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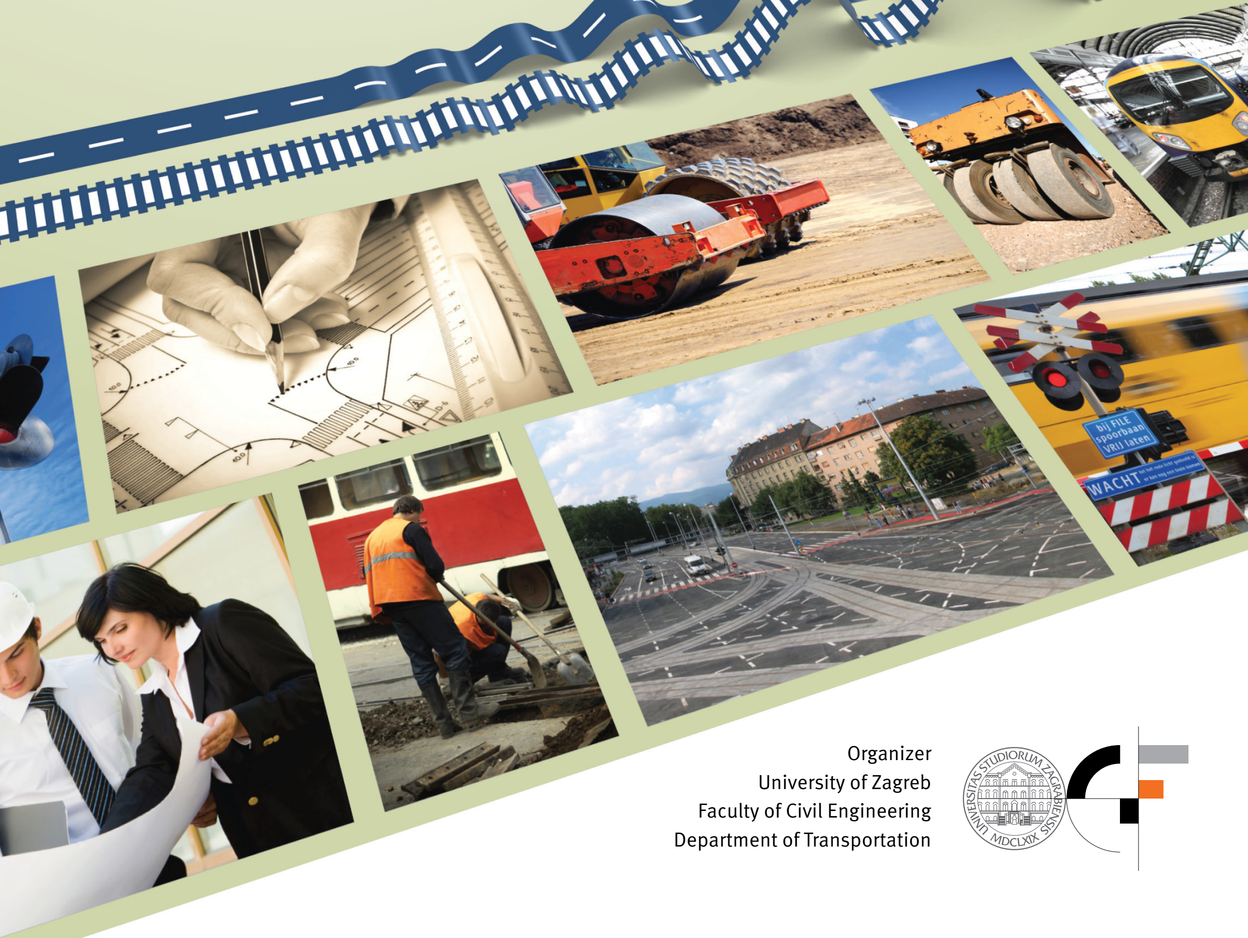
7–9 May 2012, Dubrovnik, Croatia

# Road and Rail Infrastructure II

## Stjepan Lakušić – EDITOR





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# Road and Rail Infrastructure II

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# DEVELOPMENT OF METRO ZAGREB PROJECT

**Davorin Kolić**
*Infranumerika doo, Croatia*

## Abstract

One city as Zagreb needs a massive transport public system that answers to daily public traffic commuting. First ideas about development of one metro system started more than 20 years ago. In the meantime first steps have been performed in direction of development in the future: traffic study has been finished in the year 2000 and first comparative studies for some type of metro system have been finished in 2006. Evaluation of minimal required alignments leading to the metro network and types of required structures have been evaluated and presented. Overall cost estimation and comparison of variant has been presented and prepared for future discussions.

*Keywords: massive public transport, metro system, light rail, underground structures*

## 1 Introduction

The first technically argumented views on building metro in the City of Zagreb were put forward 25 years ago [1]. The traffic demands were clearly articulated and its growth accurately forecasted as witnessed by the situation, in which we have found ourselves today: ever increasing traffic congestion, chronic lack of parking spaces, growing noise and air pollution within the urban area, large masses of people within the historic centre moving day by day in the north–south and east–west direction. Construction funding was based on the financial model normally practiced at that time (the loans taken by the city or the state government).

Today there is a broad variety of ways and means to fund urban public transport projects, the recent trend being a change from direct financing by a local owner (city, state) to involvement of private sector funding, which makes the problem of finding financial sources for construction of urban underground railway more easier to solve. The initial reactions to the article in the technical literature [2] have indicated that there exists a body of experts acutely aware of the problem and ready to share their views. Through subsequent discussion the terms used for urban transport modes were agreed upon and their characteristics specified. The term metro was used as equivalent for urban underground railways, the other urban transport modes being considered were suburban railways (light rail systems), tram based systems and bus systems. Particular attention has been given to tramways and their comparison with bus based systems, the constraints of each mode of public transport being pointed out. The detailed explanations given may be subsequently used when trying to justify the application of the metro system in the specific traffic environment of the city of Zagreb. On such basis, and supported by the enthusiasm of the engineering community a preliminary meeting of an informal group was organized 20 years after that, or more exactly on April 4, 1994, in the year marking 900th anniversary of the City of Zagreb, to review the ideas concerning the project of the working title 'Zagreb–Metro' [3]. The meeting was attended by 10 participants who, based on the working material, reviewed current awareness, demands and possibilities of the urban community, and exchanged information on the ongoing studies, plans and priorities prevailing in the city. The suggested material deals with the most visible transportation problems of the city, pointing to the solutions applied in other cities, particularly those concerning metro systems.

The idea of the first ring line of the future metro was presented along with the comparison of the traffic conditions in Zagreb with those in other cities of the similar size, geologic conditions and traffic demands. The length of the line was about 12 km, the distance between the stations from 0,5–1,5 km encompassing the inner city core on the side of Donji grad (Lower Town) and the four areas of Novi Zagreb (New Zagreb): Velesajam, Siget, Sopot and Središće. One of the most important guidelines of the meeting was the information on existence of the transportation planning study of the city of Zagreb, which at that time was at the first stage of preparation to be subsequently further elaborated [4].

## 2 Traffic demands and flows

Status–quo analysis presented in the study characterized the traffic in the city of Zagreb as follows:
- 214 private cars per 1000 inhabitants in the city of 930.000 inhabitants (excluding wider city area), i.e. about 200.000 private cars in the city;
- chronic lack of parking spaces;
- intensive daily traffic through the inner city core;
- absence of bicycle traffic (not surprising due to the absence of separate bicycle paths, and the private car traffic being so intense making bicycling very dangerous exercise);
- high degree of air pollution by exhaust gases from motor vehicles (the absence of monitoring stations for measurement of air pollution degree);
- exceptionally high noise load (the absence of detailed measurements);
- great number of traffic accidents.

The study was prepared in collaboration with one of the leading consulting companies dealing with traffic issues having head offices in Germany (Aachen/Munich). The guidelines proposed for improving traffic conditions in the city clearly illustrate the methods and means used for solving such problems in Central European cities:
- encourage use of nonmotorized modes of transportation;
- increase traffic safety;
- car–free city centre (Donji grad) (applies to all vehicles, aside from public transport, taxis, emergency–and public utility services);
- ensure safety of pedestrian movements in the car–free city centre;
- drastic lowering of pollution by exhaust gases from private cars and measurement of air pollution degree: $CO_2$, $NO_x$, $SO_2$, $O_3$;
- drastic lowering of traffic induced noise in the city centre.


**Figure 1** Natural and transport barriers in the wider Zagreb area

Further parts of the study comprise the analyses of various traffic concepts, investigating better use of existing traffic modes and corridors. The topic of metro was mentioned in one sentence only, not being further elaborated, probably due to unfamiliarity with such transport mode, as well as the absence of tradition of construction of underground spaces in soft ground and lack of experience of our investors, designers and contractors in tunnelling in urban environment. In any case, that particular study had decisive influence on traffic–related ideas to be elaborated in preparing proposal of the metro system presented in this work.
The city of Zagreb is spread longitudinally in the east–west direction, the natural and transport barriers in the city area being of the same direction: the Medvednica Mountain, the main railway line passing through Glavni kolodvor (Main Railway Station), the motorway running north of the Sava River (Ljubljanska Avenue), the flow of the Sava River, the southern railway passing through the Zagreb railway freight yard and finally the Zagreb bypass road.
Traffic flow process in the city is characterized by the intensive traffic in the east–west direction, but also in the north–south direction connecting Novi Zagreb with Donji grad. The traffic flow is intensive also over the roads linking outer suburbs and satellite towns Velika Gorica, Sesvete, Samobor, Zaprešić and Podsused with the inner city core. Following such relations the alignments of the first metro lines were set down, having underground, at grade and elevated sections.


**Figure 2** Final variant of the proposed Zagreb metro alignment network

The first stage, representing the first section of the proposed first line will be a link of two areas located on the north–south tangent line from Donji grad to Novi Zagreb, and extension of this line further south to the Pleso Airport and the satellite town of Velika Gorica. The southern part of the line to the Sava River would run at grade to cross the Sava River over the bridge after which it would continue underground. The underground section would follow Draškovićeva street up to one of the future underground junctions: Trg hrvatskih velikana.The second stage of the development would comprise closed ring line running from Trg žrtava fašizma across main city square (Ban Jelačić Square) and further across Trešnjevka to the new areas such as Jarun, crossing the Sava River again to reach Dubrovačka Avenue in Novi Zagreb, and proceeding further to TE-TO (thermal power plant), from where it would return back to the city centre and the junction at Trg hrvatskih velikana. This line strengthens the link of the central part of Donji grad with new suburbs, linking at the same time the historic city centre with regional centres in new suburbs, thus strengthening the regional traffic south of the Sava River. [5,6].

## 3 Geological setting

Providing, the plan view arrangement of metro lines proves to be acceptable, the question remains at what depth to locate the underground system, so as to make the construction process cost effective and safe for execution, and future operation efficient. Looking at the geological longitudinal profiles we could see that the basin below the Medvednica Mountain covering Donji grad area, Sava river bed, and Novi Zagreb plain consists of layers of sand, gravel, sandy and silty gravels or gravely clay. The groundwater levels are typically at about 2–3 meters below ground level, and the layers of clay are located at about 8–12 m below ground level [7]. The geological longitudinal profiles considered during analysis are located along the north–south direction and crossing the city across three directions: Trešnjevka– Sava–Remetinec–Botinec; Donji grad–Sava–Velesajam–Klara–Mala Mlaka; D. Bukovec–Maksimir–Sava–Zapruđe–Hrelić–Buzin, Fig. 3.

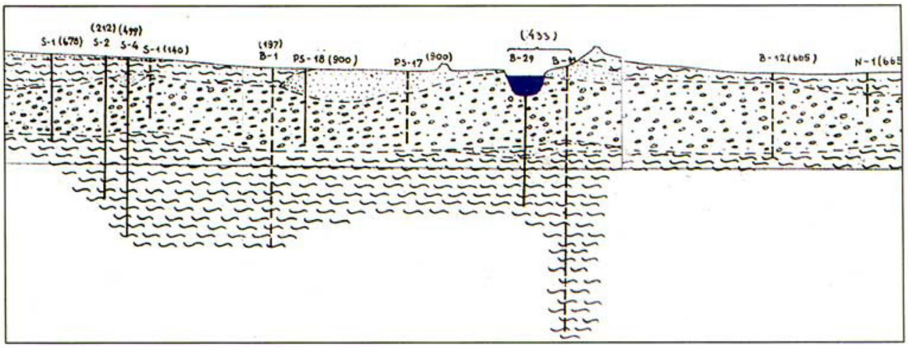


**Figure 3** Geological longitudinal profile at the location of the new bridge.

Taking into account the experiences of other metro systems in the cities lying on the plains along the rivers (Munich, Budapest, Vienna), it would be to advantage to lower the longitudinal axis of the underground line to a depth of 15–20 m under the ground into the layer of clay. Such location has several advantages and represents the best solution, for the following reasons:

Simpler construction of the line being driven through mostly uniform sediments of a single geological formation, the cohesivity of clay being to advantage when tunnelling by either conventional method (NATM = New Austrian Tunnelling Method), or by using TBM, or by compressed air method.

Tunnelling in clay strata has an advantage as the clay layers, on account of their lower permeability, act as a sort of barrier to ingress of water, thus reducing substantially dewatering costs and increasing safety of tunnelling works, regardless of the excavation method applied.

## 4 Technology of construction of metro structures

If we consider the technology of construction of underground and aboveground structures as parts of the metro system, we could apply the methods used in the Central Europe under similar conditions, e.g. those in Munich, Vienna and Budapest [8–14].The stations of the said metro systems are located at a depth of about 15–20 m (rail top level at the station platform), those in Budapest being located somewhat deeper: in the range of 20–35 m. These depths make it still possible to build the stations from the ground level. That method of building underground station developed in the last thirty years consists of first constructing the diaphragm walls (nowadays, pile walls are used more often), followed by excavation of a building pit to a depth of several meters, the roof slab is then constructed, upon completion of which the ground is subsequently back–filled and the traffic reinstated. Following that all the works on station construction are carried out underground under the protection of the roof slab. This method is known under the name of top–down method, or in German speaking countries as Schlitzwand–Deckelbauweise, Fig. 4. It is a cost effective and appropriate solution for construction of stations in urban environment, in soft soils with problems of water ingress.

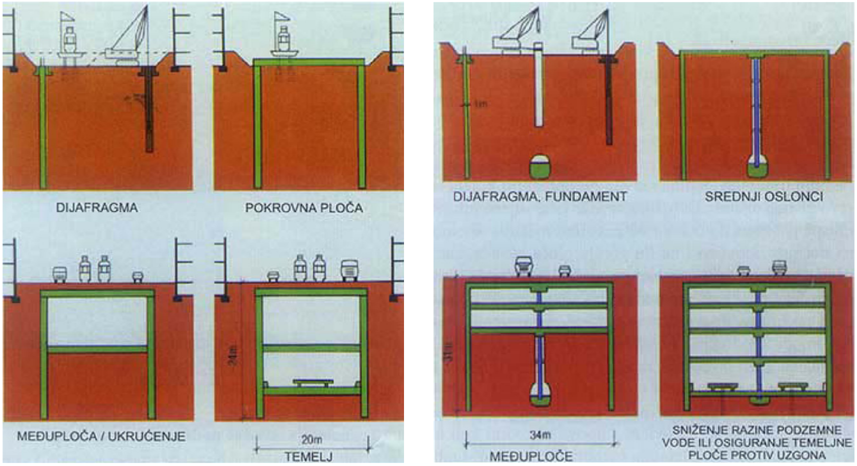


**Figure 4** Construction of metro stations by Top–Down method (case of Munich subway) : construction of diaphragm with roof slab (left) and with roof slab and central column (right).

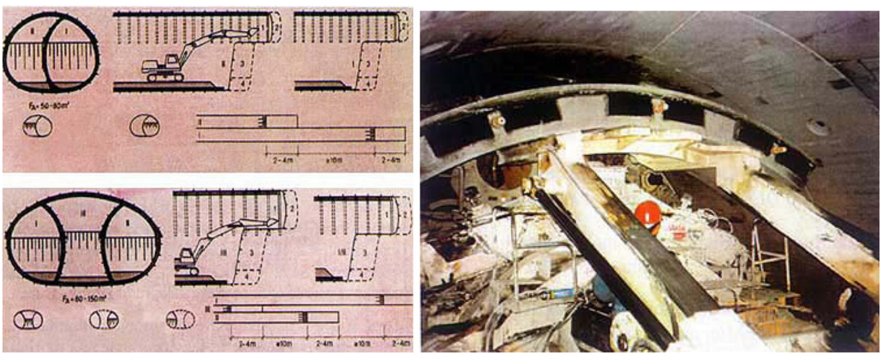

**Figure 5** Excavation methods–conventional: top left– single sidewall drift;bottom left– twin sidewall drift, TBM technology (example from Paris metro)

The excavation of tunnel between adjacent stations is carried out by conventional methods or by using tunnel boring machines (TBM). The most often conventional method used is the New Austrian Tunneling Method (NATM) known in Germany under the name of Spritzbetonbauweise. Its application in soft soils in the city of Munich differs in regard to geological formations: tertiary sediments (marl, clay) or quaternary sediments (sands, gravels). NATM was applied most of all on account of being cost effective considering that each metro section from station to station represented separate tender lot during procurement process. As the distances between stations in the city are relatively small, 0.4–1.5 km, NATM was in most cases superior to other methods due to its flexibility in regard to geology variation and smaller initial costs. Application of tunnel boring machines (TBM) is nowadays considered as a common tunnelling method with provided economic justification. By rough estimate, tunnelling by TBM techno-

logy is cost effective for the tunnel lengths over 2 km, regardless of the diameter. In other cases, TBM is applied in soft soils when the measures needed for soil stabilization are of such extent that the application of TBM is more advantageous in regard to safety and cost or results in smaller settlement of ground surface. Some cities, e.g. Budapest, divided procurement of construction works for new Budapest Metro Line 4 into several lots: for bored tunnels of 8.0 km length, and separately for the stations.
Of course, all the lines, or sections of the line, of the metro system need not be run undergro-und, at least not in the first stage of construction. The first line of 'Zagreb–Metro' is planned with surface sections too including crossing of Sava River, and for that purpose a conceptual solution of a new bridge is prepared located on the extension of Draškovićeva street [15]. The cabled–stayed bridge option was selected with single pylon and stay cables in inclined symmetrical arrangement as the economically most feasible solution for the designed loads of road, railway and pedestrian traffic which the new city bridge of central location should bear, [15].

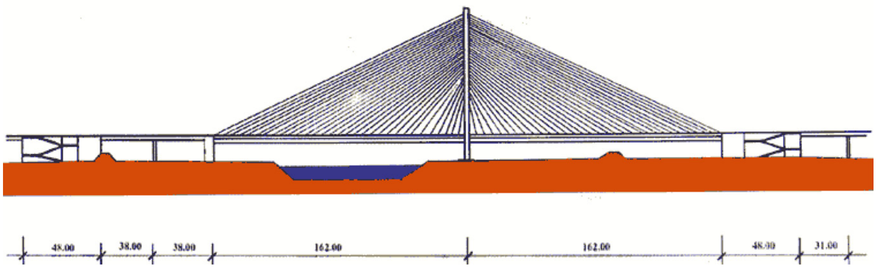


**Figure 6** New bridge across Sava River

## 5 Economical factors and system development dynamics

Looking at current representative costs on tunnel markets in urban environment in Central Europe, the total capital costs per route–meter including stations (and excluding equipment and ventilation) lie mainly between EUR 17.500–25.000 (2006 prices). These costs should be adjusted in accordance with respective labour cost on home market, but also in accordance with real productivity of that labour. This analysis shows that any cost estimate is site and country specific as regards ground conditions, environmental and safety constraints, labour costs, etc. However, such a complex venture could hardly be carried out without collaboration with foreign contractors, because it requires specific experience and expertise which is built over the years working on concrete projects. As the time schedule is concerned, it takes in average 12–14 years to develop a single metro line, which broken down into stages gives as follows:
· elaboration of variants 4 years; year 1–4
· design preparation 8 years; year 5–13
· line construction 5 years; year 8–13
· line equipment 4 years; year 9–13

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