ASSESSMENT AND REPAIR OF RC WALL FOR DEFENSE AGAINST SAVA FLOOD WATERS

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Summary: *At the end of the seventies, it was noted that built defensive line, along the left bank of the Sava River in the city core of Sremska Mitrovica (km 3+009 to 6+150), does not meet the criteria for defense against the ruling 1% of the great water of the river. Accordingly, the drafting of project documentation and, later, construction of the facility, started. Defense on section 4+189 to 4+232km represents the reinforced concrete wall.During the period of high water levels of the Sava River in May 2014, the water leaks through the concrete wall were registered. In this study, a series of activities to assess the condition of the RC wall and the proposal for its repair were carried put, in order to restore full functionality of the defensive wall, i.e. the defense of the city of SremskaMitrovica from the flood waters of the river Sava.*

Keywords: *defensive line, high water, wall, cracks, repair*

1. INTRODUCTION

At the end of the seventies, it was noted that built defensive line, along the left bank of the Sava River in Sremska Mitrovica (km 3+009 to 6+150), does not meet the criteria for defense against the ruling 1% of the water of the Great Basin. Accordingly, the drafting of project documentation andconstruction of the facility started. Defense on section 4+189 to 4+232km represents the reinforced concrete wall.Profile of reinforced concrete wall consists of a crown width of 40 cm, external vertical wall face and the inclined innerface with a slope 1: 0.7 and the footing 0.5 m thick. Behind the concrete wall, there is the embankment of the cohesive soil with a width of 6.00 m and a crown elevation 80.76 m above sea level and slope inclination 1.3. Embankment coated with cobblestones with slope of 1: 2 was designed in front of the wall. The wall has two openings, one of a width of 6.0 m, and the other a width of 2,0 m [1]. During the period of high water levels of the Sava River in May 2014,the water leaks through the concrete wall were registered. In this

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study, a series of activities to assess the condition of the wall and the proposal for its repair were carried put, in order to restore full functionality, i.e. the defenseof the city from the flood waters of the river Sava.

2. DETAILED VISUAL INSPECTION

The subject section of the concrete wall along the embankment on the left bank of the Sava River include: the upstream part of the wall, openings of the wall for the pontoon bridge and downstream part of the wall (Figure 1). Visual inspection of the concrete defensive wall clearly shows the boundary between the "old" concrete wall and "new" - the extension of the concrete wall.Besides the visible lines of continuation of concreting, lower and upper part of the wall differ in appearance of concrete surfaces. The lower (old) part of the of the concrete wall is constructed with a flat concrete surfaces, while the new (upgraded) is part of the defensive wall constructed with shallow vertical channels - cannelures (Figure 2).

Fig. 1. The concrete wall on the left bank of the Sava River

Fig. 2. The appearance of the "old" and "new" part of the concrete wall (downstream part)

By analyzing existing technical documentation, geometry and the current design of the concrete wall on the downstream and upstream side, it was observed that the concrete wall was not performed in accordance with the design documentation. The following differences were registered:

- there are no visible parts of the counterforts on either the upstream or the downstream side of the defensive wall, while the counterforts in the zone openings were performed,
- the width of the defensive wall in the area around openings is not in accordance with project documentation,
- in the downstream part, slope in the flooded part doesn't start directly from the defensive wall, a horizontal plateau is builtfirstly, then the slope covered with concrete slabs.

A detailed visual inspection has revealed following characteristic damages:

- vertical cracks in the upstream part of the wall,
- settlement of soil in the area of junction of pontoon bridge and a defensive wall,

- vertical cracks in the "new" part of the defensive wall on the downstream side,
- slump of concrete cover on the slope of downstream embankment part,
- the concrete surface erosion.

In the upstream part of the defensive wall, crack width of 1mm was registered (Figure 3). The crack is located at the place of the wall thickness change. Crack is vertical and passes through the new (upper) and the old (lower) part of the wall and covers the entire cross-section. The crack is wider on the new section of the wall.

In some places, local crushing of concrete in the zone of cracks has been observed. The figure clearly shows the erosion of the surface layer of concrete, which manifested with flushing of cement stone and bearing of larger aggregate grains. This appearance is characteristic for the so-called "new" part of the of the concrete wall.
Characteristic damages of the upper part of the concrete wall are vertical cracks, passing throughout entire wall thickness. Described cracks are usually located in places of cannelures - Figure 4.

Fig. 3. Vertical crack on the interior defensive side of the concrete wall (at the place of the extension of the wall)

Fig. 4. Cracks in the concrete wall (view from the side and top)

Width of the cracks ranges from 0.5 - 5 mm, and pass through the cement stone (aggregate grains bypassed). On some cracks white spots were observed, as a result of leaching of cement stone. Possible causes of the described cracks are the shrinkage of concrete and/or thermal contraction. Besides the cracks, on the downstream part of the concrete wall, following damages were observed: erosion of the concrete surface in the form of increased porosity of the surface layer of concrete, flushing of cement stone due to bearing of coarse aggregate grains.
Visual inspection revealed settlement of certain parts of the concrete cover on the horizontal part of the embankment. It is assumed that the contact filtration, below the slipway of pontoon bridge, consequently caused a settlement of this cover, which is close to the opening for slipway of pontoon bridge (Figure 5).

Fig. 5. Settlement of concrete cover over a length of about 10 m

3. QUALITYCONTROLOF INCORPORATED MATERIAL

For the purposes of determining the condition of the defensive concrete wall and the conceptual repairdesign, 12 concrete cores were taken and the following was examined:

- concrete compressive strength,
- resistance of concrete to frost and
- water-permeability of concrete.

Figures 6-8 present samples for testingof mentioned properties.

Figure 6 - The concrete core for determination of the concrete class

Figure 7 - The appearance of the damaged sample after 50 cycles of freezing and thawing

Figure 8 - Concrete specimen with visible border of penetrated water

Based on the tests of compressive strength of concrete samples, reduced to the age of 28 days, it was found that the concrete incorporated in the concrete wall (new part) meets the requirements for class C35/45.
During the test, after 50 cycles of freezing and thawing, five samples suffered damages due to the destructive effects of frost, such as:

- net-like fissured in the concrete surface,
- crumbling, spalling and falling of concrete parts.

After that, testing was stopped and it was concluded that the concrete incorporated in concrete defensive wall on the embankment on the left bank of the Sava in Sremska Mitrovica does not meet the minimumclass of resistance to frost - M50.
Based on the maximum depth of penetration of water under pressure, it was concluded that the concrete incorporated in concrete defensive wall on the embankment on the left bank of the Sava in Sremska Mitrovica meets water-impermeability class V4, asthe average depth of water penetration is 50 mm.

4. EVALUATION OF THE CONCRETE WALL CONDITION

Based on the conducted survey, tests and collected data, following facts were found on the concrete wall on the left embankment along the Sava in Sremska Mitrovica:

- Concrete wall is not fully derived in accordance with project documentation from 1970. During the flood in 2014, leakage of water through the defensive wall was observed (new part) at the place of formed cracks, and below the plateau in the zone of openings of pontoon bridge.
- The characteristic damages of the concrete wall are vertical cracks, which encompass the whole cross-section of the wall and whose opening width ranges up to 5mm.
- The concrete surface of the new (upper) part of the concrete wall is affected by erosion processes (flushed cement stone, exposed and visible grains of coarse aggregate, porous surface layer of concrete…).
- Due to soil washing in the zone of openings in the concrete wall, there was a local deformation of embankments and settlement of concrete cover.
- Concrete incorporated into defensive wall has high mechanical characteristics considering the designed class 160 MB (old code). After 45 years of exploitation, concrete satisfies the conditions for class C35/45.
- Concrete does not meet the minimum class of resistance to frost - M50.
- Concrete meets water-permeability class V4.

Analysing all the test results, collected data by detailed visual inspection as well as data on levels of high water during the flood of 2014, the condition of the concrete wall can be assessed as follows:

- Registered damages are of such extent and nature that load-bearing capacity and stability of the concrete wall are not endangered, but its functionality (barrier to water penetration) and durability are jeopardized.
- In order to ensure the functionality of concrete defensive wall, or prevent the entry of water through the cracked parts of the concrete wall and the ground beneath the plateau, it is necessary to implement appropriate repair measures.
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5. REPAIR SOLUTION

Repair proposal for concrete wall in the embankment on the left bank of the Sava in Sremska Mitrovica includes the following repair works, whose main goal is to prevent water penetration through the concrete wall and the penetration of water through the soil:

- repair of vertical cracks on the upstream part of the concrete wall (one crack, length of 1.5 m),
- repair of cracks in the downstream part of the concrete wall(23 cracks, the average length of 0,8m),
- repair of water penetration through the embankment in the area of the opening of the pontoon bridge and
- repair of concrete cover settlement and deformations of the embankment part on the undefended side of the wall.

Vertical cracks on the upstream part of the concrete wall can be repaired using the technique of injection under pressure (Figures 9 and 10).

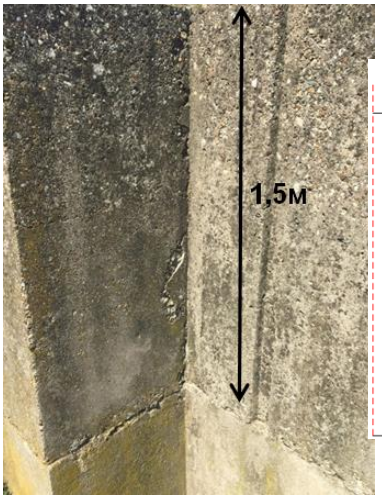

Figure 9 - The appearance and position of the subject crack

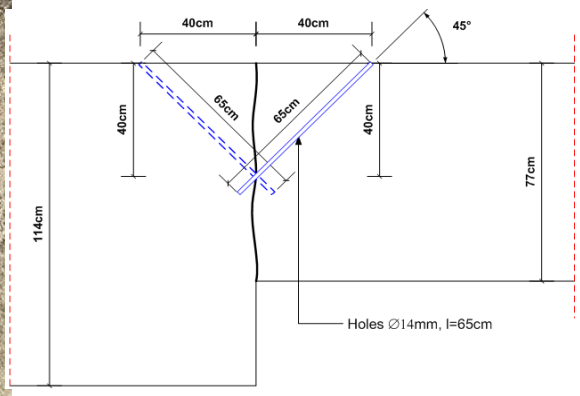

Figure 10 - Detail of drilling holes in the wall for injection of vertical cracks

Order of operations is as follows:

- Drilling of injection channels, alternatively from the left or right side of the crack at an angle of 45˚, so the gap is cut in the middle of concrete wall.
- Surface caulk on the sides of the wall with quick-setting mortar to prevent the loss of resin.
- Setting the packers from stainless steel, with double protection, that endure the pressure up to 200 bar.
- Injection of cracks using the elastomeric resin and a one-component injection pump.

- Packers' removal.

Cracks in the downstream part of the concrete wall (in the "new" - upper part) can be repaired by roating and sealing technique (Figure 11).

Order of operations is as follows:

- Surface sealing of cracks on the sides of the concrete wall to prevent loss of resin.
- Roating of concrete in the crack zone on the upper side of the wall, in a "V" shape, to a depth of 2cm - formation of a "reservoir" on the upper side of the wall.
- Sealing the cracks by injection elastomeric material with low viscosity.
- When it is determined that the resin does not longer penetrate into the crack, floating resin on the top should be sprinkled with quartz sand.

Figure11 – Repair of cracks byroating and sealing technique

Settlement of concrete cover on the undefended side of the wall should be repairedby reconstruction of concrete cover and embankment part (Figure 12).

Order of operations is as follows:

- Careful removal of concrete cover over a length of 10 m.
- Reconstruction of the front part of the concrete prisms (optional) with concrete (1.0 m^3 of concrete needed for the repair of this part of the cover)
- Filling settled embankment part with approximately 10 m^3 of sand and about 3 $m^3$of buffer layer of gravel.
- Replacing the concrete cubes.

Figure 12 - Reconstruction of concrete cover and embankment

The penetration of water through the embankment in the area of the opening of the pontoon bridge is repaired by creating filtration curtains (the mixture of bentonite and sand, thick 4-6cm depth up to 6m). The technological process includes performing filtration curtains by injecting hollow steel piles and filling the cavity by injector pump (Figures 13 and 14).

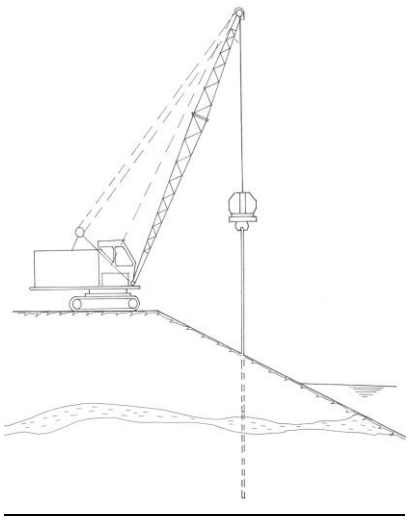

Figure13 – Injecting hollow steel piles

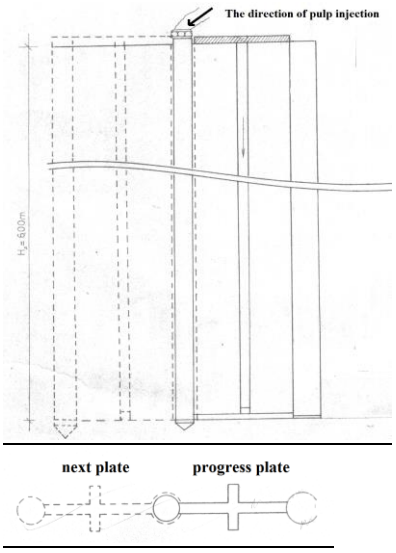

Figure14 – Installation scheme of filtration curtains

6. CONCLUSIONS

This study presented a series of activities to assess the condition of the RC wall and the proposal for its repair, in order to restore full functionality, i.e. the defenseof the city from the flood waters of the river Sava. Based on the results, the condition of the wall was assessed as follows:

- Registered damages are of such extent and nature that load-bearing capacity and stability of the concrete wall are not endangered, but its functionality (barrier to water penetration) and durability are jeopardized.
- In order to ensure the functionality of concrete defensive wall, or prevent the entry of water through the cracked parts of the concrete wall and the ground beneath the plateau, it is necessary to implement appropriate repair measures.

Repairproposal for concrete wall included the following repair works:

- repair of vertical cracks on the upstream part of the concrete wall,
- repair of cracks in the downstream part of the concrete wall,
- repair of water penetration through the embankment and
- repair of concrete cover settlement and deformations of the embankment part on the undefended side of the wall.

By the implementation of the proposed repair measures of RC wall, it is possible to prevent the entry of water through the concrete wall and the penetration of water through the soil in the zone of opening for the pontoon bridge, which provides the functionality of a

concrete of the wall and the defense of the city of Sremska Mitrovica from the flood waters of the river Sava.

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ПРОЦЕНА СТАЊА И САНАЦИЈА АБ ЗИДА ЗА ОДБРАНУ ОД ПОПЛАВА РЕКЕ САВЕ

Резиме: *Крајем седамдесетих година прошлог века констатовано је да изграђена одбрамбена линија дуж леве обале реке Саве у градском језгру Сремске Митровице (км 3+009 до 6+150) не задовољава постављене критеријуме за одбрану од меродавне 1% велике воде реке Саве. Сходно томе, приступило се изради пројектне документације а касније и изградњи објекта. Одбрамбену линију на деоници од 4+189 до 4+232 чини армирано бетонски зид. У току трајања високих водостаја регистрована су процуривања воде кроз зид. На конструкцији зида уочене су пукотине кроз које је вода процуривала у брањен терен. У раду ће бити приказан низ активности на процени стања АБ зида и дат предлог за његову санацију, у циљу враћања потпуне функционалности, тј одбрана града Сремске Митровице од поплавних вода реке Саве.*

Кључне речи: *одбрамбена линија, висок водостај, зид, пукотине, поправка*