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STRUCTURAL ASSESMENT OF EXISTING SUSPENSION BRIDGE BETWEEN CAMEROON AND NIGERIA

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SUMMARY

Our firm performed an inspection and analysis of an existing suspension bridge crossing the 'Cross River' between Cameroon and Nigeria. The bridge was designed in the 1940s by a British company and was completed in the early 1950s. Once the original drawings were located in an archive in the U.K. a team was established to examine the existing bridge. The bridge was surveyed and all information collected in the field and archives was processed in the office for a detailed review report including the status of all the elements including ranking and identifying major defects. A full model of the bridge was computerized based on the findings and calculated for both the original and up to date loads in order to examine the capacity of the bridge members and the global stability. From the information collected and calculated, the recommendation was to preserve the bridge as a unique element in Nigeria's heritage.

Keywords: *Historical structure, Suspension bridge, Load rating, Structural assessment.*

1. INTRODUCTION

The consulting services for the Existing Bridge Assessment among the design of a two-lane bridge over the Cross River at the Cameroon-Nigeria Border (Ekok/Mfum) with approach roads was part of the consultancy services required for the implementation of the Program for Transport Facilitation along the Bamenda (Cameroon) – Enugu (Nigeria) Road Corridor. The Border Bridge at Ekok/Mfum is jointly owned by the Government of Republic Cameroon and Federal Republic of Nigeria. The procurement of the bridge project is the responsibility of Joint Technical Committee (JTC) comprising the Project Implementation Units in Nigeria and Cameroon, ECOWAS Commission, ECCAS Secretariat and CEMAC. The purpose of this research is to deliver an assessment of the existing 1950's suspension bridge at the Nigerian-Cameroon border and provide recommendation about its rehabilitation or dismantlement.

This research contains information such as methodology for the investigation, bridge age, location, type of structure, ground investigation plan, schedule, scope of work and assessment possess stages was generated in addition to a report of the existing bridge assessment including the Bridge geometric data, Results of the Bridge Investigation and Assessment of the bridge, Comments and analysis of the results, and Recommendation for rehabilitation or dismantling of the bridge including a Bill of quantities for corrective measures on the bridge.

Fig. 1. *Existing Cross River Bridge*

2. DATA COLLECTION

During the preliminary visit to the bridge important tasks were accomplished by the consultant team including Meeting local government officials, community leaders and chiefs, Collecting initial records of the existing bridge by a preliminary tour across the bridge and underneath it, Obtaining photographic records of the existing bridge elements, Gathering information from local government officials, community leaders and chiefs, and Cross River State Government agencies concerning the bridge assessment and current use and Establishing the necessary data for optimal preparation of the site for the Full Bridge inspection and defining the equipment that will be needed. In order to assess the bridge current condition, it was highly important to locate any information concerning the bridge design and construction. Since the basic information that was in the hands of the consultant team is that the bridge was constructed during the early 50' by a British company. Using this information, the research began. It included contacting archives in order to locate data concerning the bridge. From researching the National Archives of the United Kingdom (London, UK) a photograph taken during the bridge construction was found:

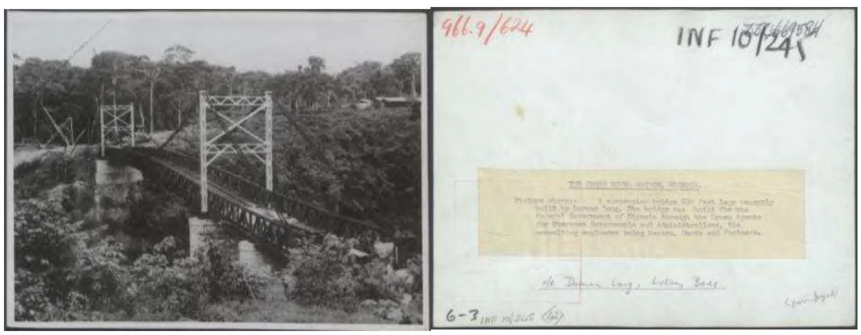


***Fig. 2.** Cross River Bridge during construction (Back and front of picture)*

From the photograph description we assured the contractor firm of the bridge as "Dorman Long". From researching the Teesside Archives (Middleborough, UK) four original drawings of the bridge, dated 1947 & 1953, were found. The gathered information was of high significance for the team to investigate the bridge complex structure, its conditions and capacities.

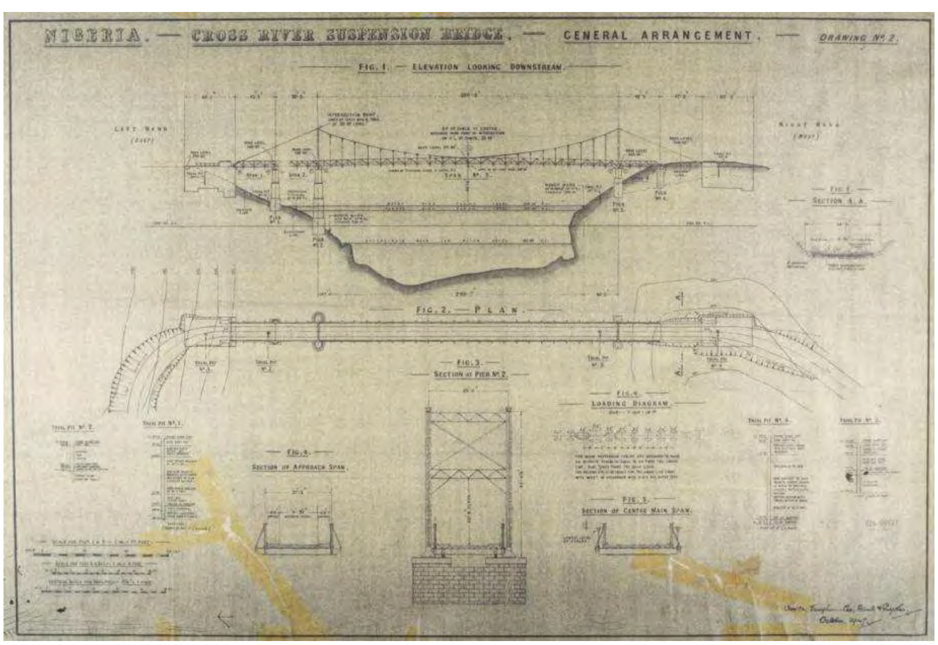


***Fig. 2.** Original drawing of general arrangement*

3. EXISTING BRIDGE DESCRIPTION

The existing Cross River Bridge is a suspension bridge over the Cross River at the Cameroon-Nigeria Border. The bridge is located at the South West Region of Cameroon and Cross River State of Nigeria. On the west bank of the river (Nigeria) lays the community of Mfum including various government offices and a cross the river, on the east bank (Cameroon) lays the village of Ekok.

3.1. HISTORY

The Bridge was designed during the late 1940'. The design drawing located indicates the year 1947. The bridge was constructed during 1950's by a British contractor named 'Dorman Long'. On the original drawing 'Concreting Arrangement', dated 1953, the location of all the contractor site arrangement can be seen including the site offices, worker accommodations, excavations etc. According to the drawing 'Original Location and Site Plan' the project included, besides the suspension bridge, an additional smaller bridge across a local stream located north east of the existing bridge.

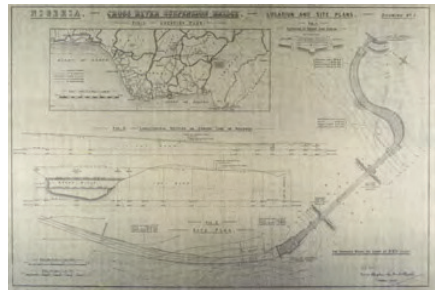


Fig. 3. *Original Location and Site Plan*

A suspension Bridge combined with stiffening girders was an excellent engineering solution for spans as long as 100 meters and more at the years 40'-50' of the 20th century. This bridge represents fine engineering combined with high construction capabilities mainly when examining the complexity of the structure and the challenging site conditions.

3.2. BRIDGE CURRENT STATUS

Fig. 4. *View on the bridge from the tower and from the river*

The existing Cross River Bridge is, in the international aspect, a significant linking point between Cameroon and Nigeria aspect, and in the local aspect an important connection between the villages of Mfum and Ekok located on both sides of the river.The Bridge is in daily use for crossing transportation in both directions. The transportation is often in two parallel lanes using the sidewalks as traffic lanes. Due to the location of the immigration and customs stations at both sides of the bridge the transportation stops and parks on the bridge before crossing the border stations. The transportation using the bridge are heavy and light trucks transferring goods and agricultural products, private vehicles, motorcycles and pedestrians. Crossing of the river using boats is rare at this point. The boats located at the bridge site are used mainly for fishing but also for transferring goods and passengers along the river. The existing bridge is a vital route of transportation for both countries on one hand and for the local community on the other hands and enables trade between both sides in both aspects. The local communities, from the two sides of the river, have trade relationship and family relations which are possible due to the existence of the bridge. During the consultant team visits to the bridge a few tourists were seen at the bridge site. This does not seem to be a common sight but it can indicate of a future potential. This issue was not further examined. From conversations with local community leaders and chiefs the consultant team got the impression that the Cross River existing bridge is a source of pride for the area and that the people feel connected to the bridge. From the Engineering aspect, the existing bridge is a magnificent structure representing the most complex design and details of the bridge developing period. It is needless to say that the structure is an Impressive structure by itself and its impact is magnified due to the natural surroundings. From both the local population and the consultant team point of view, the bridge is a local Icon, symbol of an era in the continent and the achievements of humanity in the infrastructure field.

4. BRIDGE GEOMETRY

4.1. GENERAL

This type of bridge has cables suspended between towers, plus vertical rods that carry the weight of the deck below, upon which traffic crosses. The suspension cables are anchored at each end of the bridge, since any load applied to the bridge is transformed into a tension in these main cables. The main cables continue beyond the pillars to deck-level supports, and further continue to connections with anchors in the ground. The roadway is supported by vertical rods, called hangers. The bridge will has outer smaller spans, running between pillars and the highway, which is supported by a truss bridge to make this connection. The Cross River Bridge has a total length of 151.0 meters and consists of four spans where the main span is of 106.0 meter and the length of the outer spans varies between 14.0-15.2 meters. For this report the spans were given numbers from west to east and the bridge axes were given letters from west to east.

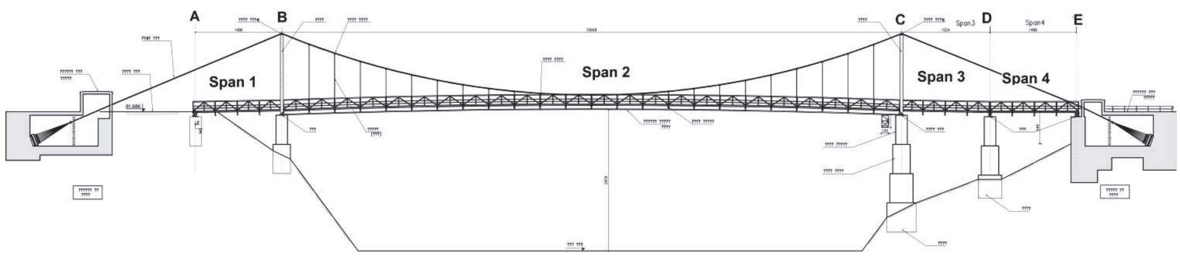


Fig. 5. General arrangement

4.2. SUSPENSION SYSTEM

The Main span is suspended by two sets of two cables anchored in underground chambers located behind the abutments. The suspension cables are supported at their peak points by steel saddles on top of two main steel pylons. The slab of the main deck is connected to the cables by steel rods.The Main Cables are supporting the main span by hanging of transverse beam, cross through top of pylon and anchored to Cable Anchors block (Two cables in each side). On each side of the bridge there are two cables with a distance of 304 mm between their centers. Each cable is compounded from seven strands. The diameter of each strand is 45 mm.

Fig. 6. *Cables saddle (left) bottom Underground cable anchor (right)*

The Rod suspenders are supporting the main transverse beams and connect them to the main cables. The rods are set symmetrically on both sides of the transverse cross section of the main span. One rod is connected by a joint to two cables on the top and connected to a suspender connection detail on the bottom. The rod is made of a full steel cross section with a diameter of 45 mm. The Pylons are steel truss towers located at axes B and C. The Pylons transfer Vertical force to the pier column, and they are joint supported at the bottom. On top of the pylon there are the cable saddles. The height of the pylons 13.26 meters and their width is 7.94 meters. The tower columns are steel plate girders and the transverse and diagonal components are steel profile trusses. The main cables of the bridge are anchored on each side in anchorage chambers located at the back of the abutment. The chambers are concrete cast and act as counter weight in addition to them being casted against solid rock. The width of the element is 10.4 meters and its length is 18.3 meters. The total height is approximately 5.5 meters. The cables are entering the chamber from above the ground into a large void reachable thru a manhole and ladder. Inside the cables are connected to an anchoring system which also enables the tuning of the cable tension.

4.3. SUPERSTRUCTURE

The suspended Main span and the side spans are not continuous in the longitudinal direction and between them there is an expansion joint. All spans have the same elements but they serve different purposes. The trusses are connected on both sides of the superstructure along the whole bridge. The trusses are not continuous from span to span. The truss function at the main span is to prevent lateral buckling in the Bridge and stiffen the flexible suspended system. In the main span the truss is a secondary element. In the side spans the trusses are the main elements as they serve as the main span construction. At all spans the trusses act also as parapets to prevent car from falling off the bridge and it has also a pedestrian railing. The trusses are 2.35 meter high and are made of bold connected steel profiles and they are transverse held with diagonals to the transverse beams. The bridge deck is 6.5 meters wide and it is supported on transverse beams connected to the main trusses in the side spans and to the steel rods in the main span. The Transverse beam therefore a main element in the suspended span and a secondary element in the side spans. The deck has a composite cross section of concrete casted on steel profiles. The slab cross section consists of one traffic lane and two sidewalks. Along the slab there are water drainages. Between the spans there are steel expansion joints. All spans are supported by steel bearings between the end transverse beam ant the piers. The Bearings are connected with bolts to columns. The bearing longitudinal release is critical for the proper behaviour of the bridge mainly to withstand the effect of temperature on the bridge and participate in the flexibility of the structure. The bearings of the main span are sliding in the longitudinal direction with steel stoppers and the enable rotation. The bearings at the external spans (1,3,4) are sliding pins. They are sliding only in the longitudinal direction.

Fig. 7. Pylon bottom joint connection (left) Column at axis C (right)

4.4. SUB STRUCTURE AND FOUNDATIONS

The columns of the bridge are concrete casted in forms with brick pattern. The columns are casted in steps with dimensions narrowing towards the top of the column. The columns at axis B and C support both the spans from both sides and the pylon towers and the column at axis D supports the spans from both sides. The abutments are located at the bridge edges on axis A and E. they are supporting the end spans. At axis A the abutment is a standalone element and it supports the ground behind it. At axis E the abutment is part of the anchorage chamber. The original drawing show the soil logs for four trial pits. At the area there is solid sandstone rock. The depth of the rock is marked in the drawing and is clearly seen on site. The foundations are shallow concrete foundations casted against and inside solid rock.

5. LOAD COMPARISON

At this chapter, the loads used for calculating the structure during the original design are compared to the loads of the current codes used for bridge design and the actual loads acting on the bridge. According to the year mentioned on the drawings and additional data from the drawings, the bridge was designed according to the British Standard 'BS 153: 1933'. The loads were compared to those of the British Standard 'BS 5400:2006 Part 2'. The comparison concerned only the live loads since all the Permanent loads remained unchanged. According to the 'ICE Manual of Bridge Engineering', Institution of Civil Engineering (2008) there is a constant increase in the heavy vehicle loads (graph attached). The Variation is highlighted in the shown graph

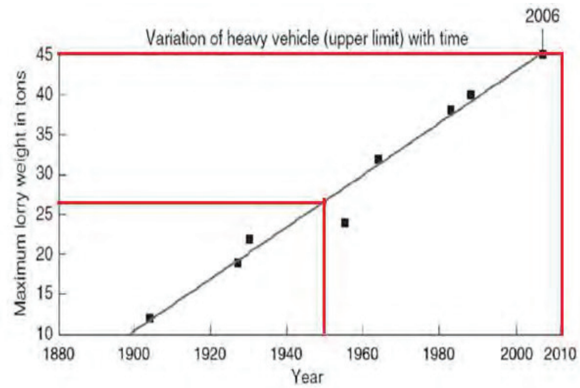


Fig. 8. *Variation of heavy vehicle with time*

According to this graph, the maximal truck load at the years of the bridge design and construction (1950') was approximately 26 tons. The maximal truck load representing the current time (2010') is approximately 45 tons. This represents a load increase of more than 70%. The live loads of the original design refer to the British standard 'BS153:1933'. The drawings of the bridge indicate the type of load used for the design including a load diagram and explanation. This represents a historical vehicle including a pulling lorry and carts.

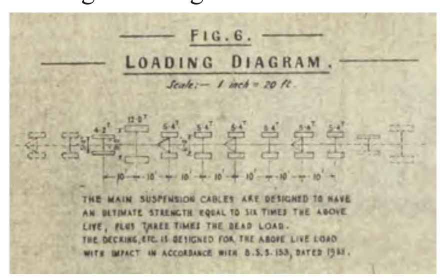


Fig. 8. *A picture of the historical vehicle* ***Fig. 9.*** *Loading Diagram from the original drawing*

The Current design code refers to the British Standard 'BS5400:2006 Part 2'. This code divides the live loads on the bridge deck into: HA, KEL, HB. These loads were specified and calculated. The final comparison sums the data of both original designed load and the updated code loads for both main span and external spans.

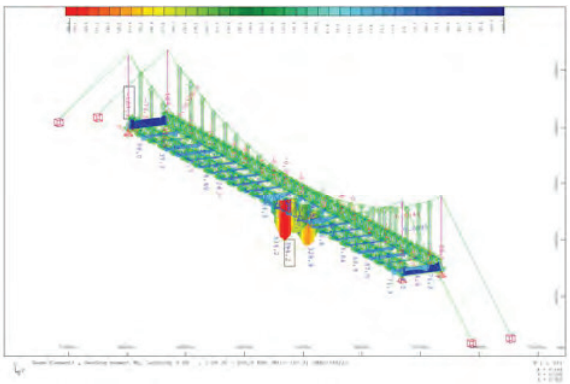
According to load comparison it can be seen there is a 70%-80% increase in Live Loads. This fact was taken into account in the calculation of the main element capacities. This is also referred to at the conclusions and recommendations concerning the adequacy of the existing bridge to the current loads.

6. BRIDGE ANALYSIS AND ELEMENTS CAPACITY CHECK

The capacities of main elements of the bridge were calculated and compared with the forces acting on the elements due to original loads and current code loads. All capacity checks refer to the bridge in perfect condition, without defects. Concerning the Bridge inspection (see next chapter) this is obviously not the current bridge status. The main Elements analyzed in the mid span are the transverse beam and the rod hanger. As indicated in the drawings, the cables are calculated to a load much higher than the rest of the elements and therefore the transverse beams and rod are the weakest link for this span. The main elements analyzed at the external spans are the trusses. These support the whole span and therefore the trusses steel profiles are calculated and examined. The calculations were performed using finite elements software 'Sofistik'.

Fig. 9. *FEM Model visualization (SOFiSTiK)*

According to the capacity check we found that the beam withstands the original live load. In addition, the capacity of the transverse beam can cover the forces from a HA loading on one traffic lane or a HB load up to 80 tons as a single load on the bridge. The above section refers to a perfect condition bridge, which is nut the current status. The Trusses are described in the geometry chapter. The Truss is the main support for the deck slab and is supported on sliding bearings on both sides.



The Span was modeled as fully modeled using Sofistik final element software. The representing span analysed is span 1. Material type (According to "Historical Structural Steelwork Handbook" Compiled and Written W.Bates). According to the capacity check we concluded that the truss elements withstand the original live load. In addition, the capacity of the truss elements can cover the forces from a HA loading on one traffic lane or a HB load up to 80 tons as a single load on the bridge. The above section refers to a perfect condition bridge, which is nut the current status.

Fig. 9. *FEM Model results*

7. BRIDGE INSPECTION

7.1. General

The inspection of the Cross River existing bridge was performed as a part of the assessment of the existing bridge. A five day long Field detailed inspection took place at the Cross River Bridge site between the 11th and 18th of April 2014. During the inspection, varieties of defects were checked and documented. The inspection procedure included a visual non-destructive inspection and examination of the various elements. The bridge element condition was rated using different importance levels (from Low to Very High). This was performed and guided according to the procedures described in the next chapter. For the inspection of the bridge local workers were hired. In addition the team used the service of army security.

Fig. 10. *Inspecting Trusses*

7.2. Summary and Inspection Conclusion

a. Value of Condition PI Av = 58 and Condition PI Crit = 0. According to methodology noted in paragraph 3.3.4.6., the structure can be analyzed as a structure **which has retained 58% of its service potential and is in a "very bad" condition** and must be taken with conclusion and safety factors deriving from elements capacity. There are several damages and failure of several elements which are rated with a very high importance (Bearings, Trusses, Deck Slab and Transverse Beams). In addition, **the structure lost 58% of its capacity to function as planned.**

From this relationship it can be clearly seen that, because the rate of deterioration increases as the SCS increases, the work and expenditure involved in improving the condition of a structure required improving the condition of the same structure from grade 4-5 to 3 and even 2.

b. The cables are found in in a good condition (very high importance), no severe defect (listed in chapter 4.15) were observed except the corrosion activities on cable surfaces caused by 50 % of coating missing through in length of the elements.

c. All the span bearings are in bad condition mainly due to corrosion, and they are not functioning concerning the designed static scheme. This can result in additional loads to the columns and slab.

d. The main trusses at span 1 are not functioning due to reduction of cross section of up to 100%. This leads to a capacity reduction of the span.

e. During the visual inspection of abutment blocks (were casted against bedrock) and closest to abutment areas, No Damages such as: scours soil, bedrock cracks, visible sliding and abutment rotations, settlement of substructure were found. Those findings are indicating on ground stability in current site during last 60 years.

f. Applying steel and concrete sampling is highly recommended in order to observe the material mechanical and chemical properties. These tests were not allowed in this project.
g. The main cause for the bridge structural condition is the lack of maintenance.
h. An immediate Rehabilitation procedure is highly recommended to be applied on bridge elements for guaranteeing of increasing an element's condition rates and the life cycle of the bridge.
i.

8. CONCLUSIONS

The existing bridges was examined, calculated, tested and assessed as specified in this paper. Along the report conclusions concerning the bridge status, structural condition, capacities and loads are given. This chapter summarizes the conclusions as a base for the consultant team recommendations. Across the river, along the existing bridge, a new bridge will be constructed. The research in this report should indicate the options concerning the existing bridge after the new bridge is constructed. The existing Cross River Bridge is a magnificent structure representing the most complex design and details of the bridge developing period. In addition, from both the local population and the consultant team point of view, the bridge is a local Icon, symbol of the era of the colonialism in the continent. This leads to the will of both the local communities and the consultant team to preserve the existing bridge rather than dismantling it. From conversations with local community leaders and chiefs the consultant team got the impression that the Cross River existing bridge is a source of pride for the area and that the people feel connected to the bridge. Across the world, Governments and Organizations are restoring unique structure as part of the history and heritage for the future generations to come. This Global phenomenon must be considered. From the environmental aspects, the impact of the existing bridge was utilized during its construction. Since the bridge construction the nature is restored and the bridge is an integral part of its surroundings. Dismantling of the bridge will require the accesses of heavy load equipment to the river bank and bridge including vast forest clearing and even the use of explosives. These tasks have a severe impact on the environment including vegetation, and animals. After the construction of the new bridge, the existing bridge will still serve the two villages located on both sides of the bridge. In addition, keeping the existing bridge will provide redundancy to the transportation between the two countries since, in case of a problem in the new bridge, the existing bridge could be temporary used (for example, in the case of a car accident on the new bridge, rescue teams and ambulance can use the existing bridge for arriving to the site) this is relevant only under the condition specified later on. According to load comparison it can be seen there is a 70%-80% increase in Live Loads comparing the loads from the original design and the loads from the current relevant codes. Since the typical loads these days are also higher than those of the construction period, the weight of transportation crossing the bridge should be limited. Note: The capacity check refers to a Bridge in perfect condition, this is not the current status. According to the capacity check we can see that the bridge elements withstand the original live load. In addition, the capacity of the truss elements can cover the forces from a HA loading on one traffic lane or a HB load up to 80 tons as a single load on the bridge. After a full rehabilitation of the bridge the bridge could carry the following loads: Pedestrian and motorcycles with no limit, One traffic lane of vehicles (in one direction only)., One single truck of up to 80 tons with no other vehicles on the bridge. The main cause for the bridge structural condition is the lack of maintenance. The bridge at the current status suffers from serious capacity reduction. the structure lost 58% of its capacity to function as planned. In order to maintain the bridge in a functional and safe state it should be rehabilitated.

9. RECOMMENDATIONS

From combining all data and conclusions, the consultant team recommends the following: The Existing Bridge should not be dismantled for the reasons of Environmental impact, transportation redundancy, Importance of Heritage. The Bridge should be fully rehabilitated as soon as possible In order to maintain the bridge in a functional and safe state. After the opening of the new bridge and rehabilitation of the existing bridge the transportation allowed on a daily basis should include pedestrians and motorcycles only. The crossing of cars and trucks should be only in special cases and under supervision and gates or another physical obstacle (that can be removed if necessary) should stop vehicles from crossing the bridge. Applying steel and concrete sampling was highly recommended in order to observe the material mechanical and chemical properties of the bridge elements.