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Load Rating of Al Halfaia Bridge over the Nile

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ABSTRACT

This paper summarizes the results of applying load rating process that has been applied to Halfaya Bridge over the main Nile in Khartoum, Sudan. Load rating procedures have reviewed as per Manual of Bridge Evaluation of AASHTO Standards. Three levels of H/Y live loadings have been considered. AASHTO HL-93 is used for design load rating. For Legal load rating the Sudanese legal loads - as per Sudan National Highway Authority- are considered. Permit load rating process has been made using actual special heavy truck used in Sudan during the last 20 years .The rating process has been made on the assumption that the capacity of the main structural element of the bridge, which is Girder type II Composite Steel I-beams, had been decreased with different percentage from 10%up to 20%, due to different factors. Suitable software, CSi Bridge, has been used for calculations and the results are presented. The paper predicted the load rating factors for the composite steel I-beams of the bridge- moment and shear wise- for considerable capacity loss in future .The paper also checked the deflection of the composite I-Girder .Results showed that deflection is the governing factor when stiffness is lost by 8%, but still the moment capacity is the governing factor –design load rating –when the loss is 5%of the capacity. Suggested several recommendations to save such vital structure are given.

المستخلص

هذه الورقة تلخص نتائج اجراء عملية المعايرة الحملية التي أجريت على جسرالحلفايا الواقع على النيل الرئيس في الخرطوم بالسودان. عمليات المعايرة الحملية تمت مراجعة نظرياتها وفقا وفقا لدليل آشتو لتقييم الجسور، حيث تم الاخذ بثلاثة مستويات لمعايرة احمال المرور السريع الحية. تم استخدام حمل آشتو لمعايرة الحمل التصميمي، بينما تم استخدام الاحمال القانونية السودانية المقررة من الهيئة القومية للطرق والجسور السودانية لاجراء معايرة الحمل القانوني، ثم تم اجراء معايرة الاحمال التي تحتاج لتصريح باستخدام شاحنة حقيقية ثقيلة جدا تم استخدامها على الطرق السودانية خلال العشرين سنة الماضية. تم اجراء عمليات المعايرة بافتراض أن سعة العضو الانشائي الرئيس في الجسر- وهو العارضة الفولاذية المركبةعلى شكل I قد فقدت بنسب تتفاوت من (10 -20) % لاسباب مختلفة. تم استخدام برمجية مناسبة لحسابات المعايرة، وتم عرض النتائج. الورقة تنبأت بمعاملات المعايرة الحملية لعارضة الجسر الفولاذية المركبة لكلا العزوم والقص وفقا لفقد معتبر في السعة مستقبلا، و الورقة ايضا اختبرت الهبوط في العارضة الفولاذية المركبة. أظهرت النتائج ان الهبوط يصبح العامل الحاكم عند فقدان الجساءة بمقدار8% ، بينما تظل سعة العزوم هي العامل الحاكم بمعايرة الحمل التصميمي لنسبة فقد في السعة مقدارها 5 % . تم اقتراح عدة توصيات للحفاظ على هذا الصرح المهم.

Keywords: bridge load rating; Al- Halfaia Bridge; AASHTO-LRFD

1. Introduction

The safe live load carrying capacity of a highway structure is called its load rating. It is usually expressed as a (rating) Factor (RF) of a defined vehicle or as a gross tonnage for a defined vehicle axle configuration.

2. Rating Procedures

According to AASHTO MBE -2011 [1], load rating is performed either to design loads (inventory or operating), legal loads or permit load.

2.1 General load rating equation

$$RF=[C-(\gamma_{DC})\,DC-(\gamma_{DW})\,DW-(\gamma_P)P]\,/\,[(\gamma_{LL})\,(LL+IM)] \quad (1)$$

For the Strength limit state:

$$C = \varnothing_C \varnothing_S \varnothing\, R_n \quad (2)$$

$$\varnothing_C \varnothing_S \geq 0.85 \quad (3)$$

For the service limit state:

$$C = F_R \tag{4}$$

where:

RF = rating factor ,

C = capacity

F_R *= Allowable stress specified in the LRFD code*

Rn = Nominal member resistance

DC = dead load effect due to structural components and attachments

DW = Dead load effect due to wearing surface and utilities

P = Permanent loads other than dead loads

LL = Live load effect

IM = Dynamic load allowance

Y_{DC} *= LRFD load factor for structural components and attachments*

Y_{DW} *= LRFD load factor for wearing surfaces and utilities*

Y_p *= LRFD load factor for permanent loads other than dead loads*

Y_{LL} = Evaluation live load factor,

$ø_c$ *= Condition factor*

$ø_s$ *= System factor*

ø = LRFD resistance *factor.*

Components subjected to combined load effects should be load rated considering the interaction of load effects (i.e. axial –bending interaction or shear-bending interaction) as provided in the Manual.

2.2 Design Load Rating

B. Design Load Rating: The design load rating assesses the performance of existing bridges utilizing the LRFD-design loading (HL-93) and design Standards [2]. The design-load rating of bridges may be performed at the same design level (Inventory level) reliability adopted for new bridges by the AASHTO LRFD Bridge Design Specifications or at a second lower-level reliability comparable to the Operating level reliability inherent in past load-rating practice [1]. As per AASHTO MBE-2011 [1], live load factor is taken as 1.75 for inventory level, while it is taken as 1.35 for operation level.

2.3 Legal Load Rating

If there is no sufficient live load capacity for a bridge under the design-load rating, then such a bridge shall be load rated for legal loads to establish the need for load posting or strengthening. This second level rating provides the safe load capacity of a bridge for the Sudanese legal loads [3], [4]. Figure (1) here after presents them [11].

Strength is the primary limit state for legal load rating. Live load factors were selected based on the ADTT at the bridge as shown in Table (6a.4.4.2.3a-10) of the MBE [1]. For Halfaya Bridge load factor is 1.8.

2.4 Permit Load Rating

Permit load rating checks the safety of bridges in the review of permit applications for the passage of vehicles above the legally established weight limitations. This is a third level rating that should be applied only to bridges having sufficient capacity for legal loads. Figure (2) below presents the configurations of the most common permit trucks in Sudan [5], [6], which were used during last 20 years.

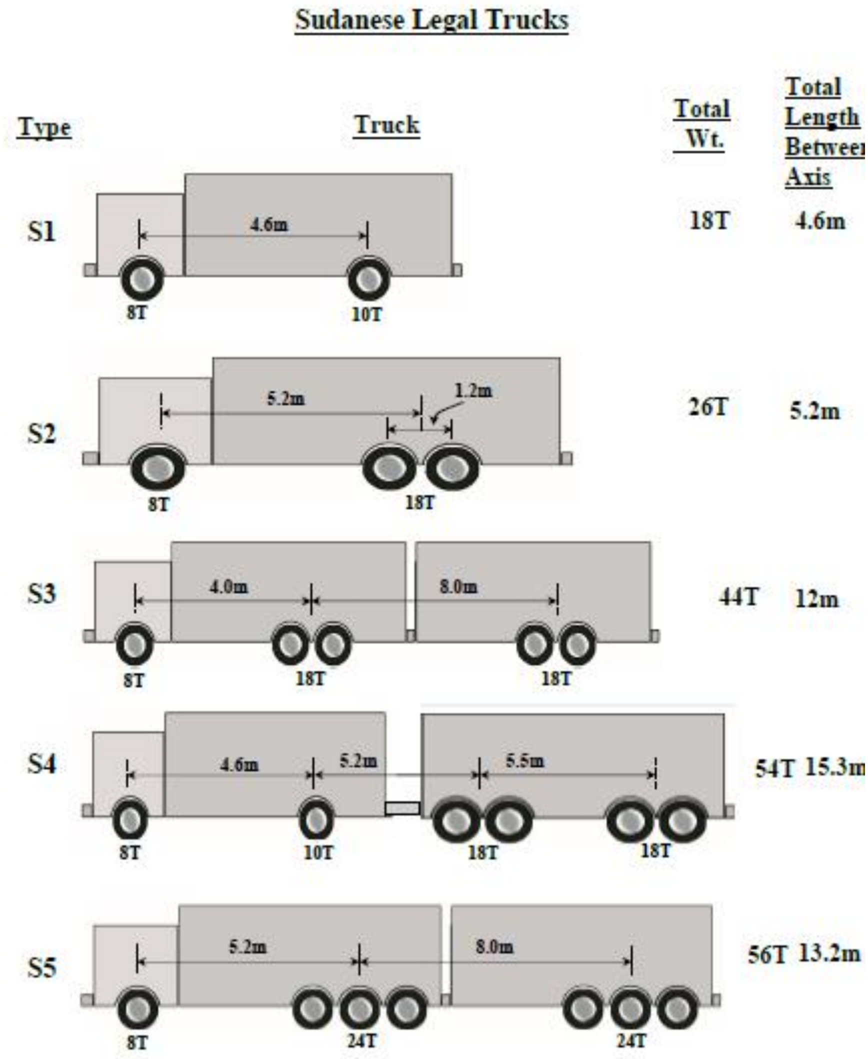


Figure 1: Sudan Legal Trucks [11]

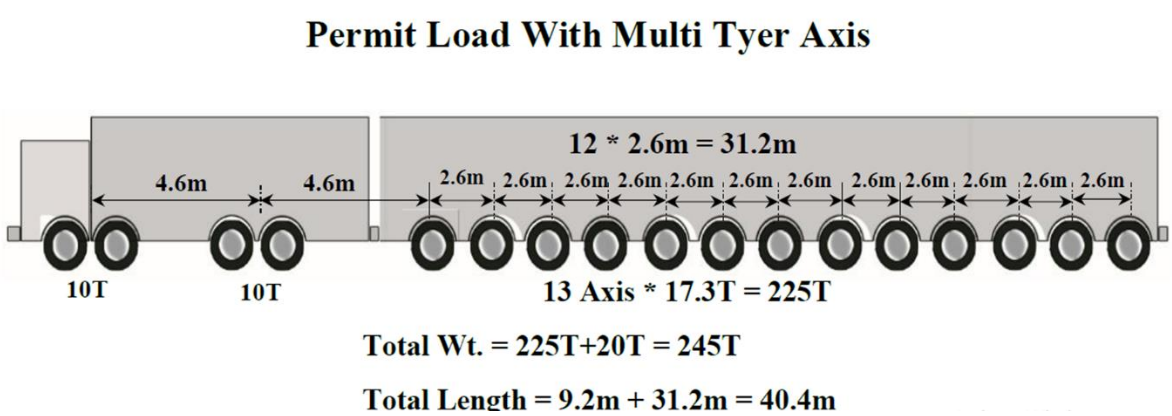


Figure 2: Sudan Permit load Truck [11]

3. Al Halfaia Bridge

Constructed over the Nile between Omdurman and Khartoum North at 2010, with the following characteristics:

3.1 Outlines and Features [7], [8]

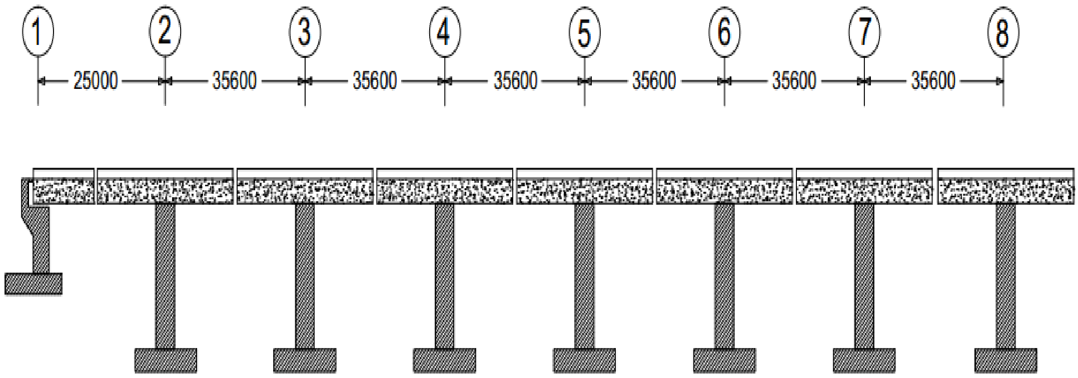
Total Length = 910 m
Width = 27 m (identical double deck, 4 lanes (10.8m) /direction)
Median strip width = 0.7 m
Sidewalks = 2.0 m wide
Longitudinal slope = 0.25%
No. of spans = 4

3.2 Structural Forms of Super-structure [8]:

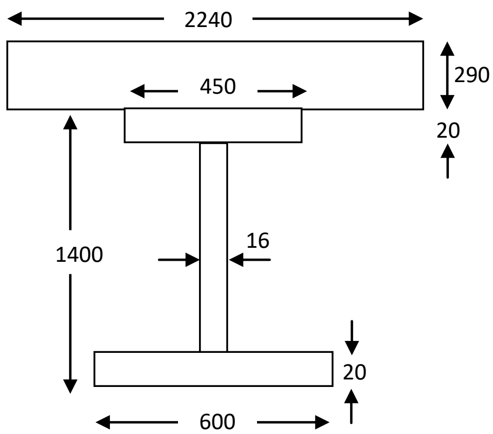
The structural system of the Al Halfaia Bridge consists of the two bridge types, over 25 spans. Three semi-integral composite steel bridges were arranged between the Axes 1-23 and a continuous composite steel bridge at the navigation channel between axes 23-26 was utilized. Four partial bridges with lengths of: 238.6+ 284.8+239.2+147.4m was used to span the Nile in Haffaia Bridge, see Appendices (A) and (B).

1) Bridge 1,2 and 3 (semi-integral Bridges):

The structural system between axes 1-23 in longitudinal direction is a continuous beam along 7 spans (25m+6x35.6m) for Bridge1 and Bridge 3, and continuous beam along 8 spans (8x35.6m) for Bridge 2 where the superstructure is integrated the inner piers.The superstructure is made of 140cm steel I-girder with60cm width of bottom flange and reinforced concrete deck slab with a total thickness of 29 cm. The distance between the steel girders was chosen according to the use of trapezoidal steel sheet as formwork element for deck slab, and fixed at 2.24m distance. See Fig. (3).



(a) Beam Elevation, Bridge 1 (dim. in cm)



(a) X-Section (dim. in mm)

Figure 3: Bridge 1 of Alhafaya Bridge

2) Bridge 4 (continuous Composite steel box Girder)

For the structural system of the 147.4m long bridge, Bridge 4, is composed of a continuous steel composite beam system with three spans (42m+64m+41.4m).

The cross section consists of two box girders with a 150 cm width and 180cm height mound at 9.8 m and a reinforced concrete deck with a total thickness of 29cm.

3.3 Analysis Model:

The sectional elevations of the bridge (1) and x-section of the composite steel I-Girder is shown in Figure (3). Structural analysis are performed using CSi bridge software [9].

3.4 Rating Assumptions of AL-Hahlfaia Bridge

1) The composite steel I-section beam (named as girder type II in the design drawings) in the bridge is the major and critical part of the Whole Bridge.
2) Both moment and shear capacity to live load is the governing factor of the bridge rating,
3) Losses in capacity can occur due to different reasons.

3.5 Strength limit States [10]:

1) Moment Resistance

The moment resistance capacity of composite section depends upon where the plastic and compact neutral axis falls within the section.

For continuous spans with compact positive bending sections and non-compact interior negative moment sections the nominal positive flexure resistance is limited to as in Ref [2] section (A6.10.7.2) :

$$M_r = 1.3 R_n M_y \tag{5}$$

Where:

R_n: is the hybrid flange stress reduction factor as in ref. [2] section (A6.10.1.10).

M_y: yield moment

$$M_y = f_y \, S_{NC} \tag{6}$$

Where:

S_{NC}: section modulus for long term composite section

The calculated capacities are shown in the Table below:

Table 1: Results of Girder's Moment Capacity

Components	Moment capacity (kN.m)
For top	17743.638
For bottom	12352.872

2) Shear Resistance:

Shear resistance of composite beam is similar to that steel pure beam

$$V_n = 0.58CF_YDt_W \quad (7)$$

Where:

D: total depth of web,

t_w: thickness of web

The calculated capacity of shear in web = 4569.6 kN

3.6 Composite section properties:

The moment of inertia of the composite I-steel Girder for a long –term using AASHTO-LRFD[11] is found to be:

$$I_{composite} = 26.7x10^9 \ mm^4$$

3.7 Rating Factors Results:

1) Girder Dead and live Load Moments Calculations:

The girder moments due to dead loads and different live loads levels are calculated using CSi Bridge software [9]. Live loads moments are calculated due to HL93- AASHTO-LRFD, Sudan Legal loads and Sudan Permit Load. The following Tables present the results. Table (2) shows the Results of Max. Moments Due to dead loads, different Live loads levels as calculated using CSi Bridge software along Bridge (1).

Table 2: Results of max. bending moments along Bridge (1)

Layout distance (m)	DC (kN.m)	DW (kN.m)	L.L + IM (kN.m)	Legal load, kN.m	Permit load (kN.m)
0	0	0	0	0	0
25	2381.38	2976.72	2102.01	1155.44	1561.00
60.6	3568.68	4461.08	3767.94	1148.11	1565.22
96.2	2092.94	2626.06	3290.79	1154.25	1567.55
131.8	2458.94	3073.68	3309.47	1153.10	1565.13
167.4	2378.62	2973.28	3308.58	1153.10	1585.14
203	2404.47	3005.09	3309.46	1153.25	1565.53

2) Rating Factors Calculation Results:

The rating factors of the composite steel I-beam girder for both moment (RF_m) and shear (RF_s) have been calculated using the rating equation given above. The results of RF with respect to each live load are shown in graphical form in the following Figures 4 to 7.

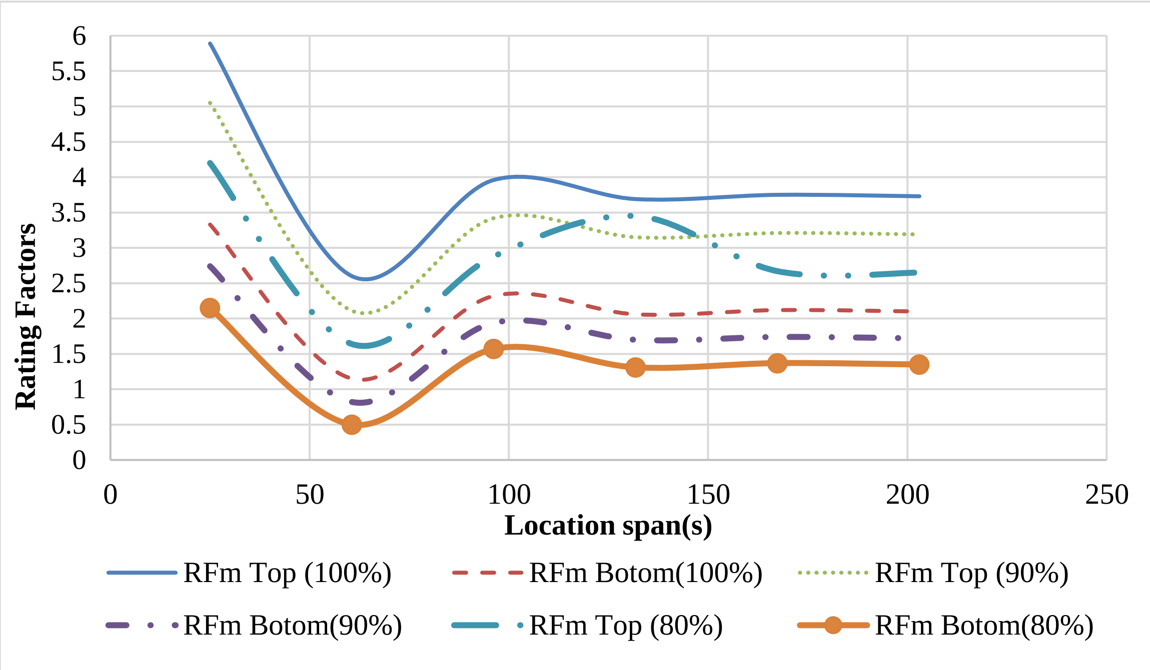


Figure 4: RF Variation due to decreasing capacity with respect to AASHTO HL 93 LRFD, Design Rating (Moments)

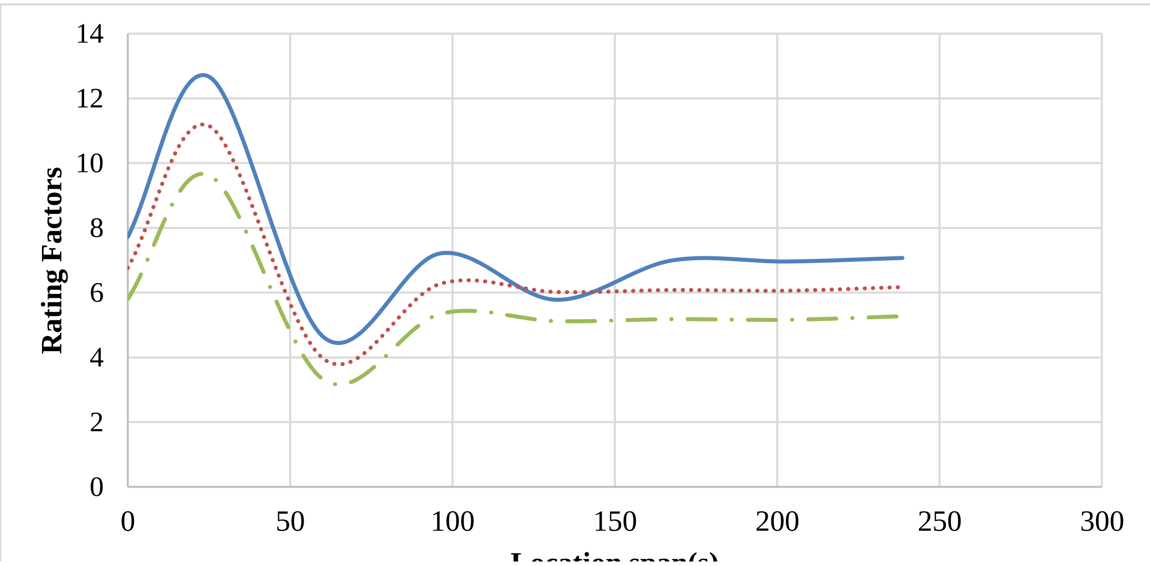


Figure 5: RF Variation due to decreasing capacity with respect to AASHTO HL 93- LRFD, Design Rating (shear)

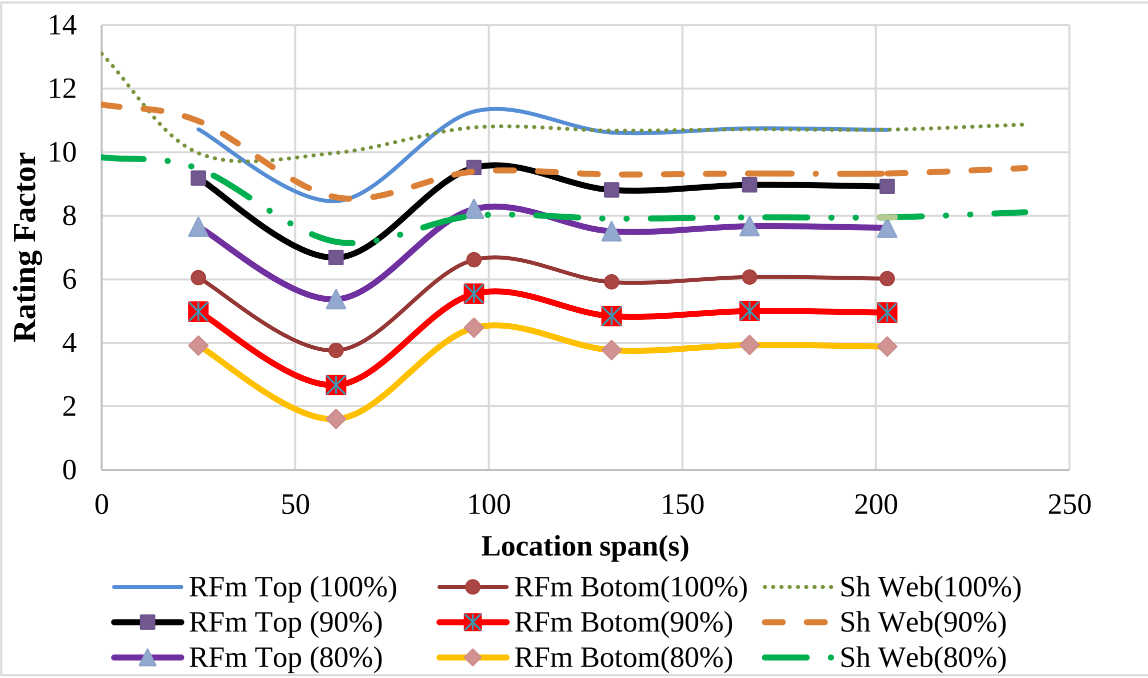


Figure 6: Variation due to decreasing capacity with respect to legal Truck type S5

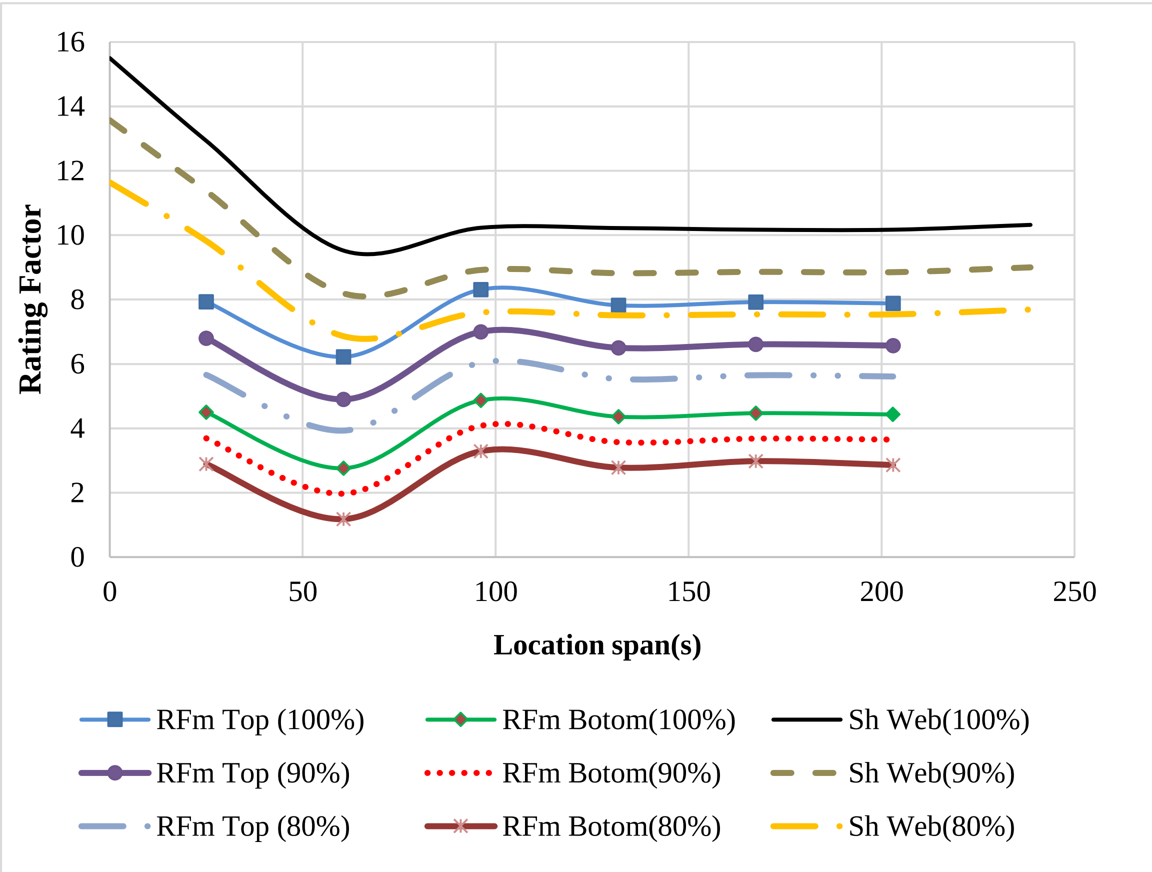


Figure 7: RF Variation due to decreasing capacity with respect to Sudan Permit Truck

3.8 Deflection

In order to calculate the deflection of a composite beam designed for full composite action, transformed moment of inertia is found by transforming the concrete slab into an equivalent steel section .The allowable maximum deflection (L/800), in a 35.6m span is equal to 45mm.Table (3) shows how loss in stiffness can affect calculated deflection of bridge (1) according to AASHTO Service limit states.

Table 3: Calculated max. deflection in Bridge (1) due to loss in EI

EI	Calculated max. deflection (mm)
100%	41.0
95%	43.1
90%	45.6
85%	48.2

4. Conclusions and Recommendations

The conclusions can be drawn from this study as follows:

1) the section of bridge (1) is critical for moment due to design load rating at a distance 60.6m from Omdurman side if the capacity is loosed by 5%; this can be calculated by interpolation for rating factor between 0 and 10%
2) Bridge (1) is safe for considered capacities for both moment and shear due to legal loads and permit loads.
3) Deflection check showed that at the second span from Omdurman, the allowable deflection is reached at 8% loss of moment inertia.
4) Cleary moment capacity is the governing factor (design rating).

It highly advisable to account for the following recommendation to insure the bridge safety and durability:

1) Periodical check should be done for the bridge to safeguard against section loss due to any case.
2) Other service limit states should be checked like vibrations in the semi integral bridges, and fatigue limit state should be checked for welds in in the main elements.

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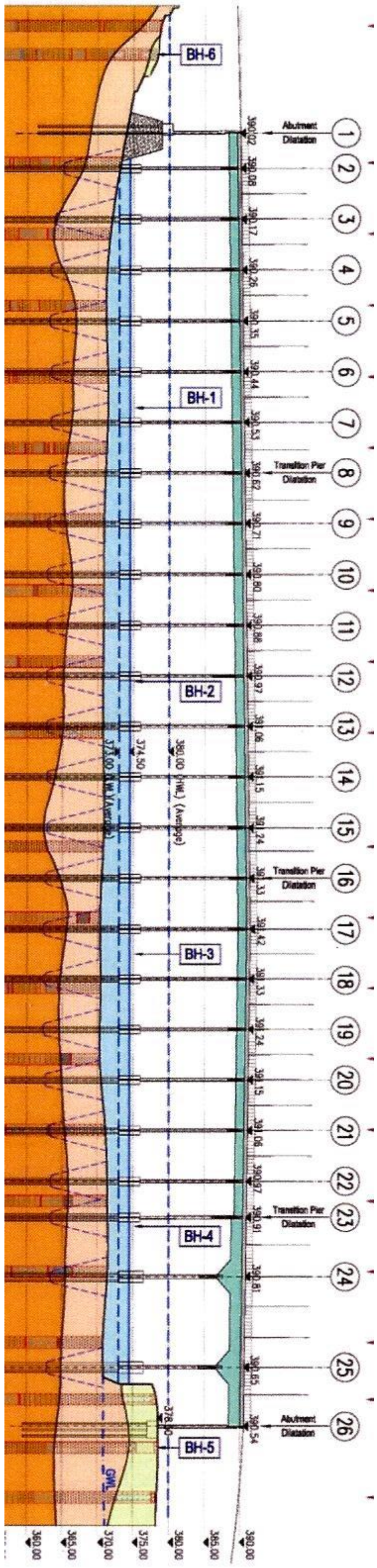
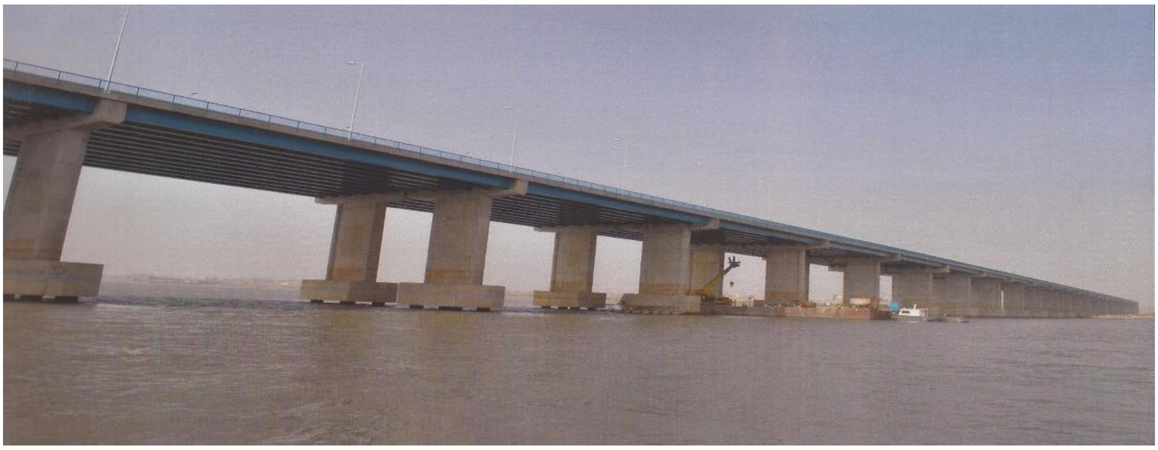
Appendix (A): Longitudinal Section of Halfaya Bridge along the 25 spans from Omdurman to Khartoum North:



Appendix (B): Hlafaya Bridge Photos

The completed Main Span of the Navigation Channel (Feb. 2010)



View from the Completed Bridge (Feb. 2010)

Completed Bridge Overlook from Omdurman to Halfaya