Changes of hydrogeological conditions provoked by construction in the coastal zone of Rijeka

Čedomir Benac[1], Josip Rubinić[1], Barbara Karleuša[1], Branka Jardas[2] & Maja Oštrić[1]

[1]Faculty of Civil Engineering, University of Rijeka,
Rijeka, V.Cara-Emina 5, Croatia; E-mail: benac@gradri.hr
[2]Civil Engineering Institute of Croatia, Center of Rijeka, Vukovarska 10 a, Croatia

Abstract: This paper presents hydrogeological conditions in coastal area of Rijeka, which have changed considerably over the last 150 years, since development of the city and spreading of the port began. We analyzed risks caused by planned constructions and long-term impact of expected sea-level rise on hydrogeological conditions and groundwater flow dynamic.

Key words: karstic groundwater, geological hazard, coastal hydrogeology, Adriatic Sea

Introduction

Coastal areas usually have a distinctive geological hazard. If the construction causes change of groundwater dynamics, the total risk increases too. In places of older, usually shallow founded constructions, bigger structures are built, with added basement floors due to a lack of space. Foundation of this kind of structures and protection from groundwater usually involves construction of waterproof concrete diaphragm, which can significantly change the dynamics of groundwater flows. If such modification in foundations is done in wider area, it could well cause an increase of groundwater velocity and washout of foundation soil particles, as well as endanger the stability of surrounding structures with shallow foundations.

One of these locations is the city nucleus of Rijeka, which has continuously been a settlement since the Roman times. The settlement was built by Rječina river-mouth, on karst rocky elevation, which is, abound in springs of drinking water. During the last two millenniums, the dynamics of groundwater has changed, due to a filling of estuaries in Rječina valley and rising of the sea-level. The human impact on groundwater dynamic changes became dominant from the middle of 19th century, when filling of the coastal line and construction of the port and the first sewage system started. Besides the changes in the sewage system in the coastal part of Rijeka, more structures with waterproof diaphragm in basement floors were built to this day. All those construction works have caused visible changes in groundwater dynamics and partly increased geotechnical risk.

Scientific paper

HYDROLOGICAL AND HYDROGEOLOGICAL SETTING

Coastal area of Rijeka is a part of karst plateau, which is mildly inclined towards the coast of Rijeka bay. The bedrock is composed of Cretaceous and Paleogene carbonate rocks (limestones, dolomitic limestones and carbonate breccias). Carbonate rock mass visible on elevations is intensively fractured and karstified and because of that in major part is highly water permeable. Low and plain parts of the relief are covered with both sandy-gravely to sandy-silty alluvial deposits of Rječina River and rocky embankment (BENAC & ARBANAS, 1990; ARBANAS ET AL., 1994). Coastal part of the relief is significantly changed by filling during the spreading of the city and construction of the port (Fig. 1).

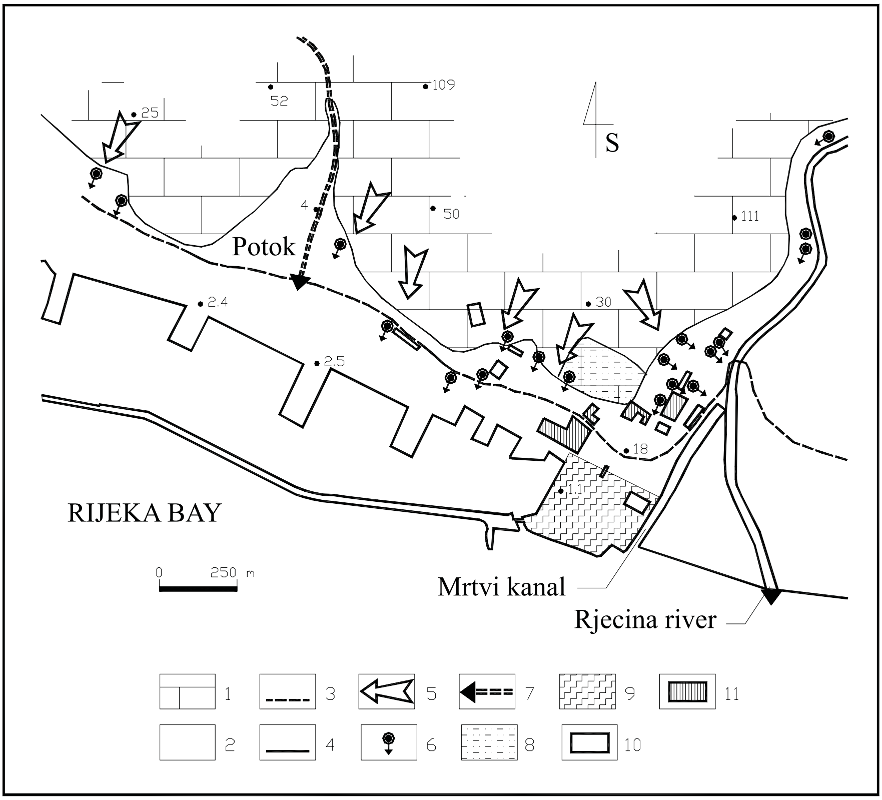

Figure 1. Coastal zone development of Rijeka
Legend:
1-carbonate bedrock visible from the surface (karst aquifer); 2-low and plain part, covered with alluvial deposits and rocky embankment; 3-medieval coastline; 4-present coastline; 5-main direction of groundwater flow; 6-karst spring; 7-position of filled creek; 8-position of medieval city; 9-filled plateau with distinctive subsidence; 10- structures with basement storey; 11-structures with waterproof diaphragm.

Coastal area of Rijeka abounds in surface and underground waters. Surface water flows to the sea through Rječina river canyon and Potok valley. Groundwater flows from the wide karstic catchment area to the coastal springs (Biondić, 2000) (Fig. 1). Mean annual inflow of Rječina water on its river-mouth is $13.1 m^3s^{-1}$, and total capacity of coastal springs is $12.0\ m^3s^{-1}$. During longer dry periods, mean minimal total capacity of all springs is only $2.0\ m^3s^{-1}$, of which half of water is flowing out diffusely (Hrvatske vode, 2002).

Development of the City

Ancient Tarsatica and medieval nucleus of the city were located on a rocky elevation, skirted by Potok valley to the west and Rječina canyon with homonymous stream to the east. In ancient times Rječina valley was a navigable estuary, by the end of 19th century completely filled up (Benac et al., 1992). After a series of earthquakes between 1750 and 1754, a new urban development plan proposed a spreading of the city (Civitas Nova) on the coast in front of the city walls. In 1782, a protective ditch was filled up, and the city fort was partly ruined. In 19th century, filling of the sea-bottom started. By 1843, the second series of buildings on embankment was completed and Rječina river-mouth was moved closer to the open sea, due to the construction of a new coast and protection embankment. In 1855 a new channel of Rječina was excavated. By the end of 19th century construction of the port was completed and since then the outlook of the coastal line remained mostly unchanged (Fig. 1).

Sewage system in the center of Rijeka was embodied by the end of 19th century. A series of springs from the eastern part of the city were canalized by the Fiumara main, which takes to the old channel of Rječina river (Mrtvi kanal). At the same time, more mains, which run water from springs in the central and eastern part of the city to the sea, were built. By the end of 20th century, basic reconstruction of the sewage system was made and since then a part of groundwater flows to a separator on Rječina river-mouth.

The lowest storey of the most buildings that were constructed by the middle of the 20th century has always been above groundwater level, and their foundations were in embankment. By the end of 20th century, more structures with waterproof diaphragm were built. Those structures reached carbonate bedrock and functioned as a protection of the basement from the groundwater penetration (Fig 1).

Discussion and Conclusion

Ancient and medieval nucleus of Rijeka was placed on a rocky karst elevation under which more springs were located. In the second half of the 19th century the coast morphology was significantly changed by filling of the sea-bottom. A new part of the city and port warehouses were built on that embankment. At the same time the sewage system was built,

where Potok creek and karst springs flewed in, while the part of the groundwater was infiltrated through embankment to the sea. The dynamics of groundwaters in the coastal area of the city was significantly changed with the construction of several buildings with waterproof diaphragm and with the reconstruction of the sewage system. The lowest storey of most buildings was always above groundwater level, and their foundations were in embankment. By the end of 20th century, more structures reaching the bedrock were built.
The dynamics of groundwater was significantly changed on two occasions. Results of foundation soil yielding are visible on some structures (PAVLOVEC ET AL., 1992). If this trend of construction continues, it could change direction of drainage and flow discharge. This can cause significant changes in velocity of groundwater flows and oscillation of the groundwater table. It could cause a suffosional washout of soil particles under the existing older structures and endanger their stability. Additional problem in the coastal part of the city is expected sea-level rising (PIRAZZOLI, 2000). A bad impact of that process will be especially visible in the south-east plateau, where subsidention of 90 cm was determined in the period from 1901 to 1993, so that part of the city is flooded in the conditions of the extremely high sea-level (PAVLOVEC ET AL., 1998).

REFERENCES

ARBANAS, Ž., BENAC, Č. & JARDAS, B. (1994): Geotehničke značajke priobalnog područja grada Rijeke. *Pomorski zbornik* 32, 467-480, Rijeka.

BENAC, Č. & ARBANAS, Ž. (1990): Sedimentacija u području ušća Rječine. *Pomorski zbornik,* 28, 593-609, Rijeka.

BIONDIĆ, B. (2000): Karst groundwater protection: the case of the Rijeka region, Croatia. *Acta Carstologica*, 29, 1, 33-46, Ljubljana.

BENAC, Č., ARBANAS, Ž. & JARDAS, B. (1992): Morphogenesis and Evolution of the River Mouths in the Kvarner Area. *Proceedings of International Symposium Geomorphology and Sea*, Mali Lošinj 1992, 37-45, Zagreb.

PAVLOVEC, E., ARBANAS, Ž., BENAC, Č. & GALIĆ, D. (1992): Sedimentacijske i deformacijske značajke platoa južno od Starog grada u Rijeci. *Pomorski zbornik*, 30, 655-677, Rijeka.

PAVLOVEC, E., BENAC, Č. & ARBANAS, Ž. (1998): Slijeganje priobalnog područja grada Rijeke. *Građevinar* 50, 203-208, Zagreb.

PIRAZZOLI, P. A. (2000): *Sea-level Changes. The last 20.000 Years*. Wiley, p.p. 196, Chichester - New York – Brisbane – Toronto –Singapore.

HRVATSKE VODE (2002): Vodoopskrbna osnova Hrvatske. Hidrološka studija za vodno područje primorsko-istarskih slivova, Rijeka. (unpublished).