TECHNOLOGY OF EXECUTION THE MORAČICA BRIDGE ON THE HIGHWAY BAR – BOLJARE

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Abstract: *This paper presents method of statement for the span structure of the bridge Moračica on the highway Bar-Boljare, built by Chinese company CRBC. The company COWI-Denmark, has been engaged as a contractor support for monitoring the execution of the bridge Moračica. Besides other participants in the construction, the Government of Montenegro has created the Committee for comparative technical work examination during the execution. Thereby, the Committee for technical examination, bears in mind the process of construction and has the possibility to overlook the monitoring and analyze all necessary technical documentation which would otherwise be subject to the usual technical inspection after construction. Since the similar paper in which foundations and pillars have been analyzed has been shown at the previous meeting we thought that this part should be presented to the public. The applied procedure and the data obtained during the implementation of this part of the project may be of use to a wide range of civil engineers engaged in similar activities.*

Keywords: *span structure, ladder cage, cantilevering, prestressing, formwork, monitoring, pre-cambering.*

1. INTRODUCTION

As part of construction of the highway Bar–Boljare through Montenegro, the bridge Moračica is under construction, which represents at the same time the most demanding structure on this route. The design of the bridge construction was made by Željko Ličina, M.Sc., and ordered by the Chinese company CRBC, who arranged complete engineering with the Government of Montenegro, i.e. the production of the Main design and execution. The Main design was made on the basis of preliminary design, made by Faculty of Civil Engineering, University of Montenegro in Podgorica. Figure 1 shows the layout so far realized a part of this magnificent struc.

Figure 1: Realized part of the bridge construction as of 25. 04. 2019.

1.1. Bridge data – layout [4]

The bridge is designed as a single structure, with a wheelbase lanes highway from 11.70m. The Bridge spreads from chainage km 6+482.14 to km 7+442.33 per left i and chainage km 6+476.57 to km 7+436.38 per right axis. The space between roadway axis in the basis is 11.70m. The left roadway is on the section in front of the bridge, on the bridge as well as behind the bridge. It is parallel to right roadway. The bridge bridges main road Podgorica–Kolašin, river Morača and plateau Moračica (the bridge is named after this plateau), respectively. It connects northeastern slopes of hill Ždrvanj and west slopes of hill Smrdulja. There is a gorge between them and it’s width is approximately 1000 m. The bridge is approached from shorter part of open route (it’s length is approximately 400m). The tunnel “Mrke” is located in front of it. There is an open route of highway of about 4km behind the bridge and there is a tunnel “Klopot” afterwards (first breached tunnel on the route). The elevation of vertical alignment of the highway at the beginning of the bridge is about 253 meters above sea level, the elevation of vertical alignment at the end of the bridge is about 293 meters above sea level (difference Δ=40 m). As measured by left axis of highway, the length of bridge structure is L = 960 m. The maximum height of the bridge above the terrain exceeds 175 m. It exceeds the additional 30 m on the part above river Moraca (this is the depth of the canyon in relation to plateau Moračica) so the total height of the water level is about 205 m. The total width of the bridge is 23.40 m, of which 7.70 m go on both roadway (traffic and roadside lane 2x3.50 m + 2x0.35m) and pedestrian walkway 2x2.00 m. Crossfall on the part of transition curve is changing, ranging from one sided crossfall of 4% to double sided crossfall of 2.5%. Grade on the part of the bridge, in front of the bridge and behind the bridge is 4%.

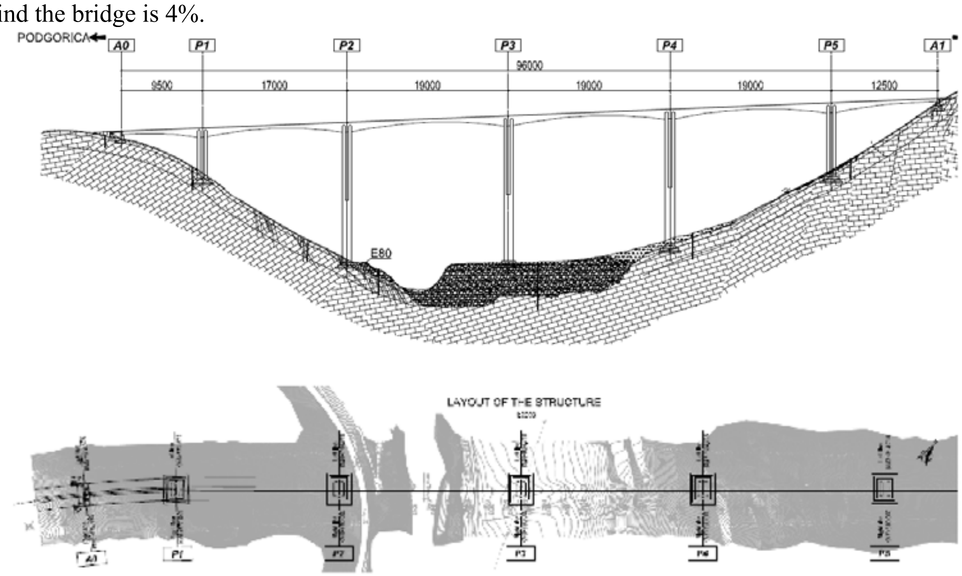


Figure 2: Layout of the bridge Moračica

The bridge is a continuous prestressed frame structure of variable cross section. The adopted solution has a range of 95 + 170 + 3 x 190 + 125 m, so that, axially, the length of the bridge is 960 m, and with the wing walls 988 m. This span ratio is favorable for continuous frame construction system whose bridge structure is constructed by the balanced cantilever method.

The piers P1–P5 establish rigid connection with the structure and abutments A0 and A1 are connected to the structure through bearings. This is how the horizontal impacts are divided onto a few piers. The system with larger inner spare bearing capacity is obtained on this way. From the aspect of construction technology, the rigid connection is favorable as well. Frame structure also requests smaller dimensions of foundation.

The bridge starts from a small incision in the mount, which then goes into a mound height of 10 m. Highway quickly enters the high cut behind the bridge. The terrain under the bridge on the right bank of the river Morača descends to the river canyon steeply. At the section of abutment A0, the gradient of terrain in longitudinal direction is still slight, that is, about 1:5 towards the river of Morača. In the transversal direction, it inclines to the left side. Furthermore, longitudinal and transversal gradient of terrain increase towards pier P1, so both, longitudinal gradient and transversal gradient of terrain is about 1:2. The terrain in the zone of pier P2 near the main road keeps steep longitudinal gradient towards Morača. Transverse gradient is getting lower and becomes relatively slight. The pier P3 is located on the plateau “Moračica. Transversally, the terrain around piers P4 and P5 is slightly inclined to the right side. Longitudinally, the gradient increases slowly around the pier P4 towards pier P5 and it reaches 1:2 (as well as on the right river bank). The abutment A1 is located under the top of the hill which the highway route comes in behind the bridge. The longitudinal gradient is very steep, that is, 1:2.

1.2. Foundation structure

Considering the geotechnical conditions, shallow foundation is chosen. All the piers are founded in limestone rock, except the pier P3 that is funded in terrace sediments, conglomerates. According to the reccommendations from geotechnical elaborate, it is adopted for the foundations to be located in geotechnical environment marked with "C" for at least 1–2m (glacio fluvial sediments – from weakly to well attached conglomerate and sandy gravel, a width of about 140 m with altitudes of 98 to 102 m above sea level).
The depths of founding of edges of foundation towards the hill are very high due to great longitudinal gradient and cross gradient of the terrain. Although the allowed stresses are extremely high even for the limestone, high degree of safety was applied during the defining of dimensions of footing because the rock is cracked and it can be locally unfavorable. Benched foundations of middle piers provide safe and uniform transfer of forces from pier into the soil. The gradient of force transfer is in accordance with valid regulations. The dimensions of foundations of piers P1 and P5 are 30x26 m and the dimensions of piers P2 – P4 are 33x26 m. The total height of all the foundations is 7.5m. The height and width of all the foundation stairs and distance of pier edge and foundation edge are 2.5m. There is an underlayer concrete under the foundation whose thickness is 20 cm. It's width is larger than foundation for 40 cm.
Bigger parts of foundations of end piers are set under the embankment. There are two reasons why this position is more favorable: the purpose of the relying of standing wing walls and the purpose of balancing of influences exerted from structure and soil pressure. On that way, eventually settlement is also controlled to be uniform. The upper area of the foundation is at longitudinal gradient. The height of footing at the section beside the wall sheet is 2.5 m. The thickness of under layer concrete that is applied at these foundations is 20 cm as well.

1.3. The piers (substructure) of the bridge

The great height of piers, wind as dominant influence and rather big differences in the pier heights caused kind, shape and law of change per height of the cross section. Shorter piers P1 and P5 that would receive more significant influences are less rigid in order to equalize the longitudinal influences on the middle piers. Higher piers are more rigid up to the height of rigid joints of shorter ones. Furthermore, the high piers are rigid up to the full height, their rigidity is the same as the rigidity of short ones. This is how the aesthetically favorable solution is accomplished, all the piers are laterally transparent up to the approximately same height. (the beginning of "fork" – two-part section).
Middle piers P1 and P5 consist of two box cross sections that are set parallel along the longer side, that is, transversely to the bridge axis. Both sections are identical, that is, both sections are two cell sections. The shape of the section is modified rectangular. The sections are stiffed with horizontal rib at the half of the height. (diaphragm). The sections which are separated in transverse direction and aerodynamically favorable shape of side areas reduce the wind influence on the piers. There is a recess on the longer sides which allows the efficient separation of air vortex and pier surface. External dimensions of these piers are 15x3.5 m. The thicknesses of walls are 80 cm and 170 cm. These thicknesses are constant per height. There are haunches planned on all the places of connections for horizontal slabs (ribs). There is a unique cross section of three meters height above the foundation as well as on the top. Full sections and large haunches enable right force transfer from the structure into the piers and from the piers into the foundation.
There is an inspection manhole in the top slab. There are two opposite ventilation shafts left in each cell of the section at each 5 m of height. There are also drainage holes in the bottom of the pier at the lowest point. Their diameter is 10 cm and they are left there to take away water that can possibly appear from the inside of the pier. The slope of these holes towards the exterior side is 5%. There are also inspection doors, stairs with safety hoops and rest platforms at each 10 m of height. All the openings in the structure must be protected with plastic mesh because of the birds.
Cross section on the upper part of the piers P2 – P4 is identic as the cross section of piers P1 and P5. Two box sections of the top part of the pier connect into one unique cross section of the bottom part of the pier. Outer dimensions of modified rectangular cross section formed on this way are 17.20x11 m. The thicknesses of walls are increased to 100 cm, the thickness of longitudinal walls reaches 120 cm. There is a rib in the middle, it's thickness is 80cm. Outer edges of the sections keep the slopes and notches which are the same as the one on upper part of the section. The sections here are also full sections, just like the sections of piers P1 and P5. It's thickness is three m at the top, bottom and crossing between two kinds of sections. Inspection chambers, inspection doors, inspection stairs, ventilation shafts and drainage holes are set as the ones at piers P1 and P5.
End abutments are massive. Considering that wall sheets transfer the reactions from structures whose spans are 95 m and 125 m, their thickness is 2.5 m. Parapet wall is almost 6 m high, so it's thickness is 80 cm. Sufficient rigidness of parapet wall which is supporter for expansion joint is the precondition of it's durability. There are

short elements on both sides of this wall. The purpose of one element is the supporting of crossing slab, the purpose of another one is supporting of expansion joint.

Parapet wall is connected to wall sheet by the means of strong haunch. This haunch and upper part of the wall sheet form hidden bearing beam. There better transfer of forces from bearing concrete cube will be achieved by stressing the beam concrete with stirrups and vertical tie-rods. There are two kinds of bearing concrete cubes on the bearing beam: bearing cubes for transfer of vertical forces and bearing cubes for receiving of horizontal forces (earthquake and wind forces, primarily). The height of bearing cubes for receiving of horizontal forces is about 140 cm and this is determined by the size of the necessary bearings. This height also defined the height of bearing cubes for the receiving of vertical forces. The height of the bearing cubes enables the strong reinforcement in bearing cubes to receive the tensile stress caused by local compressive stress under the bearing. The tensile stress is not transferred into bearing beam.

Wing walls of the end abutments are 50 cm thick. Part of these walls are standing walls, part of them are hanging walls. It all depends on terrain gradient and possibility of forming of slope round heads. The walls are strengthened with beams because of the length. There are cantilevers on top edges of wing walls that carries the pedestrian walkways and installation channels inside it (with the same section as the one on the bridge). These cantilevers have statically favorable influence on wings because they stiffen the top edge. The length of crossing slab is 3.7 + 2.5 m and it is installed at the gradient of 10% in the relation to gradient of vertical alignment. Plain concrete is constructed under the slab.

1.4 Span structure (superstructure) of the bridge

The main girder of the bridge Moracica is prestressed reinforced concrete box girder of two-cell section, with variable height along the span. The width of the upper plate of the main girder is 22.70m. The total length of the main girder above the pier P1 is 10.50m, and above the pier support on the piers P2, P3, P4 and P5 is 11.50m. The height of the beam in the middle of span and above the bearing on abutments A0 and A1 is 3,80m. The height of the main girder changes along the parabola with the parameter 1.8 Visina glavnog nosača mijenja se po paraboli sa parametrom 1.8.

The thickness of the bottom plate section of the field A0-P1 and P5-A1 is variable from 30 cm above the supports A0 (A1) of up to 120 cm above the supports P1 (P5). The thickness of the bottom plate section in the fields of P1–P2, P2–P3, P3–P4 and P4–P5, spans of 30 cm in the middle of the span of up to 120 cm above the supports of middle piers. The thickness of the bottom plate changes along the parabola with the parameter 1.8, and is constant at the top of pier. Bottom plate has a thickness of 80 cm above the support of the abutments. The connection between bottom plate and longitudinal reinforced ribs is strengthened with hanches. Rib of a box section may have three different thicknesses (65cm, 55cm and 45cm). This division corresponds to three segments beam lengths (3.00m, 3.75m 4.50m). The thickness of the top plate of a box-section has a constant thickness of 30cm. The thickness of the underlying rib segments is 85 cm in the basic part.

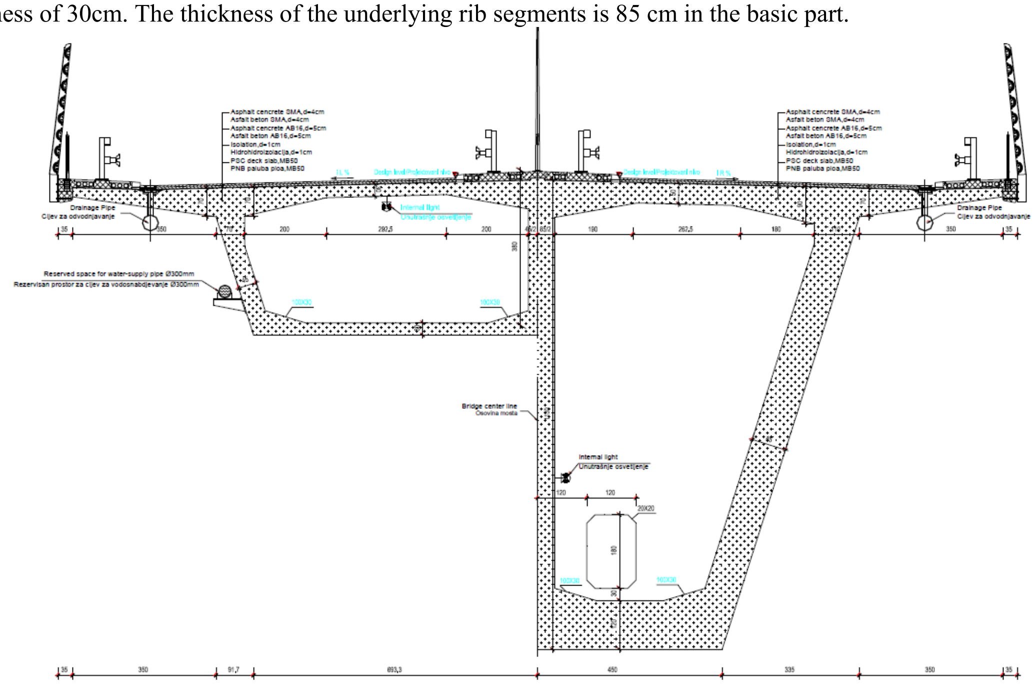


Figure 3: A typical cross section of the bridge beams

There are four transverse beams above the piers with the thickness of 80 cm. The upper plate between the cross-beams with one and the other side is reinforced to a thickness of 160 cm and makes the wave shaper cables. Thickness of the plate in the middle (between the deviators) is 50 cm. The thickness of the ribs and upper plate hanches dimensions provide sufficient space for the installation of the anchor cables. Cantilever length of box girder is 3.50m. The upper plate comes along the slope pavement. Designed protective layers are 4.5 cm from outer side and 4.0 cm from inner side.

1.4 Designed materials

The used materials are given along. All the concretes belong to B II category. Main girder, aerated concrete C42/53 (MB 50), V–8, M–200, frost resistance and salt resistance "1". Middle piers and bearing beams: aerated concrete C38/47 (MB 45), V–8, M–200. Abutments with wing walls: aerated concrete C25/32 (MB 30), V–6, M–150. Cornices with concrete safety fences: aerated concrete (C33/42) MB 40, V–8, M–200. Frost resistance and salt resistance "0". Bearing concrete cubes, aerated concrete C42/53 (MB 50), V–8, M–200, frost resistance and salt resistance "0". Foundations, C25/32 (MB 30), V–6, M–100, V–6, M–100. Transition slabs, C25/32 (MB 30), V–6, M–100. V–6, M–100. Slope concrete, C25/32 (MB 30), Underlayer concrete C17/21 (MB 20). Reinforcement B 500B for whole structure. a B 500B. According to EN 10138, cables belong to class Y1860. Nominal diameter 15.2 mm and relaxation rate is low. The pipes of the cables are plastic. Prestressing system have to have ETA certificate (European Testing Approval). Steel elements on the bridge, such as pedestrian fence and safety fences, are all made of steel S235, and winds barriers of S355, also hot galvinizaded.
For all elements of the bridge structure preliminary tests of components, fresh and hardened concrete and other materials have been made. These documents represent a piece of the Concrete design book [5] and are presented in the form of individual laboratory reports in attachment.
It should be noted that, during the execution, at the request of the contractor, the recipe for all concrete construction elements has been changed, such as air entraining being removed with the approval of State Commission for the Review of the Project.

2. CONSTRUCTION TECHNOLOGY

Balanced cantilever construction determines the rational ratio between main and side spans ranging from 0.6 and 0.7, as it was stated in the widely used French guidelines for bridge designing SETRA (bridges that apply balanced cantilever construction). This ratio is adopted in order to decrease the parts of structures next to the abutments that are constructed on the scaffold (as much as possible). In this particular case, this is extremely important because the slope gradients in the side spans are very steep, so the installation of scaffolds and their foundations is more difficult. In the final layout plan (variant) that was provided in this Design, the lengths of parts of bridge structure that are constructed on the scaffold are 18.5 m at abutment A0 i 28.5 m at abutment A1.
Free cantilevering means performing in the segments of the span structure with both sides symmetrically. Technology of the span structure is divided into several steps:
Step 1:
– Installation of scaffolding for segment # 0 of box girders above the piers.
– Installation of formwork, reinforcement and cable bundles or ropes, installation of concrete segments # 0 in three phases.
– When the concrete reaches 75% of the designed strength and modulus of elasticitz, and when the age of concrete is not les than 3 dazs, followed bz installation of the scafofolding (hereinafter referred to as "ladder cage") in the segment # 0 (Figure 4).

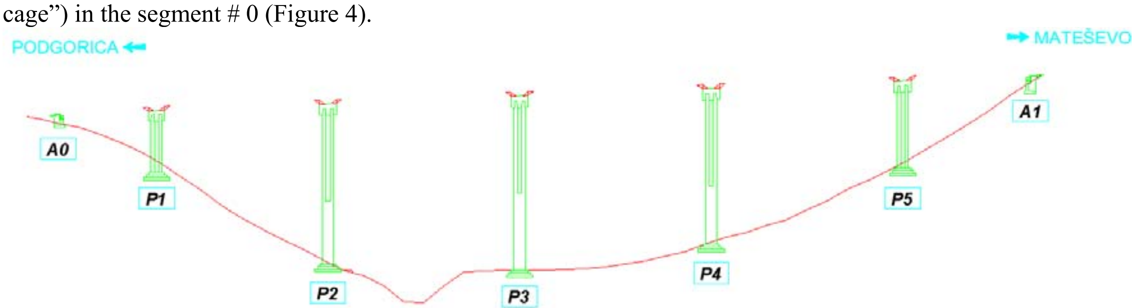


Figure 4: Performing of zero segment and preparations for the implementation of free cantilevering
Step 2:
– Installation of formwork, reinforcement and rebar cables, installation of concrete segments no. 1 by symmetrically balanced cantilever method.

– Installation of an adequate beam of ropes for pre-stressing, when the concrete reaches 90% of the designed strength and modulus of elasticity, and when the age of concrete is not less than 5 days and their shrinkage.
– Movement of ladder cage to segment no 1.
– Shrinkage of transverse beams ropes from the top segments # 0.
– Repetition of previous steps for performing segments from no. 2 to no. 19 for the pier P1, and segments from no. 2 to no. 24 for the pier P2, P3, P4 and P5., with the necessary adjustment and installation of pipes for transporting pumped concrete and thus step by step, to advance towards the center (Figure 5).

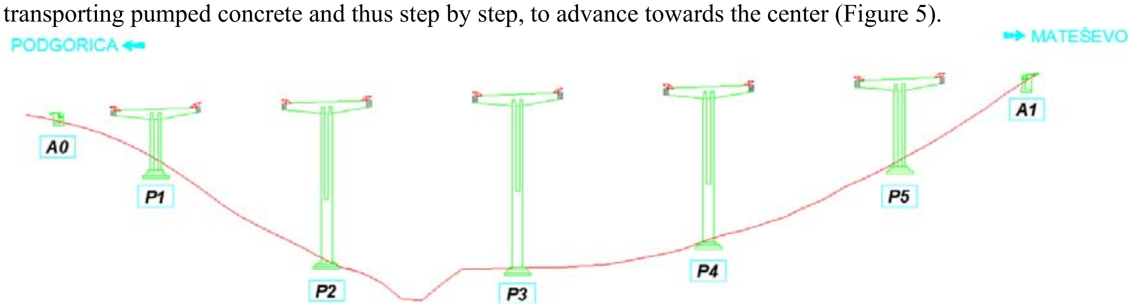
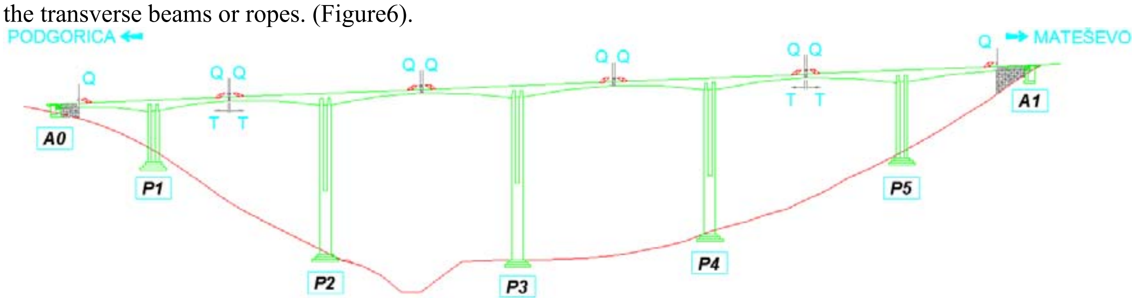


Figure 5: Symmetrical free cantilevering span structure of bridge Moračica

Step 3:

– During the execution of segment no. 2 to no. 24, installation of scaffolding segment casted on -site for the first to sixth span at the appropriate time. Installation of formwork, installation of reinforcement, cables, for bundles or ropes shrinkering, and then concreting segments on – site.
– Moving ladder cage in all spans back to one segment, installation of framework for lifting and applying counter load Q = 480 kN on the cantilever beams for all spans.
– Mounting and fixing rigid frames in the middle of the third and fourth span at the appropriate time, and skrinkering part of the temporary longitudinal beams or ropes.
– Installation of the formwork, installation of reinforcement and the cable ducts for the bundles or ropes shrinkering for the final segment in the third and fourth span.
– Concreting of the final segment in the third and fourth span, the gradual removal of the respective counterweight at the same time.
– Installation bundles or ropes for shrinkering, and when concrete finishing segments reaches 90% of the designed strength and modulus of elasticity, and when the age of concrete is not less than 5 days, shrinkage of the respective longitudinal beams or ropes and the transverse beams or ropes.
– Application of the horizontal force T = 3000kN in the middle of the second and fifth span.
– Fixing the rigid frames for the final segment, a horizontal relief force T = 3000 kN and shrinkering part of the temporary longitudinal bundles or ropes. Installation of formwork, installation of reinforcement, cables, for bundles or ropes shrinkering.
– Concreting of the final segments, the gradual removal of the respective counterweight at the same time.
– Installation bundles or ropes for shrinkering, and when concrete finishing segments reaches 90% of the designed strength and modulus of elasticity, and then shrinkage of the respective longitudinal beams or ropes and the transverse beams or ropes. (Figure6).



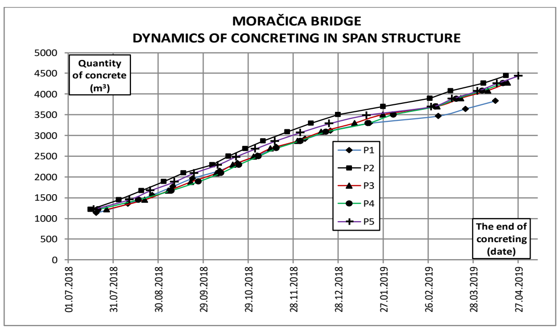
Slika 6: Preparation for the execution of the final segments of the Moračica bridge

Step 4:

– Fixing the rigid frame on the final segment in the first and sixth span, shrinkering part of the temporary longitudinal bundles or ropes. Installation of the formwork, installation of reinforcement and the cable ducts for the bundles or ropes shrinkering.
– Concreting of the final segments, the gradual removal of the respective counterweight.
– Installation bundles or ropes for shrinkering, and when concrete finishing segments reaches 90% of the designed strength and modulus of elasticity, and when the age of concrete is not less than 5 days shrinkage of the respective longitudinal beams or ropes.
– Removing the ladder cage and all the scaffolding (completion of construction).

2.1 The process of building the span structure

The authors didn't write in detail about the construction of scaffoldings (ladder cage) and machine technology in this paper, noting that for synchronized replacement of the construction for concreting one segment take only about two hours. Length of the structure, which includes a complete platform in front of the segment to be concreted is approximately 20 meters. With the application of stable tower crane (fixed to the pier), this technology allows concreting the next segment for a period of about 15 days on average (cycle time).
Concreting planned segment always ends as a whole without lengthy interruptions at the junction of the ribs with the bottom or top plate. After removal of the formwork and mounting in the position for executing the next segment, then so-called quick coupler. roughening is treated, and carries out the corresponding pre-stressing ropes bundle in the longitudinal direction and transverse to the top plate. After the supervising engineer views reinforcement and ropes of the next segment, including all necessary documentation (chek lists) concreting of next segment is allowed, which is carried out symmetrically on both sides. In this way, the projected position of the next segment within given tolerances is provided. The average amount of concrete for one section was slightly less than 200 m^3, but mostly the effect was approximately 20 m^3/h. On average, it was necessary approximately 10 hours per section.
On the following diagrams (Figure 7) the dynamics of execution for span structure with footing can be viewed, and by the end of September 2019. the completition of all piers is expected (22 months), or for the construction of the bridge about 3.5 years). It should be noted that in the foundations, abutments and middle piers (undercarriage) was placed close to 70,000 m^3 of concrete, and in the span structure about 20,000. m^3 so far, which is approximately 2450 m^3/monthly, or more than 80 m^3/day.



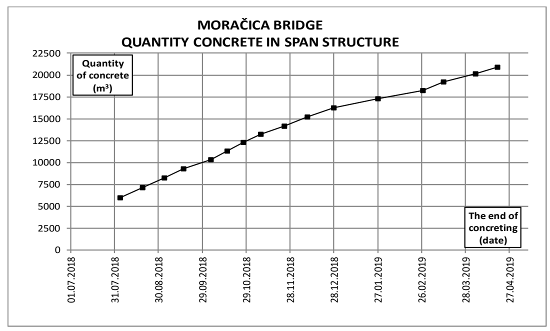


Figure 7: Graphic display of work executions on the substructure of the bridge Moračica (seventeen months)

Applied dynamics of the work execution on span structure, give the ability of smooth roadway construction on all spans. Above every pier a special group of workers and engineers worked on each part of span structure, and all of them had an independent equipment, and they've managed to finalize the work at the same time by planning the activities.

2.2 Monitoring the process of building the span structure

According to Project monitoring, the whole process of building has geodetic survey and the structure progress is being overlooked. The company COWI, Denmark has been engaged as a contractor's support during the monitoring of the execution of the superstructure of the bridge Moračica.
The task of these specialized company representing synchronized monitoring performance of individual segments (based on geodetic measurements) and the performance of the permanent correction of the position of the formwork following segments (left and right) according to budgetary parameters (including data obtained by measuring the rheological properties of concrete and thermal hygrometric data on the location of the execution works, in accordance with procedures described in detail in the monitoring Project. Absolute displacement of supports in a free virtual cantilever construction are viewed separately: shift due mainly axial stresses in the pier and foundation settlement, which is measured after every 5 symmetrical construction of the segments.
The theoretical values of the relative displacement (deflection) are calculated in accordance with the disposition, loads (including the pre-stress) and stress-strain state of the built elements, taking into account the rheological characteristics of the incorporated materials and phenomena related to the history of construction.
COWI's task is that in addition to imperfections during the execution of which are registered by geodetic measurements, includes actual rheological parameters into the control calculation, in order to monitor the deformation line along the theoretic grade line and after coupling the bridge get satisfactory matching, according to the tolerances, and the projected convexity. This is how the projected bridge grade line after 30 years of exploitation will be provided, when it is considered that there is no change of rheological parameters.

Stress – strain state is also monitored in relation to the history of the building and the possible effects on certain parts of the structure. This process is of particular importance when building a span structure, whose final disposition depends on a number of influential parameters, and the experimental measurement of this condition is necessary in order to follow the direction of the cantilever and the amount and basis and thus meet the limit states usability in service during the execution.

3. TECHNICAL REVIEW

The Committee for comparative technical review has carried out regular checks during all phases of construction to be closed and which won't be available later by visual control. At the same, the Committee continuously had access to all necessary documents, based on which give partial reports of the technical review of certain phases could be written. The Commission has carried out partial technical inspections of the middle foundation piers, abutments, and middle piers (lower structure), so that these reports along with the report of the span structure, constitute an integral part of the final report on the technical inspection of the bridge, which can thus be carried out considerably more efficiently. After the load test, equipping, development of terrain and roadway structure, there'll be the final report with the offer to the investor about the possibility of use.
During and after the construction a geodetic report will be formed, i.e. the structure review with the real position of the dimensions (a zero reading for the exploitation), by height and situational, and according to the surveying of soil and structure project, continuously geodetic observation during operation is necessary. Preparation of the design of buit structure represents the end point in the realization of such an important endeavor.

4. CONCLUSION

For the construction of large infrastructure and other important structures, it is necessary to carry out technical reviews during construction works in stages. This includes all the necessary procedures, as it is usual for the technical review of built structure with more quality, since the Committee has access to the hidden works. It seems that this approach can contribute significantly to the quality of construction, which can significantly reduce maintenance costs during exploitation. National authorities that establish regulations and standards, which must be in accordance with the latest European regulations – Eurocodes, should incorporate this approach in their national annex.
Technology of constructing large structures, often influences the choice of structural solutions, which must be adapted to the optimum and efficient construction conditions. Application of cantilever method in the construction of high bridges, can contribute significantly to cost–effectiveness, and systems which are the product of this approach present lean and aesthetically pleasing structures. The bridge Moračica which with its grandiosity exceeds the current limit within Montenegro and the region represents such an example. In support of this constatation is the fact that on this structure go over 10% of the total investment for the construction of a section of highway Podgorica – Mateševo, whose length is 41 km.
Applied construction technology free cantilevering span structure with the scaffold exemplifies Moračica bridge, such that the large structures can be constructed more quickly and efficiently, as shown by the parameters presented in this paper, which are obtained from the dynamics of work execution. It should be particularly emphasized the importance of constant monitoring of construction, since the length of the free cantilevers are close to 100 meters. Applying real budgetary parameters of concrete and taking into account all the effects, can significantly help to solve problems and reduce undesirable errors in the final bridge grade line. The presented data in this paper, may well serve to civil engineers while planning the construction of major infrastructure facilities, or facilities of particular national importance.

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