

Darko Popovic | dig
Director DNEC d.o.o.
E-mail: darko@dnec.com

Nenad Jovanovic | dig
Director DNEC d.o.o.
E-mail: nenad@dnec.com

RECOVERY AND RECONSTRUCTION OF THE COLLAPSED STEEL BRIDGE OVER RIVER OMO IN ETHIOPIA

Brief: Recovery of the collapsed steel bridge in this remote part of the Ethiopia presented a serious challenge both from the engineering, design and execution point of view. Sophisticated heavy lifting equipment supplied by VSL (Switzerland) and DNEC engineering design effort were met with a limited locally available material and human resources to bring this project to success. With the careful engineering approach, structures that were never meant to be used in such configurations were pushed to the limit with minimum additional strengthening. Operating with the real measured loads and controlling the risk of unknown loads and events, combined with the wild nature, made this job even more challenging. The operation was conducted in three steps; bridge recovery from the water, repair of the bridge damaged section and final bridge launching to its designed position. From the engineering point of view the project was a complete success, and the clean safety record of the operation made all of us even more proud.

Keywords: Omo, Callender-Hamilton, Heavy Lifting, Launching, Engineering, Collapse, Recovery

1. INTRODUCTION

Omo bridge is planned on the major Ethiopian route connecting Addis Ababa to the future agriculture and oil rich region near the border of South Sudan and Kenya.

The bridge is approximately 800km south –west of the capital Addis Ababa and links Jinka and Kelem banks near Omorate town. The bridge is designed as a two-lane bridge with 128m main span and two 36m approaches on both banks. Both approaches are designed as conventional reinforced concrete structures and main span is designed as Callender-Hamilton type steel truss with concrete deck.

The original construction process involved the main span truss being launched from the Jinka bank of the river using a temporary launching nose extension attached to the truss. The main span and the nose were assembled on the Jinka bank and launching begun in April 2011.



*Slika 1: Most u privremenoj fazi inicijalnog navlačenja pre kolapsa
(Photo 1: Bridge in the temporary phase of initial launching before collapse)*

Under unclear circumstances, just as the launching nose has reached the Kelem side the connection

¹ Zvanje, Institucija, adresa institucije, broj telefona, e-mail adresa (Stil SGP Institucija)

between the nose and the truss failed causing the truss to rotate around its support at Jinka pier. The collapse was inevitable and the rotation stopped only after the bottom chord front nodes reached the river bed.



*Slika 2: Izgled mosta neposredno nakon kolapsa
(Photo 2: View of the bridge immediately after collapse)*



*Slika 3: Oštećenje elemenata donjeg pojasa rešetke na
Džinka oporcu
(Photo 3: Extent of the damage of bottom chord joints at
Jinka pier)*

In 2012, the Ethiopian Roads Authority commissioned Pan Africa Construction Engineers (PACE) to carry out the bridge recovery utilizing VSL heavy lifting technology. DNEC joined VSL as an Engineering consultant to develop the methodology and full design of temporary elements required for the safe and successful recovery operation.

During the months after the bridge collapse took place, the truss section that submerged into the river was moved downstream by the river flow causing a horizontal shift of the bridge and further serious damage of bottom chord and secondary members that were still supporting the truss on the Jinka pier. The extent of the damage required modification of methodology and substantial repair of the truss bottom chord members prior to re-launching. As a consequence the recovery job that was already quite demanding became even a greater engineering challenge.

2. RECOVERY METHODOLOGY

The recovery operation was staged in three following steps:

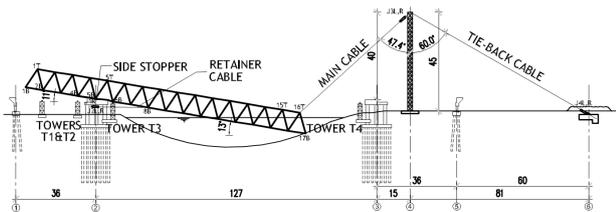
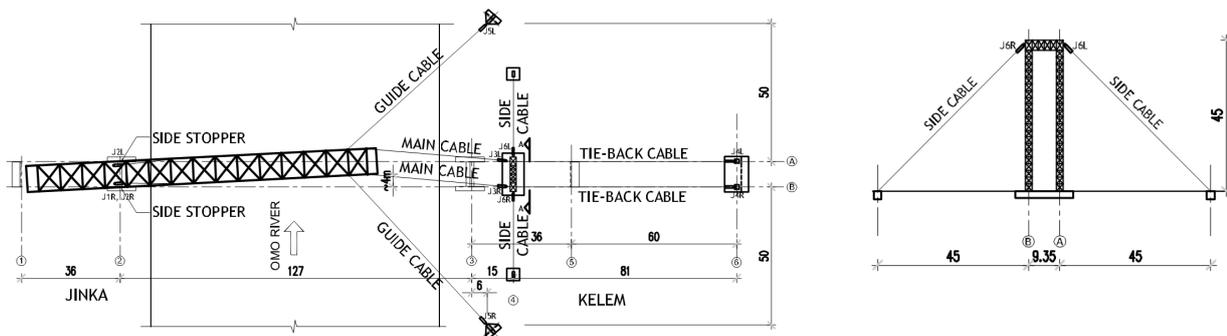
1. Bridge recovery from the river and positioning of the bridge to its design centre line and in near-horizontal position.
2. Straightening of the bridge and repair of the damaged elements.
3. Final launching to design position.

Each of the above steps required detailed methodology to be developed and unique tools to be fabricated and installed.

2.1 Bridge recovery from the water and re-centring – Step 1

Prior to commencement of the work on detailed methodology, a bridge survey was carried out in its current position. The original drawings of the bridge were recovered and studied. Initial structural analysis of the bridge was carried out using FEM software. Capacities were derived for each bridge member and connection. Modular type of bridges, such as Callender-Hamilton are very sensitive to forces applied inconsistent to the strictly predefined supporting conditions.

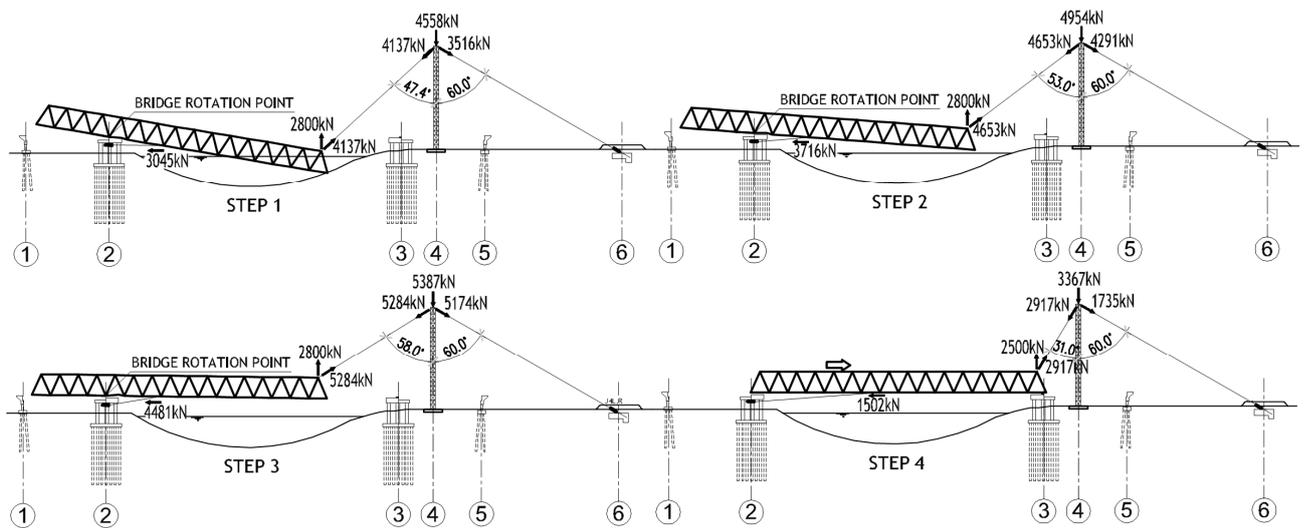
After discussing several options, the following option prevailed. It was decided to recover and launch the bridge using 45m tall temporary towers constructed on the Kelem bank tied back to the mass concrete foundation constructed at the back of the temporary tower. Towers were stabilised for the sideways movement by another pair of side cables. The lifting force, originated by the main cable inclination, is retained by the Retaining cable connected to the abutment on the Jinka bank. Side stopper system was provided at the Jinka pier to prevent bridge side movement over the pier.



Slika 4: Pozicioniranje privremenih elemenata za operaciju izvlačenja mosta iz reke
(Photo 4: Layout of temporary elements positioned for the recovery operation)

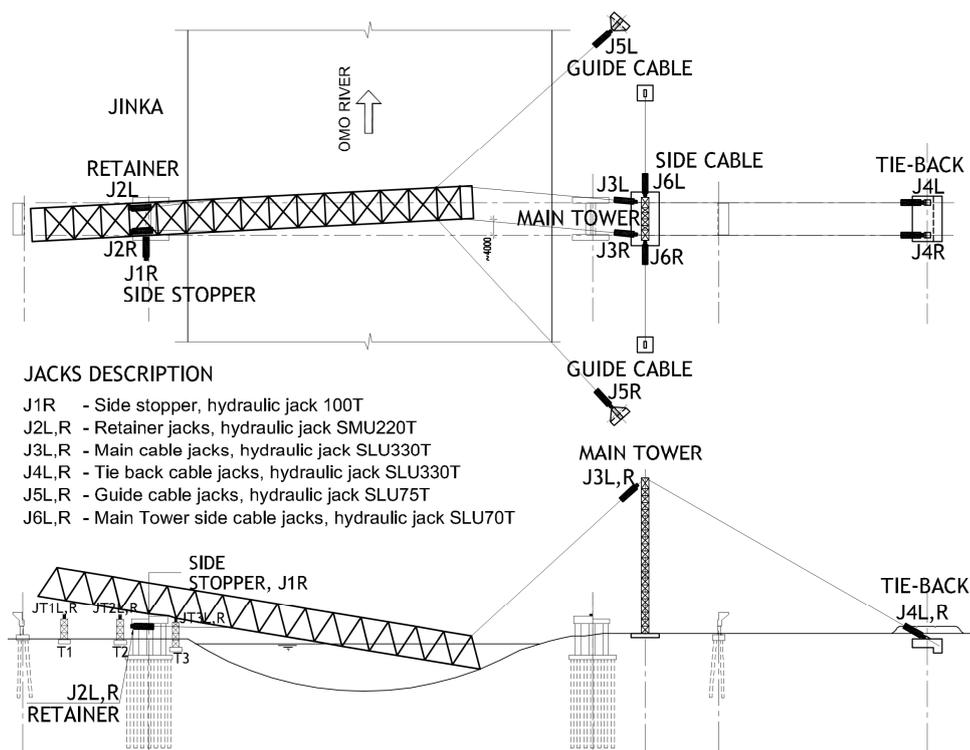
The overall weight of the bridge central span was estimated to be 500T. Design of temporary works had to take into consideration the unknown weight of the nose submerged in the water and the weight of the debris trapped by the bridge as a result of blocked river flow. Near-zero visibility in the river water made it very difficult to assess the actual conditions on site. There was a potential risk that the bridge nose could get stuck in the river bed thus increasing lifting force.

Another very important factor needed to be carefully studied - the effect of the river flow and the lateral pressure induced after the bridge is lifted from the river bed, but still submerged in the water. Seasonal river conditions were reviewed as well. To resist the lateral pressure caused by river flow, set of guide cables was provided. Guide cables were dimensioned to resist the lateral pressure produced by the river flow with maximum water speed of 1.5m/s. The river flow speed was to be monitored during the entire operation. It was calculated that the river flow pressure on the submerged bridge portion could produce force of close to 60T in the direction of the river stream using factor of safety 2.0.



Slika 5: Projektovane sile u glavnim kablovima (parovi kablova) tokom operacije izvlačenja i navlačenja
(Photo 5: Calculated forces in pairs of main cables during the recovery and launching operation)

After complete lifting assessment, governing forces were derived for a number of critical bridge positions and load cases. VSL hydraulic strand-jacks were dimensioned with required allowances covering the maximum derived loads.



Slika 6: Pozicioniranje VSL presa
(Photo 6: Layout of VSL jacks)

The strand-jack system used during the operation consists of hydraulic pulling and lowering jacks that use PT strands as a pulling/lowering cable. Jack operation is very sensitive to the angle of strand approach to the lower anchorage of the jack assembly. For the undisturbed pulling/lowering operation the angle of the strand at the approach to the lower anchorage should not exceed 2° . Therefore the jacks were positioned at the predesigned frames with biaxial rotation capability allowing for almost 0° deviation between the strand cables and the centreline of the jack. Recovery operation was conducted from the control room located on the Kelem side of the river using wireless system to control the release of the tie-back jacks with the lifting jack on the top of the tower.

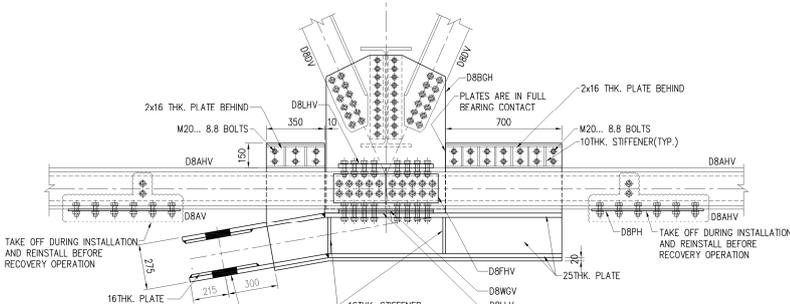
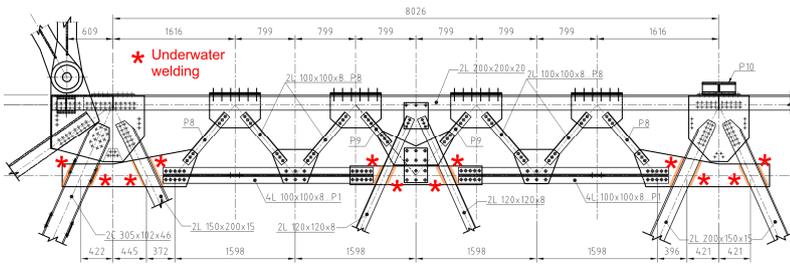


*Slika 7: VSL oprema, hidrauličke prese, pumpe i kontrolna tabla na testiranju pre instalacije
(Photo 7: VSL equipment, hydraulic jacks, pumps and control units under testing regime prior to installation)*

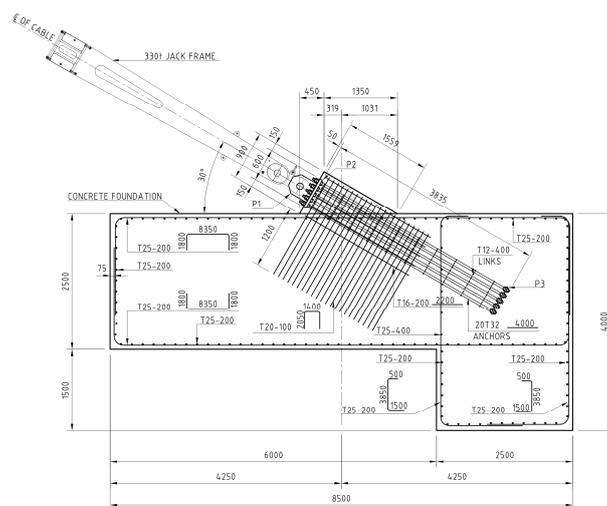
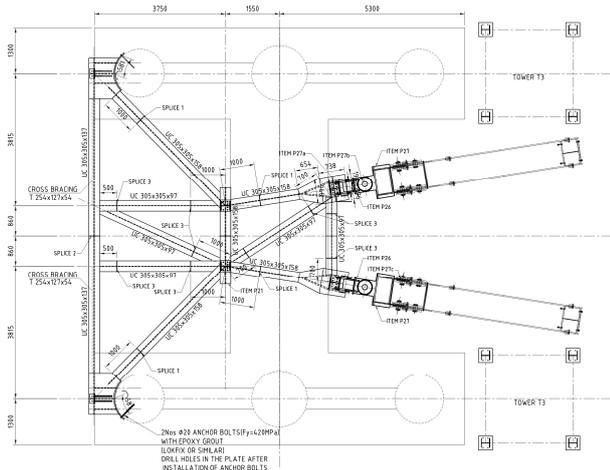


*Slika 8: Instalirane prese sa rotacionim ramom na glavnom kablu na vrhu jarma (levo) i na kontra zatezi na Džinka osloncu (desno)
(Photo 8: Strand-jacks with rotating frame on the main lifting cable at the top of the temporary tower (left) and on retainer cable at Jinka pier)*

Connection of main lifting cables and retainer cables to the bridge steel structure had to be carefully assessed as the bridge had not originally been designed for such load application. Strengthening of the truss top chord near the pulling cables connection point required additional members forming a local truss shape and careful detailing to allow installation without dismantling the bridge joints. In few instances installation of additional members required underwater welding in the river with zero visibility. The Client has contracted this task to Indian based underwater welders who successfully completed this challenging work.

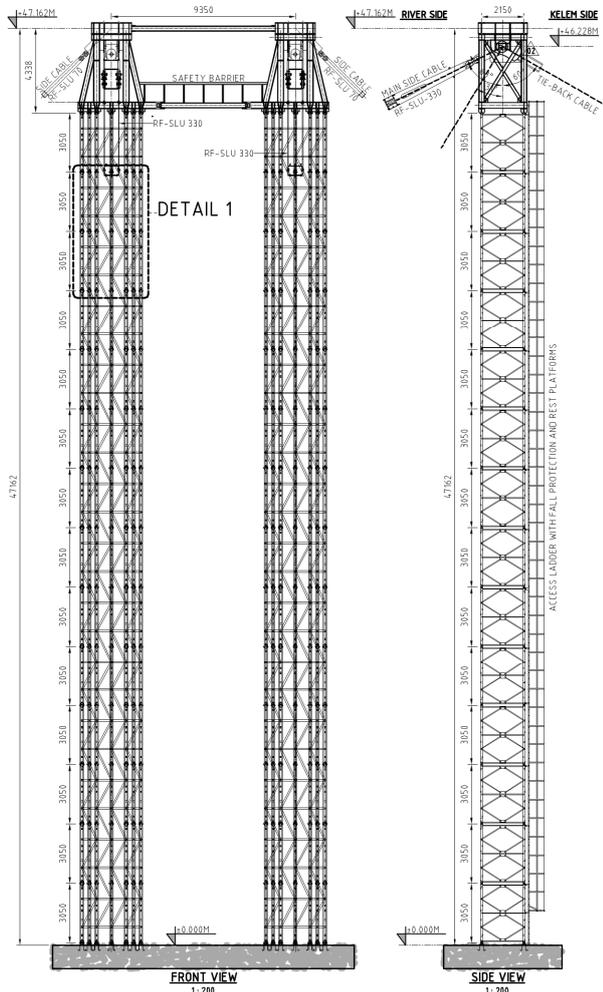


Slika 9: Detalji veza ojačanja rešetke mosta na vezi glavnog kabla (gore) i kontra zatege (dole)
 (Photo 9: Details of truss strengthening at main cable connection (above) and tie-back connection (below))



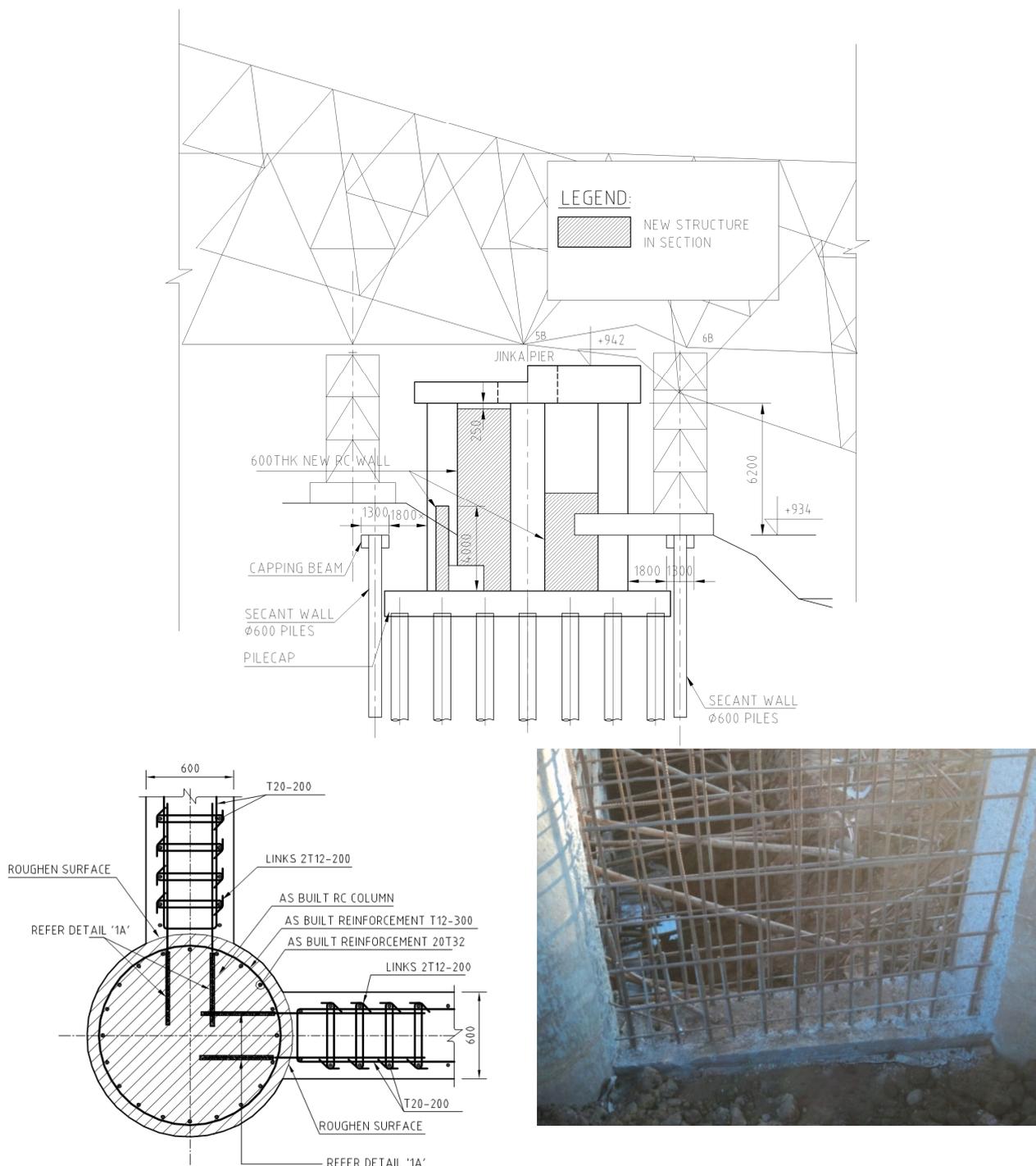
Slika 10: Detalji ankerovanja kontra zatege na Džinka obali (gore) i temelja kontra zatege na Kelem obali (dole)
 (Photo 10: Anchoring details for retainer on Jinka bank (above) and foundation of tie-back cable at Kelem bank (below))

Additionally, the Client wanted to use locally available Bailey bridge sections for the 45m tall main tower construction. Incorporation of available Bailey bridge sections into the tower formation required additional interconnecting bracings. Top parts of the main towers were separately detailed. The detail of tower top frame needed to allow a concentric connection of the main cable, tie-back cable and the side cable in a very congested area. Additionally top tower frame had to be detailed in a way to provide uniform distribution of the loads to the multiple legs of the main tower.



Slika 11: Crteži i slike jarma i detalji ramova na vrhu jarma
(Photo 11: Drawings and photos of tower and its top)

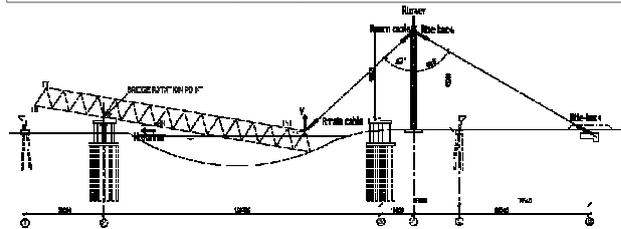
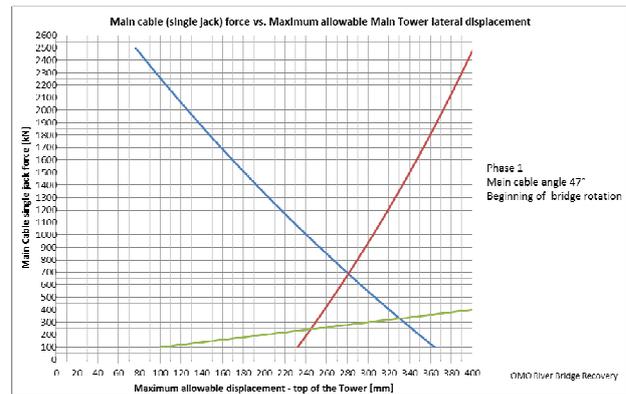
Towers support and cable ground anchorage foundations were designed with limited information on soil parameters. A particular challenge was the reinforcement of the Jinka abutment in order to withstand retainer reactions. The columns of the pier were additionally stiffened with the shear wall in-between the piers columns to limit pier columns bending.



*Slika 12: Crteži i slike ojačanja Džinka oporca
(Photo 12: Drawings and photos of Jinka abutment strengthening)*

After completing all preparation tasks the recovery operation was ready to commence. Very detailed monitoring plan was set in place and designated personnel was appointed. Recovery commenced in several steps where each step represented steady increase of the load at the main lifting jacks. During the operation towers were continuously surveyed to record displacements and cable forces were monitored from the control room.

After each step, the survey of the tower displacements and jack forces was compared with predicted values. The signal to continue from the responsible engineers was requested after each load step. The actual recovery operation lasted two days and the bridge was successfully pulled out from the water.



Slika 13: Kontrolna soba i grafikon za praćenje pomeranja glavnog jarma tokom operacije
 (Photo 13: Control room and main tower displacement monitoring graph)

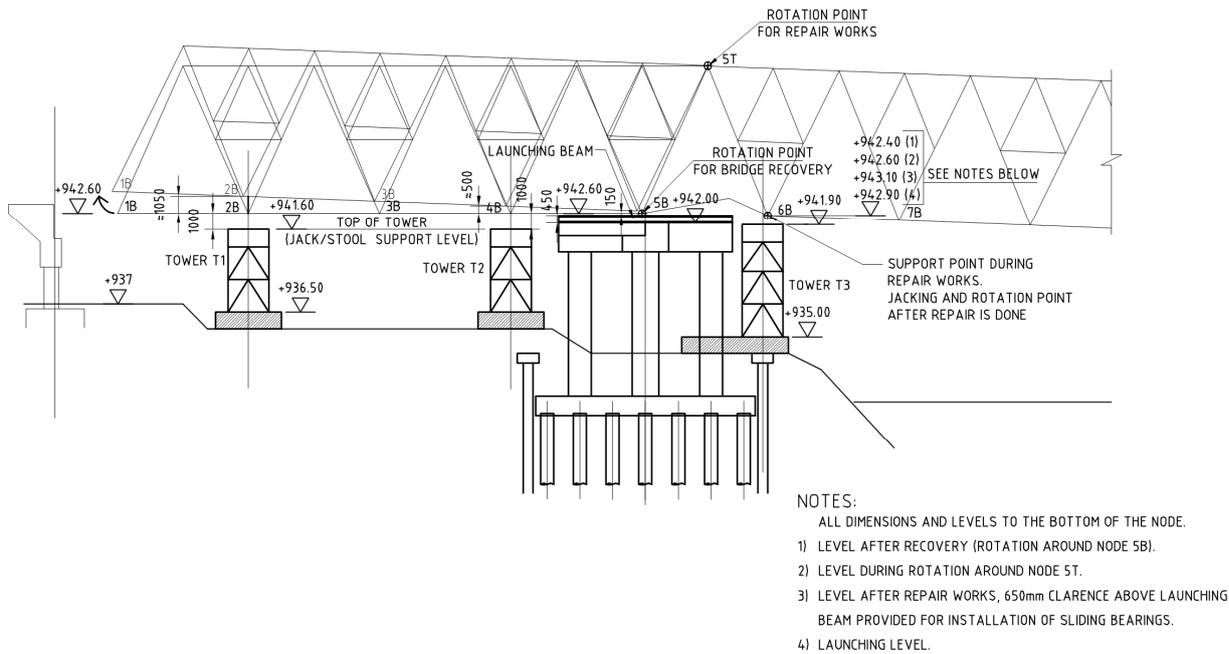


Slika 14: Most posle uspešnog izvlačenja iz vode
 (Photo 14: Bridge after successful recovery from the water)

2.2 Straightening of the bridge and repair of the damaged elements – Step 2

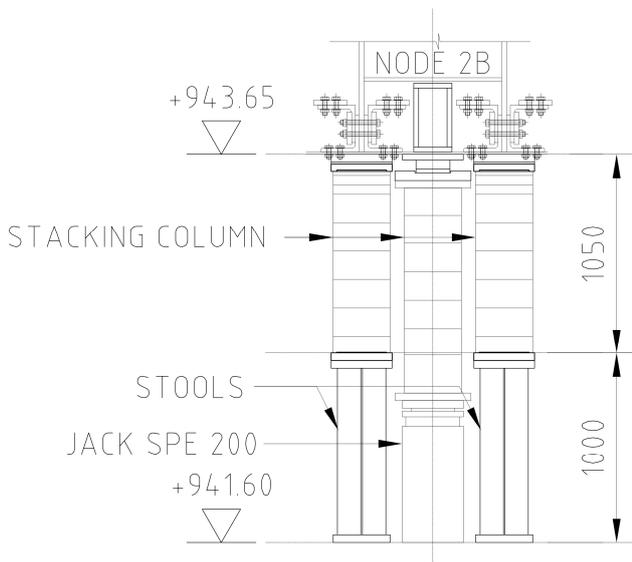
After the bridge was recovered from the water it was brought to the near-horizontal elevation and rotated horizontally to align with the designed centre line. At this point of time, jacks were mechanically locked. In order to allow for the bridge to be straightened the deformed section of the bridge needed to rotate around top chord joint 5T for approximately 3°. For this operation bridge section from joint 1T to joint 5T needed to be independently supported by the temporary towers T1 and T2 and main span of the bridge beyond the joint 5T to be supported at temporary tower T3. This load transfer operation allowed the bottom chord damaged members to be removed and truss end free to rotate.

Bridge top chord joint 5T indicated as rotation point was carefully studied and the implication of the bridge rotation to the potential deformation of its elements assessed. It was concluded that the rotation induced stresses and elongations were within design limits. Majority of the rotation was absorbed by the bolts rotation at the standard oversized holes.



Slika 15: Vertikalno poravnanje
(Photo 15: Vertical alignment)

Rotation of the bridge segment was conducted by staged jack-up operations from the towers T1 and T2 using conventional hydraulic jacks. Maximum height of the free standing jacks' piston and packing was estimated to reach 1m at tower T1. Stability of the bridge segment was provided by steel shoring using fabricated stopper beams installed at the top of the temporary towers. Damaged elements were removed and replaced using conventional tools.



Slika 16: Crtež i slika čvora 2B
(Photo 16: Drawing and photo of node 2B)

2.3 Final launching to design position – Step 3

After bridge repair work has been completed, the preparation for bridge launching was ready to commence. The original sliding beam and the pair of undamaged sliding rollers were used for the bridge sliding over the Jinka pier. The bridge was subsequently offloaded from the towers T1, T2 and T3 onto the sliding bearing and the bridge was set for final launching.



*Slika 17: Slika pokretnog ležišta i klizanje na Džinka osloncu
(Photo 17: Photos of sliding roller and its sliding at Jinka pier)*

The launching operation was conducted from the same control room used for the recovery operation and utilising the same wireless system for control and synchronisation of the release of retaining cables in parallel with the pulling activity. Full set of originally installed strand jacks were reengaged and used to control the tower verticality and bridge alignment during launching.



*Slika 18: Lansiranje mosta
(Photo 18: Bridge launching)*



*Slika 19: Most u projektovanom položaju nakon lansiranja
(Photo 19: Bridge in position after final launching)*

8. LITERATURA (STIL SGP PODNASLOV)

- [1] Marwan El Jamous and Nenad Jovanovic , Back on track, Bridge Design & Engineering, Issue 74, 2014