The storm water drainage and treatment systems at the “Gazela” bridge in Belgrade, Serbia – A case study

Le système de drainage et de traitement des eaux pluviales sur le pont "Gazela" à Belgrade, Serbie – étude de cas

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Résumé
Le pont « Gazela », situé au-dessus de la rivière Sava, fait partie de l'autoroute E75 à Belgrade. Il a été construit en 1970 et reconstruit de 2010 à 2012. Nous décrivons ici le projet de drainage du pont dans le cadre de sa reconstruction. Le pont est situé dans une zone protégée autour de la source d'alimentation en eau potable de Belgrade, et est donc soumis à des contraintes sévères en termes de rejets d'eaux de pluie. Le projet a été conçu sur la base d'une pluie décennale. L'écoulement pluvial de la plate-forme du pont et des voies d'accès s'écoule via de nombreux dispositifs : bouches avaloirs en bord de trottoir, tuyaux installés le long des structures du pont, rejets vers le réseau d’assainissement de Belgrade ou vers des dispositifs de premier flot et rétention/infiltration sur les rives de la rivière Sava. Les tuyaux sont fixés sur la structure du pont au moyen de crochets ou d’ancrages, ou posés sur des rouleaux. Les sous-systèmes comprennent plusieurs éléments de réduction ou en « T », des coudes et des installations pour compenser les différents impacts de la structure du pont, notamment les mouvements ou les affaissements de la structure. Les avaloirs sont placés à des intervalles de 11 m environ pour répondre aux critères d'écoulement acceptable de jusqu'à 1/3 de la largeur de la voie de circulation, l'eau s'écoulant ensuite dans les tuyaux en dessous de la structure du pont, puis dans des tuyaux souterrains.

Abstract
The “Gazela” bridge over the Sava River in Belgrade on the E75 highway was constructed in 1970 and reconstructed from 2010 through 2012. The paper presents the bridge drainage design project for the bridge reconstruction. The bridge is located within the protected area of the Belgrade potable water supply system, so the constraints for storm runoff discharge are severe. Design was based on the 10-year design storms. Storm runoff from the bridge deck and access roads is conveyed into numerous drainage systems comprised of gullies in the curbs, pipe connections to pipelines along the bridge structure, discharge of storm water to either the Belgrade sewer system or to the systems for treatment of the “first flush”, and retention and/or infiltration into the banks of the Sava River. Pipelines are attached to the bridge structure by hooks and anchors or laid on the rollers. Drainage pipeline subsystems consist of numerous reduction and “T” pieces, bends and devices for compensation of various impacts of the bridge structure and pipelines, particularly movement and displacement of the bridge structure. The gullies are placed at a distance of approximately 11 m to fulfill criteria of allowable flow spreading up to 1/3 of lane width, and are further drained into the pipelines along/underneath the bridge structure before entering underground pipelines.

Keywords
Bridge, Drainage, First flush, Infiltration, Pipeline, Retention, Sewers, Stormwater, Treatment
1 INTRODUCTION

An urban drainage system design principles and procedures cannot be easily taken into analysis of capturing and conveying storm water from a motorway bridge deck including access roads and approaching loops. A drainage system of a bridge functions in three directions, accounting for the strong need that the bridge structure, either steel or concrete, has to be protected from storm runoff, water infiltration into the layers or strata, or seeping over the structure downward to the fundaments.

The bridge structure (steel, concrete or composite) and the bridge drainage system which is hooked and/or attached to the bridge should be elastic and stiff. Stiffness of the structure as a whole, including pipelines, is secured with fixed points. Bridge deformations including deflexions, displacements, either elongation or shrinkage of the steel or concrete structure should be accomplished by rollers and / or compensators, and the pipe characteristics such as diameter, flows and weight usually have to be adjusted.

The composite bridge and pipeline sub-systems are under two major impacts: (1) load, and (2) temperature differences. Dilatation devices on the bridge provide certain independence of behaviour and even bending of the steel structure from concrete ones, including incident pipelines’ subsystems adjustments.

The bridge deformations estimated, either moves or deflections, due to temperature or traffic load impacts, could be of magnitude up to app. 30 cm to 40 cm, what furthermore provoke a decrease of pipelines slope up to half a percent. In such respect, pipe analysis should be completed with estimation of such changes in time, and checking if the pipe slopes and diameters could provide needed capacity. During winter freezing times, dispersed sand/gravel for de-icing purposes produce suspended sediments what furthermore decrease flow capacity and so, the minimum permissible mean velocity in pipes should be checked.

Last, but not the least, a series of construction work limits and habits have to be obeyed, e.g. “the pipe should be (hooked) at equal distance from the concrete/steel edges” or “pipes should be parallel to the structures edges or rectangular to other lines”. The least acceptable from an aesthetic point of view are slant pipes, even short ones and underneath the bridge. Such a condition is often demanded by either city or bridge architects, since major pipelines are visible from a distance but could be seen from vicinity. Also, pipelines appurtenances, like T pieces, bends, curves, revision pits and others are often designed with respect to architectural and visual adjustments.

A numerous conditions and terms for discharge of runoff waters into public urban drainage and/or sewer system, into the rivers and into retention and/or infiltration facilities, are issued by water and environment authorities, such as ISS (2011). Those were applied within design and construction of several bridges along the Sava River upstream Belgrade, such as: Obrenovac, Ostruznica, and Gazela (Despotovic et al., 2007, 2010).

2 CONDITIONS AND TERMS FOR DRAINAGE DESIGN PROJECT

The „Gazela” bridge was constructed without storm drainage system, and a series of inlets as holes drained runoff downward to either the ground, lower access roads of the loops or the Sava river, as it was practice at that time throughout. It consists of three structures: the accessing r. c. structures on the left bank (692 m), steel bridge deck over the Sava river (469 m), and access road with r. c. structures on the right bank (1,584 m). In total it makes 2,745 m. The total drained area is more than 65,000 sqm, including the two loops, “Sava Center” and „Mostar”, in Figures 1, 2 and 3.

A complete drainage consists of a numerous subsystems at the both banks, incident outlets, even based upon different Constrains in terms of bridge structure - either reinforced concrete or steel, depending also on type of waste water system, either combined or storm water and their status, including a variety of environmental, transportation and aesthetic aspects (Despotovic, 2009).

The task was to provide a thorough, detailed and efficient swiping - capturing / drainage of runoff from the each / every subsurface by inlets / gullies, from the aspect of securing high traffic safety, preventing deck flooding, and conveyance of collected surface runoffs to the piping system installed under the bridge leading further towards the public drainage / combined systems. Discharge of water should be treated under the required strong protection by municipal and national authorities, of the potable water sources zones, bathing and natural protected zones, and limits of discharge quantity into the Belgrade Sewer System (BSS).
The bridge is located within the potable water protected area and only treated water was allowed for infiltration accounting for recent environment policies. The activities on survey for design project of the bridge reconstruction including drainage and treatment system were in accordance to SRPS-EN 752 and 858, and requirements relating to pre-treatment of the surface runoff were added.

The bridge structure, either steel, reinforced concrete or composite one, including drainage systems should be flexible and stiff at the same time. That means pipes with fixed nodes, hooks and anchors, rollers and/or compensators, and the pipes’ characteristics, such as: diameters and flow rates / specific weight, have to be accepted and to get adjusted to series of deformation, such as: deflexions, displacements, either elongation or shrinkage of the steel structures, as well as of the reinforced concrete. Those composite system, bridge and pipeline sub-systems are under several impacts, such as: load - either construction weight with or without traffic, and temperature, general structure and temperature difference (between sunny and shade sides of the bridge).

At the “Gazela” bridge dilatation facilities provide certain independence in behaviour of the steel from r. c. structures, followed by the pipelines’ sub-systems proper adjustments.

Pipelines, most of those visible, should have been parallel to the structure edges, either concrete or steel, and also a tiny requirement was to have pipes of the lesser diameter as possible. Those were additional reasons that drainage concept was based on a numerous sub-systems, instead caring waste water for hundreds of meters of pipeline. In Figures 4 and 5 are presented pipelines parallel to those edges and also of rather small diameters, such as 300 mm.

3 PARTS OF THE DRAINAGE SYSTEM

A rainfall runoff analysis based on usual procedures provided a numerous criteria flow rates at the ends of a series of sub-systems. Those were defined together with Belgrade waste water authorities accounting for hydraulically less or more loaded major trunks and pipes. For defined pipes characteristics and the structure characteristics, additional series of pieces, elements and devices were used for a completion of a numerous drainage sub-systems all along the Gazela bridge. Some of those are presented using the drawings from the design projects (Despotovic et al., 2007, 2009, 2012), and some of those given in photos of the set pipelines.
The criteria rainfall specified is 10 year return period using the data from the Vracar gauge station and duration from 5 to 30 minutes. Runoff coefficient is equal to 1. Runoff at the bridge deck and access roads was calculated to be captured by special curb inlets and is discharged into the pipelines along and under the bridge, and further into either of the BSS subsystems. The inlets are placed at an average distance of 11 m. At the steel structure of the central part the inlets are doubled, set in pairs. It is calculated under the specified limits for surface flow spreading up to app. 4 m of the pavement thus utmost 1/3 of the traffic line which is 11.45 m wide. There are 20 drainage subsystems, ending toward 10 outlets, 2 of them on the left bank.

The efficiency of capturing runoff should have been of high reliability in respect to demands that surface retention of runoff water between the inlets has not been allowed, including preventing of flushing. Since the both pavement slopes were varying at the steel part of the bridge, and so is the inlet capacities (Despotovic et. al., 2005), inlets were twinned (Figures 6 and 7). The inlets are set into the curbs also due to the needs for high safety of traffic (Despotovic et al., 2007).

Figure 8 presents position of an inlet including attachment with expansion joint and the 300 mm pipeline. The pipe hanging is estimated and set at 70 cm below the concrete edge. In Figure 9 is presented a junction of a two pipelines, one horizontal along the approach road to the bridge and the cross pipeline the end of which is a revision as well.

A prevention of clogging and decreasing of the pipelines capacity is also prevented by collecting tray within the inlets, serving as a deposition pits beneath the inlet cover, given in Figure 10.

The pipe hooks and attachments along the pipelines and the equal distances from given structures can be seen in the figures. Figure 11 shows hanging for the most common 300 mm pipe.
The drainage subsystems consist of appurtenances such as, bends, reduction pieces and devices for compensation of differences between the bridge structure and the pipelines behaviours, as follows fixed points, hooks, horizontal and slant anchors and rollers (Figures 10 and 11).

It is important that inspection of pipelines and other pieces be frequent, even more frequent than for ordinary urban storm drainage systems. In this regards numerous inspection pits and revisions were installed (Figure 11). These consist of curb inlets / gullies, pipe connections to pipelines along the bridge structure and down to a series of facilities for water treatment. There are 8 separation / sedimentation units and pre-treated water to be discharged into the BSS subsystems. Two are completed with the filtering devices since: (1) runoff should be retained and then infiltrated into ground,
and (2) the discharge into the BSS sewer pipe is limited to 140 lps. Designed retention / infiltration facility accepts the pass-over flow above 140 lps, while the hydrograph peak is 630 lps, and the total volume is 400 cum. In addition, 30 barrels with total capacity of 60 l/s (StormfilterItalia) have been set in order to additionally improve treatment of the “first flush” of polluted runoff. Furthermore, infiltration of well treated and even filtrated water is a certain rainfall harvesting project for adjacent aquifer of the potable water sources of the Belgrade Water System. Estimation upon rather poor data and evidence gives in total between 6.000 cum and 7.000 cum of water on annual basis that should infiltrate into the soil (Figures 13 and 14).

Figure 11. Pipeline hanging by either hooks or anchors

Figure 12. Pipeline hanging in the concrete, either by hooks or anchors
Figure 13. Drainage subsystem at the left bank comprising division, treatment of the first flush, retention and infiltration of significant runoff volume and limited discharge up to 140 lps

Figure 14. Retention / infiltration pond - longitudinal section through retention / infiltration pond, irrigation pipes and incident inspection / revision manholes S9 and S11

Total flow discharged at 9 points or into 5 BSS subsystems amounts to approximately 1400 lps, while much less is discharged into the surrounding aquifer of the Sava River.

Additional lessons were learned during execution of the construction works, earth, equipment erection and pipelines mounting at the numerous bridge structures, since lots of surprises accounting for real dimensions, micro positions and final dimensions of pavements, curbs, concrete and steel structures repairs and additional carbon and reinforced ropes installation. Upon such circumstances lots of design procedure was repeated in order to fulfill the requirements from the Investor and the Contractor.
It is to conclude that with regard to an efficient drainage of the bridge deck and access roads and ramps to be achieved, the structure, transportation and hydraulic engineering have to be interrelated and widely interlocked, or otherwise less important sub-systems could represent additional loads and problems under the atmospheric influences, such as high temperature, wind, freezing conditions on surface and flow.

Numerous adjustments of the designed drainage systems have been introduced during construction, mostly based on revealed information relating to the underground infrastructure networks. The design project was upgraded concerning decreasing surcharge of the existing drainage system under the bridge as well as to avoid massive destruction of the bridge concrete structures in cooperation with the Client – Roads of Serbia, Belgrade, Water Supply and Sewerage system, and the Contractor - Strabag AG & Subcontractor - Mostogradnja, and the supervision and designer – Mostprojekt a. d. and Cekibeo Ltd.

Manual for maintenance and operation of the entire drainage sub-systems is provided as an appendix within the Design project, and it should be consulted in a due time intervals (Despotovic et al., 2012).

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LIST OF REFERENCES


ISS, Institute for Standardization of Serbia (2011) SRPS-EN-752 Drainage system outside the structures, and SRPS-EN-858 Separator system for light liquids.


