inspection Report (Piers and caissons Only) for The Old White Nile Bridge", November 2007.
- [2] Application of large diameter circular reinforced concrete filled tube (RCFT) shaft foundation for seismic design of railroad bridges. Eb rahim Amirhormozaki, Kelly Burnell and Nathan Johnson.
- [3] The Engineer Journal, "The Development of the Sudan", Pages 27 1-293, March, 19-1915.
- [4] Eltayeb Elrayah Khalafalla and Ali Hussein Bass (2018). Rehabilitation of a 109 – years old Blue Nile steel bridge. Second conference of civil engineering Dec 2018, Khartoum, Sudan.
- [5] Orion and span for consultancy (2008). White Nile bridge pier rea

bilitation project drawings.

[6] Orion and span for consultancy (2008).white Nile bridge pier rehabilitation project cathodic protection design.

[7] Span For consultancy Engineering, (2009). White Nile bridge pier rehabilitation project Completion report.

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