Quay Structure on River Sava in Croatia

Zorislav Sorić
Tomislav Kišiček
Josip Galić

Abstract: The 120 meter reinforced concrete quay on river Sava at Slavonski Brod, Croatia, has been finished, after eighteen months of construction work. Foundations of the structure, consisted of reinforced concrete geotechnical diaphragms and piles. The quay structure was simple and robust. It has been constructed of in-situ made base girders, longitudinal and transverse walls, and of columns. Reinforced concrete elements at upper level such as girders and plates were prefabricated, while upper slab was cast in place. Back-wall has anchorage tendons at the top for decreasing of top horizontal movement of structure. The anchorage tendons, two of them at every 5,0 m, were anchored to the another longitudinal wall that was placed in intact soil, 15,0 m away from the back wall. The space behind back-wall was filled with soil and compacted in layers.

Keywords: quay structure, reinforced concrete, prefabricated elements, construction, walls

1. Introduction

Quay structure on the bank of river Sava, near town Slavonski Brod, about 200 km east from Zagreb, was planned to be constructed in several phases. The first phase of reinforced concrete quay structure consists of two parts of 60 m length each, separated by movement joint. Inland waterway of river Sava is of IV international class, as found in Review of the Classification of European Inland Waterways, (1996), [1]. Navigation clearance of the waterway is 2,9 x 70,0 m with the minimum radius of 400 m. The waterway can take pushing convoy of one lighter and boxer whose dimensions could be as much as 85,0 x 9,5 x 2,5 m. Oscillation, i.e. difference between the extreme water levels is 10,0 m and oscillation of navigable water levels is 7,0 m. The development plan predicts in perspective that Slavonski
Brod will become an traffic and trade center. Inland waterway goods traffic on landing stage would be realized by reloading gravel, sand, grain and raw oil. The quay structure was constructed of concrete grade 40 (MPa) and reinforcement of grade S-400 (MPa) rebar.

2. Quay structure loadings

- Sustained loading: structure self-weight, hydrostatic pressure for regular high, mean and low water level (buoyancy), soil pressure for regular high, mean and low water level, uniform live load: 2 rows of containers, with loading of 35 kN/m², crane not in use; crane in use; crane driving, road loading on quay, snow, ice.
- Variable loading: additional soil pressure from: uniform live load on embankment; mobile crane on embankment; road load on embankment, temperature, braking and accelerating of: mobile crane; road vehicle, operating wind (v=20m/s) on crane in use, perpendicular to and along the quay, ship impact by landing for different water levels: perpendicular and along to quay length; rope pull force, for different water levels: perpendicular and along to quay length; vertical force due to friction of ship toward quay, for different water levels; hydrostatic pressure of residual water behind wall; wave pressure for regular high water level; wave pressure.
- Accidental loading: wind storm (40 to 50 m/s), on crane; ship impact by landing; hydrostatic pressure for accidentally high or low water level; seismic force on self weight of structure at mean water level; seismic loading on soil behind wall by different water levels; seismic forces on crane (horizontal perpendicular and alongside).

3. Structure

The quay structure has been divided into two parts of 11,6x60,0 m each. From working plateau, geotechnical diaphragm of 60-cm thickness and 15,0 m depth in soil is constructed on the riverside. The so called half-diaphragm is constructed 5,25 m apart from the center of diaphragm in transverse direction. Its depth in soil is 13,0 m, thickness is 60-cm and length 2,5 m, and its centre to centre distance is 5,0 m apart alongside, which means that every 2,5 m between two half-diaphragms is soil. Drilled piles of 1,0 m diameter are constructed on backside of quay, 5,25 m apart from the half-diaphragm in transverse direction, with depth of 13,0 m inside soil and 5,0 m apart in longitudinal direction. Figure 1 shows cross-section of the reinforced concrete structure and slope of riverbank before construction. Figure 2 shows construction of geotechnical diaphragms and piles.
The back-wall cantilever and anchorage tendons on the right side of the structure (Figure 1) could be seen as well.

Upper-structure (from the level +83.00 up) consists of lower and upper longitudinal and transverse girders grid. On the top of the lower grid, longitudinal walls were constructed (riverside-wall and backside-wall), as well as transverse walls and columns. Upper grid consists of longitudinal and transversal girders as prefabricated reinforced concrete elements. Upon them prefabricated reinforced plates of span $L = 1.1$ m and 1.8 m, and thickness of $h = 8$ cm, were placed. Girders and prefabricated plates were then all connected by reinforcement and cast in place concrete slab.

Back-wall has the longitudinal cantilever at its bottom for the reason of decreasing the overturning moment caused by soil pressure, and anchorage tendons at the top for decreasing of top horizontal movement of structure. The anchorage tendons, two of them at every 5.0 m, were anchored to the another longitudinal wall that was placed in intact soil, 15.0 m away from the back wall. The space behind back-wall was filled afterwards with soil and compacted in layers. In transverse direction, between front and back longitudinal walls, the 30-cm walls, 10.0 m apart were constructed above transverse girders. In the centre of the field between transverse and longitudinal walls (at the connection of transverse and longitudinal girders) the RC columns of cross section $1.0 \times 1.0$ m were constructed. Those columns, 10.0 m apart of each other, were provided with square ($1.4 \times 1.4$ m) heads at their top level of +89.5 m, in order to allow placing of prefabricated girders of upper grid on top of them.

Concrete cover of all elements was at least 4 cm for those that were not in contact with soil. For those in direct, unprotected contact with soil, cover was 7 cm.

Of all loading that act on top surface of structure at level +91.50 m, the mobile crane loading is the most important, because of its weight and size. Besides, the mobile crane can move in all possible unfavorable places for structural elements. This type of crane has four axles on wheels and extensible legs. Distances from center to center of legs are 11.50 m in
one and 10,00 m in other direction. The size of each leg is 1,20 x 1,80 m. Its total weight in work is 2500 kN. The maximum load on one leg could be as much as 1462 kN which means 677 kN/m2 on reinforced concrete slab below the leg. This kind of load is way above any other load and therefore is relevant for design. Calculation was done for two parallel-working cranes.

Figure 3 and 4 show reinforcement for front wall in September 2003.

In order to prevent extensive cracking in reinforced concrete elements, the thinner steel ribbed bars were used. The diameter of steel bar was no greater than \( \phi 22 \) mm in lower zone and no more than \( \phi 25 \) mm in upper zone, and the tensile stress in steel bars during service were calculated to be no greater than 300 N/mm2. All girders columns and slabs were reinforced with steel bars S-400. One of the reinforcement-plans could be seen in Figure 5.

### 4. Analytical model

Due to large horizontal forces of soil pressure on back wall, it was necessary to provide anchorage tendons at upper part and cantilever at bottom part of the back-wall of the structure.

The structure analysis has been made on the 3-D model. This analytical model comprised foundation structure and upper structure. The contacts of both structures have been modelled by springs. The mechanical properties of springs were obtained from soil mechanic expert, according to test results, as well as from iterative calculation of soil force/displacement interaction. Diaphragm has been modelled by shell-elements, while half-diaphragm and piles have been modelled by beam-elements. At first, structure was modelled without the back-wall cantilever. Though, horizontal displacement toward river, due to soil pressure, was too big, causing too high force in anchorage tendons, that it was necessary to
model back-wall cantilever. The ship impact on the front wall was modelled by movable loads. This impact force was distributed on top edge of each field at 5.0 m length and moved down stepwise every 1.0 meter. It was found that the ship impact has its unfavourable influence when applied to the top of end field of the structure, while it caused impact and torsion of the structure as well.

Figure 5 View and cross-sections of front wall with reinforcement
Figure 6 shows soil pressure loading on back-wall and cantilever as well as anchorage tie force. The mobile crane loading was modelled as a load of each of four legs by a group of three critical forces in one line. Those forces were moved along the structure on different positions in order to induce maximum internal forces in structure. There were altogether 271 load cases.

5. Construction

Construction of quay structure started by the end of the year 2001. Then it stopped for more than a year, to be continued in spring of the year 2003. At that time the construction of geotechnical diaphragms and piles was done. Erection of upper structure began in September 2003. Figure 7 shows state of structure flooded by high water in October 2003. Figure 8 shows the state of construction one month before flooding.
Figure 9 and 10 show construction of the quay structure walls in November 2003.

During winter time construction work was stopped, and continued in spring 2004. Wall framework and reinforcement of walls, in May 2004, is shown in figure 11. Connection of prefabricated beams of upper grid with column is shown in figure 12.

Thin prefabricated (6 cm) plates were then placed upon beams. Final reinforcement of slab was then placed on prefabricated slabs and beams, and connected with reinforcement from walls and girders. Figure 13 shows reinforcement of upper slab before concreting in December 2004.
6. Conclusions

Design and construction of ship landing stage is complex engineering task that needs good preparation and cooperation among several civil engineering experts. This type of structure is submitted to a great number of different influences, but analysis has confirmed that vertical and horizontal loading due to mobile cranes, ship impact forces, and soil pressure are the most relevant for analysis of the structure. Construction of the quay structure is finished by the end of the year 2004, and opening for function will take place in summer 2005. All quay structure, with diaphragms, piles and upper structure, contains 6396 m$^3$ of concrete and 650 t of steel reinforcement.

References


Authors

Professor, Ph. D. Sc., Dipl. Ing. C.E., Zorislav Sorić: Faculty of Civil Engineering, University of Zagreb, Kaciceva 26, Croatia. E-mail, soric@grad.hr

Assistant, M. Sc., Dipl. Ing. C.E., Tomislav Kišiček: Faculty of Civil Engineering, University of Zagreb, Kaciceva 26, Croatia. E-mail, kisha@grad.hr

Assistant, Dipl. Ing. C.E., Josip Galić: Faculty of Civil Engineering, University of Zagreb, Kaciceva 26, Croatia. E-mail, jgalic@grad.hr