A STUDY OF REPAIR PROCEDURE OF AN OLD STEEL ORTHOTROPIC DECK BRIDGE

Hassan, M.M.[1] Dr/ Maha Mudather M[2,4] Dr/ Hussein H.A[3]

ABSTRACT

Metallic Orthotropic Deck Bridges Are Incorporated As An Efficient Structural System In Many Roadway Bridges Due To The Large Reduction In Bridge Dead Load. The Current Study Presents A Structural Study Performed For One Of The Major Roadway Bridges, Sayeda Eisha Bridge, Located In Old Cairo, Egypt. The Bridge Has Been In Service For More Than 50 Years Representing One Of The Limited Steel Orthotropic Deck Systems In The Province. The Study Was Performed Upon The Request Of Cairo Governorate In Order To Determine The Current Condition Of The Bridge And Evaluate Its Ability To Sustain Higher Loads. Moreover, It Was Reported That The Bridge Was Subjected To Several Accidents Throughout Its Service Life Which Was Thought To Affect Its Capacity. The Assessment Study Included Visual Inspection, Non-Destructive Testing And Numerical Analyses In Addition To Proposing Suitable Repair Methodologies. In The Current Research, The Most Frequent Structural Problems Are Highlighted And Evaluated. Observed Problems Include Corrosion, Cracks, Permanent Deformations In Structural Elements, Vibration Problems And Influence Of Fire On Bridge Members. In Conclusion, The Study Summarizes The Steps Performed During The Study; Lists Study Observations; Exhibits Numerical Analysis Results And Explores Proposed Repair Methodologies. The Study Is Part Of The Efforts Made To Enhance The Transportation Sector In Egypt.

1- Introduction

In 1969, The French Ministry Of Equipment Launched A Competition For A Standardized Design Of Dismountable Steel Viaducts.

The Aim Of The Ministry Was To Avoid At Grade Traffic Crossings Particularly In The City Of Paris. In March 1970, The Jury Declared The Successful Company. This Company Suggested Standard Design Of Road Bridges Of Spans From 9 To 30 M, Which Are The Most Common Spans Used Inside The Cities For Such Viaducts. The Proposed

[1] **Structural Engineering Dept., Cairo University, Giza, Egypt**
[2] **Architectura Engineering Department, University Of Prince Mugrin, Saudi Arabia (On Leave From Cairo University)**
[3] **Structural Engineering Dept., Al Azhar University, Cairo, Egypt**
[4] **Mahamoddather@Eng.Cu.Edu.Eg**

Viaducts Could Be Simple Or Continuous And Can Accommodate One, Two Or More Traffic Lanes. The System Consisted Of Orthotropic Deck Plates Fabricated Entirely And Painted In The Shops And Rapidly Assembled In The Sites By Mean Of Bolts. It Was Clear That The Proposed Orthotropic Design Fulfilled Two Essential Conditions For Economy In Steel Bridge Design Which Are: Efficient Utilization Of Steel And Maximum Reduction Of The Material Dead Weight.

Egypt In The Beginning Of Last Century Was In Crucial Need For Such Standard Design To Avoid Firstly The Congested Intersections And The Traffic Jams And Secondly To Avoid The Interference With The Construction Of The First Cairo Underground Metro Line. Many Of These Bridges Were Imported And Assembled, Enabling Thus The Fluid Flow Of Traffic In The Congested City Of Cairo, A City Of Twelve Million Inhabitants At That Time. It Was Necessary To Adapt These Standard Designs To Suit The Alignments Of The Roads In Cairo And Tailor It To Cope With The Country’s Practice And Applicable Procedures. Upon Several Designs, The Structure Shown In Figure 1 Was Imported From France And Constructed In Cairo. It Is To Be Noticed That In France Most Of These Bridges Were Considered Temporary Then Removed And Replaced By Permanent More Aesthetic Bridges, While In Egypt Most Of These Bridges Are Still In Use In Both Governorates Cairo And Giza.

Many Roadway Bridges Worldwide Employ Metallic Orthotropic Steel Deck System Due To Its Main Advantage: Reduced Weights. The Roadway Network In Egypt Includes Many Orthotropic Metallic Bridges That Has Been In Service For A Long Time. Assessment And Rehabilitation Efforts Of These Bridges Is A Pressing Issue In Order To Ensure A Satisfactory Level Of Performance Under The Increasing Traffic Loads. Inspection And Repair Of Metallic Orthotropic Steel Deck System Have Been Investigated By Several Researchers. Most Available Research Focus On The Repair Of Fatigue Cracks Which Is One Of The Most Critical Issues In Metallic Bridges (Suzuki 2015, Liu Et Al. 2016, Mizokami Et Al. 2017, Wu Et Al. 2017).

The Current Paper Lists The Assessment And Repair Efforts For One Of The Major Bridges In Cairo: Sayeda Eisha Bridge. This Work Is Part Of The Performed Efforts During The Last Years In Order To Assess The Condition Of The Different Railway And Roadway Bridges Across The Country (Abbas And Hassan 2016a, Abbas And Hassan 2016b, Hassan Et Al. 2017, Hassan Et Al. 2017, Hassan Et Al. 2016). Assessment And Rehabilitation Procedure Followed The Recommendations By Different Researchers In Other Countries (Ermopoulos And Spyrakos 2006, Frangopol Et Al. 2008, Bancila Et Al. 2009). The Next Sections Of The Paper Include Description Of The Studied Bridge, The Observed Defects, The Performed Tests, The

Analytical Study In Addition To The Applied Repair Procedures.

2- Description Of Bridge

Sayeda Eisha Bridge Is A Roadway Bridge Constructed In A Vital Traffic Axis Around 1970 In Old Cairo District. It Is Located On Salah Salem Street, One Of The Busiest Streets In Cairo. It Connects Giza Governorate To The Eastern District Of The Capital, The Residential Quarters Of Abbassia, Nasr City, Heliopolis Passing Through Al-Gamaliya, Al-Ghoreya And Al Hussein, The Historical Districts Of Cairo. Two Adjacent Bridges With A Total Length Of Approximately 300 M Divided On 13 Successive Bays Serving Two Traffic Lanes In Each Direction. The Span Of Each Bay Ranges Between 22.9 To 24.9 M. Each Bridge Consists Of 2 Lanes Following A Straight Configuration At The Approaches And A Curved Middle Part. Bridge Deck Is An Orthotropic Floor System Consisting Of Main Longitudinal Beams Spaced At 1.75 M And Transverse Beams Spaced At 3 M. In Addition, Bridge Deck Has Welded Longitudinal Ribs At Approximately 400 Mm. Steel Moment Frames Supports The Different Adjacent Bridge Bays. Figures 1 Through 4 Show The General View And Different Structural Components Of The Studied Bridge.

Figure 1: General View Of Curved Part Bridge

Figure 2: Main Beams Of Bridge

Figure 3: Orthotropic Deck System

Figure 4: Supporting Steel Moment Resisting Frame

The Bridge Was Built As A Temporary Traffic Solution During Metro Line Construction Works. However, The Bridge Has Been In Service For Around 50 Years. During This Period, Many Accidents Were Reported Leading To Damage To Many Structural Members. The Bridge Has A Sharp Curved Part While It Lacks The Required Super Elevation Or Friction To Counterbalance The Centrifugal Force. This Resulted In Many Accidents Including Vehicles Falling From The Bridge. Figures 5 And 6 Show Examples Of Accidents Resulting In Deformations And Damage To Some Parts Of The Bridge.

Figure 5: Truck On Fire At The Middle Part Of Bridge

Figure 6: Permanent Deformations In Bridge Deck

3- Inspection And Observed Defects

Inspection Campaign Of The Bridge Started In December 2016 Upon A Request Of Cairo Governorate As Part Of The Efforts To Elevate The Quality Of Transportation Network In Egypt. It Was Part Of The Study For Assessing The Condition Of Different Bridges And Tunnels At Cairo Province. The Study Started By Several Visits To The Bridge. During These Visits, The Different Elements Of The Bridge Were Extensively Investigated To Pinpoint Defects. Inspection Focused On Critical Positions And Fatigue Prone Positions. Unfortunately, Existing Documents Of The Bridge Did Not Include All The Required Structural Details. Hence, Inspection Included Measuring Dimensions Of Some Elements And Sketching Details At Connections Including Number Of Rivets, Bolts, Spacing…Etc. Accordingly, The Structural System Of The Bridge Is Fully Understood And Changes Due To Repair Procedures Are Recorded. Upon Inspection Of The Bridge, Several Defects Were Observed Including Loss Of Expansion Joints, Cracks At The Lower Parts Of The Supporting Beams, Corrosion And Erosion Of Steel Section, And Loss Of Asphaltic Layer For The Different Traffic Lanes. Figures 7 Through 12 Show The Different Observed Defects.

Figure 7: Loss Of Expansion Joints And Large Observed Distance Between Deck Parts

Figure 8: Corrosion At Bottom Of Bridge Columns

Figure 9: Loss Of Asphaltic Layer And Exposure Of Metallic Deck

Figure 10: Accumulation Of Garbage Around Supporting Elements

Figure 11: Lack Of Speed Limit Signs

Figure 12: Bad Condition Of Guardrail

4- Fe Modeling

Sap2000 Software Was Employed To Build 3-D Grillage Models For The Studied Bridge. Figure 13 Shows The General Layout Of The Model. The Model Was Built Considering The Sectional Properties Measured During The Visual Inspection Phase. Frame Elements Were Used To Simulate The Different Bridge Components. Rigid Joints Were Used To

Simulate The Connection Of The Moment Resisting Frames While Pinned Joints Were Used To Simulate The Connection Between Main Beams And Supporting Frames. The Grillage Modelling Technique Was Used To Capture Bridge Deck Properties. Figures 14 Through 16 Shows The Different Sections Included In The Modeling Of The Bridge. The Model Was Analyzed Considering Traffic Loads Imposed By Latest Edition Of Design Codes Considered In Egypt (Ecp 2012). It Is Worth Mentioning That These Loads Are Higher Than The Ones The Bridge Was Originally Designed For.

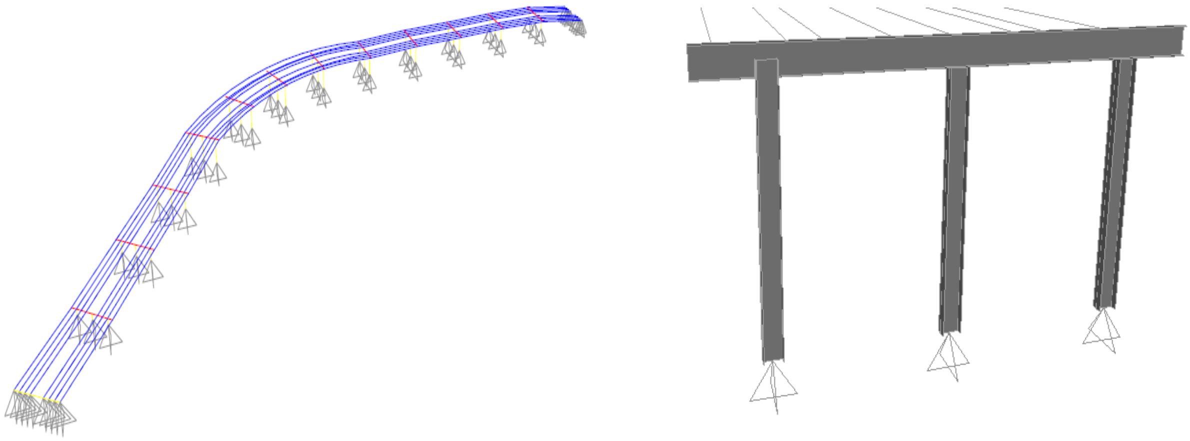

Figure 13: General View Of Fe Model And Supporting Moment Resisting Frame

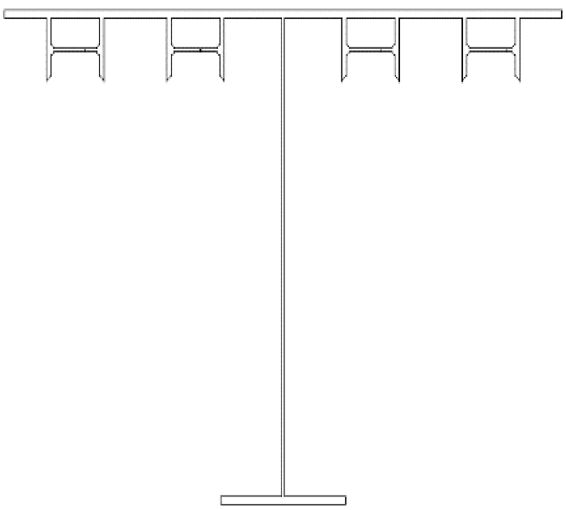

Figure 14: Stress Distribution For The Longitudinal Supporting Beam

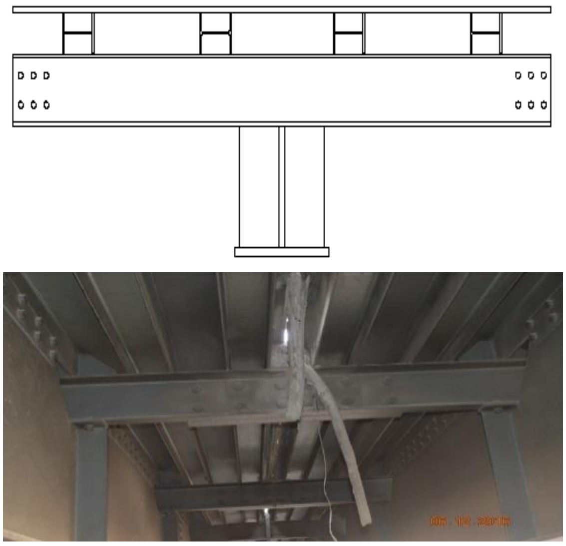

Figure 15: Relation Between Cross Beams And Metallic Deck

Based On The Built Model, The Different Members And Connections Are Checked Under The Resulting Straining Actions. It Was Found That The Stresses On Some Members And Connections Exceed The Allowable Stress Values Set By Egyptian Code For Design Of Steel Structures (Ecp 2007). For Example, The Cross Section Of The Main Beam At Was Found To Be Under Increased Tensile And Shear Stresses At Middle And Edge Of Beam, Respectively. This Was Checked By Determining The Nominal Flexural And Shear

Capacities Of The Existing Section And Comparing It To The Straining Actions Due To The Applied Loads. Moreover, Beams And Columns Of The Different Supporting Frames Were Checked And It Was Found That Column Section At Some Locations Are Subjected To Straining Actions Exceeding Their Supporting Capacity. Upon Checking The Connection Between Main Girder And Moment Resisting Frames Shown In Figure 16, It Was Found That The Existing Bolts And Decreased Section Properties Are Not Sufficient To Resist The Applied Shear.

Strengthening Alternatives Were Studied Considering Anticipated Costs And Ease Of Application. Moreover, It Was Considered Crucial By Authorities That Any Repair Procedures Should Not Hinder The Traffic Flow As The Bridge As It Is Located In One Of The Busiest Areas In Cairo. For The Main Beams, It Was Decided To Add Bottom Plates To Decrease The Resulting Tensile Stresses. One Of The Studied Alternatives Included Adding Concrete Slab And Introducing Composite Action Between Steel Main Beams And The Slab. However, This Solution Resulted In Increasing The Dead Weight Of The Bridge To An Extent That Will Require Strengthening Of Foundation. Increasing Section Depth At Main Beam Connection Was Also Adopted Instead Of Adding Cover Plates To Beam Web Due To Faced Construction Difficulties. For Steel Cross Girders, Structural Calculations Showed That Its Section Is Unsafe Upon Considering Wheel Load At Its Edge. Several Alternatives Were Studied Including Increasing Beam Section Or Adding Lateral Ties As Will Be Indicated In Subsequent Sections.

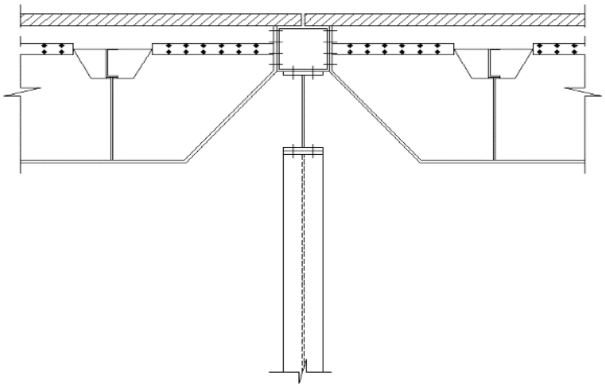

Figure 16: Connection Of Main Beam At Supporting Moment Resisting Frame

5- Bridge Foundation

Imam And Chryssanthopoulos (2009) Reported That Loss Of Pier Or Foundations Represent 16% Of Most Frequently Causes Of Failure Of Metallic Bridges Which Stresses Upon The Importance Of Checking The Condition Of Foundations Of The Considered Bridge. Accordingly, Excavation Works Were Performed In Order To Explore Type Of Foundations Under Sayeda Eisha Bridge. Foundations Of Bridge Did Not Include Piles And The Maximum Depth Of Foundations Was Found Equal To 5.5 M. Foundations Composed Of Two Reinforced Concrete Footings Connected By A Wide Reinforced Concrete Girder And Supported On Two Circular Plain Concrete Footings As Shown In Figure 17. The Middle Column Of The Steel Frame Is Only Supported On The Ground Beam Linking The Two Edge Footings. Check On Existing

Foundations Indicated That Stresses On Soil Approximately Reach The Allowable Bearing Capacity Under The Currently Applied Loads. Hence, Any Increase In Bridge Weight May Result In Requiring Strengthening Applications For The Foundation Works. Accordingly, Repair Alternatives Were Compared Based On Their Impact On The Total Weight Of Bridge.

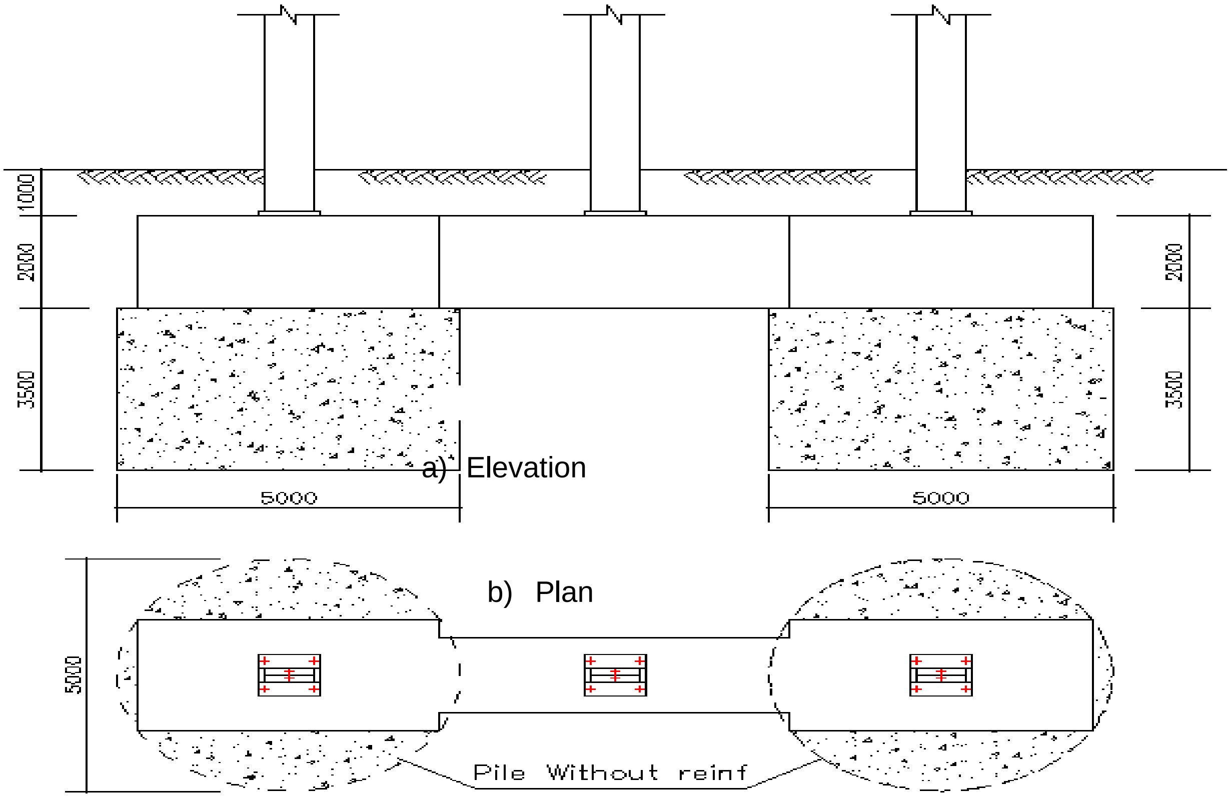

Figure 17: Foundation Type And Dimensions For Moment Resisting Frame

6- Repair Works

Based upon the observed defects during the visual inspection phase and the structural analysis following the finite element modeling, the following defects were mainly considered, and repair procedures were suggested accordingly:

* Lack Of Proper Super-Elevation Resulting In Accidents Involving Vehicles Dropping Off Bridge.

* Increased Stresses In Main Beam, Cross Beams And Supporting Moment Resisting Frame Columns When Considering Increased Traffic Loads.

* Insufficient Number Of Bolts At Main Beam Shear Connection.

* Corrosion And Loss Of Parts Of The Steel Section For Some Members.

* Lack Of Expansion Joints.

* Loss Of Top Asphaltic Layer And Exposure Of The Steel Plates.

* Lack Of Road Signs.

Several Alternatives Were Considered And Studied In Order To Solve The Above Defects.

One Of The Proposed Alternatives Included Adding A Concrete Slab Above The Bridge In Order To Satisfy The Required Super-Elevation. In Addition, It Was Proposed To Link The Concrete Slab To The Existing Steel Section In Order To Trigger The Composite Action And Decrease Stresses On The Steel Section. However, This Alternative Resulted In Increasing The Applied Loads On Foundations. Hence, It Was Excluded. Accordingly, The Following Repair Procedures Were Applied:

* Adding Proper Traffic Signs Indicating Bridge Curvature And Limiting Velocity On Bridge.

* Strengthening The Main Beams By Adding Bottom Steel Plates As Shown In Figure 18. The Additional Plates Had A Width Larger Than The Width Of The Existing Bottom Flange Of Beams And Were Connected Using Two Lines Of Fillet Welding. A Special Joint Was Used To Bridge The Existing Bolted Splices. Figure 18 Shows The Bolted Splice.

* Strengthening Of The Cross Beams By Adding Diagonal Box Braces As Indicated In Figure 18.

* Removing Of Corrosion At Bottom Of Columns By Sand Blasting And Adding Steel Plates As Substitution Of The Lost Area As Shown In Figure 19.

* Strengthening Of Main Beam Shear Connection As Shown In Figure 20.

* Strengthening Of Supporting Moment Resisting Frame By Adding Bracing Members As Shown In Figure 21.

* Replacing Of Asphaltic Wearing Surface For The Whole Bridge.

* Repairing Of Damaged Parts Of Guardrail.

These Repair Procedures Were Applied Were Applied To Prolong The Service Life Of The Bridge Till An Alternative Is Present Considering The Cairo Governorate Plan For Developing The Area.

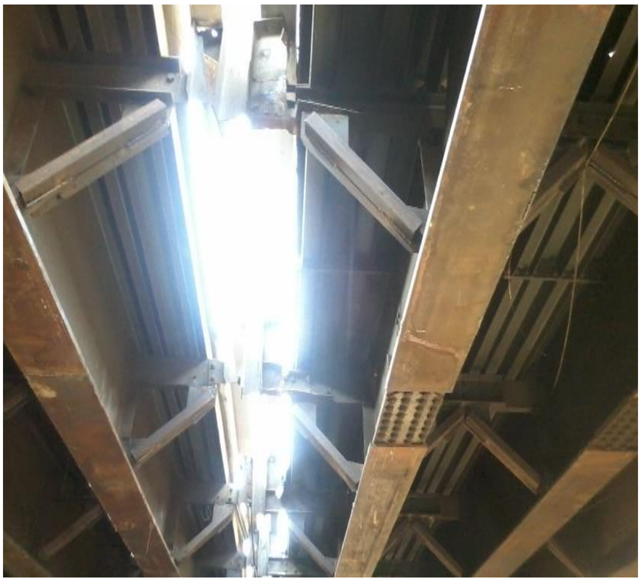

Figure 18: Adding Bottom Steel Plates To Increase Stiffness Of Supporting Beams And Diagonal Bracing To Cross Beams

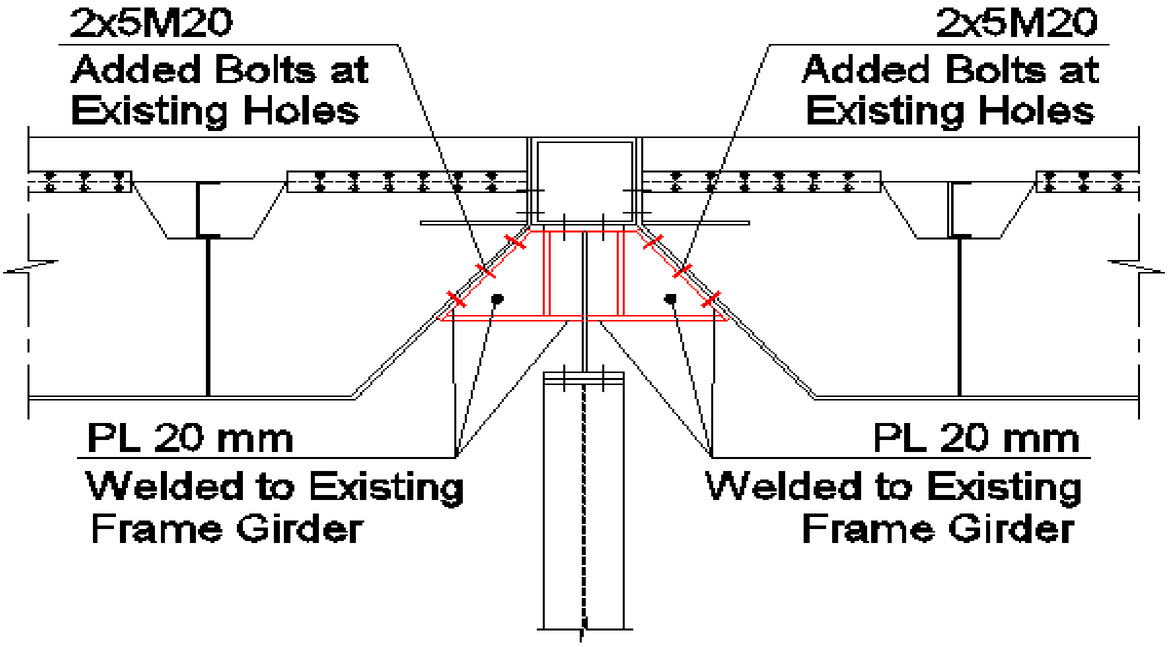

Figure 20: Strengthening Proposal Of Main Beam End Connection

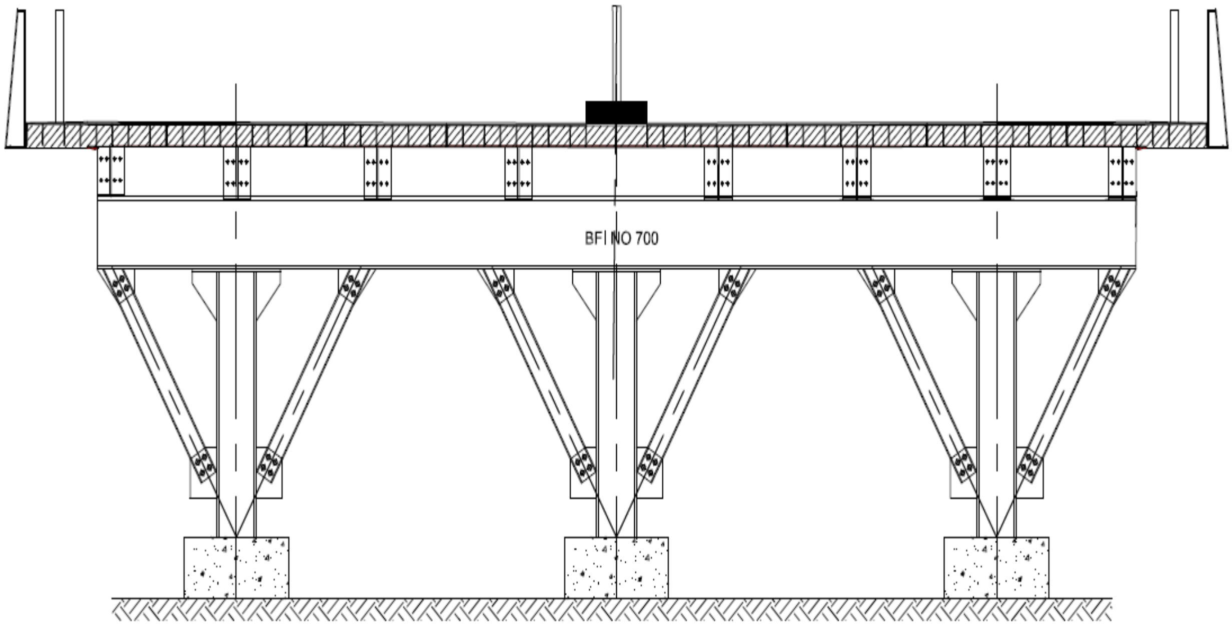

Figure 21: Stress Distribution For The Longitudinal Supporting Beam

7- Concluding Remarks

This Paper Explored The Applied Repair Procedures For An Old Steel Orthotropic Bridge Located In Cairo: Sayeda Eisha Bridge. Description Of The Bridge And Its Components Was Listed. Observations During The Visual Inspection Phase Were Exhibited. Afterwards, The Built Finite Element Model Was Investigated. Several Alternatives Were Studied, And Detailed Structural Analysis Calculations Were Performed For Each

Alternative In Addition To A Cost Analysis Study Focusing On Anticipated Direct Costs In Addition To Costs Related To Traffic Interruptions And Ease Of Repair Applications. Accordingly, Repair Methodologies Were Proposed, And Examples Of Applied Repair Techniques Were Shared.

This Paper Represents Part Of The Performed Efforts To Investigate And Increase The Service Life Of Existing Old Bridges In Egypt. The Following Main Conclusions Can Be Categorized:

* The Study Showed That The Inspected Bridges Had Many Defects Including Corrosion, Increased Stresses In Members And Connections, Inadequate Super-Elevation, Loss Of Expansion Joints And Loss Of Asphalt Layer.

* No Records Were Found Regarding The Design Drawings Of The Studied Bridge. Hence, Measuring Of Different Members Dimensions Had To Be Performed. In Addition, Excavation Works Had To Be Performed To Explore Type And Dimensions Of Foundations.

* Corrective Actions And Repair Methodologies Were Studied. The Chosen Procedures Depended On Several Economic Factors In Addition To The Sensitivity Of Bridge Location.

The Applied Repair Procedures Do Not Preclude The Importance Of Periodic Maintenance In Order To Maintain A Satisfactory Level Of Behavior And Extend The Service Life Of Bridge.

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