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Railway transport in Qatar

Abstract: The article presents the railway infrastructure projects carried out currently in Qatar with special attention to the Doha Metro Project. Types of used structures, such as viaducts and tunnels with a closer look at the construction of trackbed are described in more detail. The last past of the article contains key information about the Tram Network project in Lusail and the Long Distance Lines for the passenger and freight trains.

Keywords: Doha Metro; Qatar Railways; tunnelling

Introduction

Qatar is one of the smallest countries in the world. Its area can be compared to the area of the opolskie or świętokrzyskie voivodships. It is also the richest country in terms of national income per capita. Its population is about 2.6 million, of which about 1.5 million are residents of the capital - Doha. These figures may be somewhat misleading, because almost 90% of all residents are people who came to work temporarily without citizenship and no prospects of its receipt. Indigenous population of Qatar consists of only about 300 thousand people.

Thanks to income from the exploitation of huge deposits of natural gas since few years, the pace of development of Qatar is one of the highest in the world. This manifests by a great number of investments in residential buildings, service and industrial sectors, as well as in the construction of roads and railways. All investments are carried out with the great rate and is related with the upcoming World Cup football in 2022.

The railway company in Qatar was founded in 2009, and its first works began in 2012 in a future subway station Msheireb. To ongoing railway investments in addition to the metro network in Doha belongs also the tram network in the newly built city Lusail (Lusail Light Rail Transit). These investments are the first phase of the construction of railway infrastructure in Qatar. In the second phase, it is planned expansion of the subway, extension of the tram network in Lusail and, divided into several stages, construction of the national railway network with connections to neighbouring countries, Saudi Arabia and Bahrain.

Currently (i.e. in September 2016), Qatar have no single underground rail road. The first trains are to go according to the plan as early as in 2019.

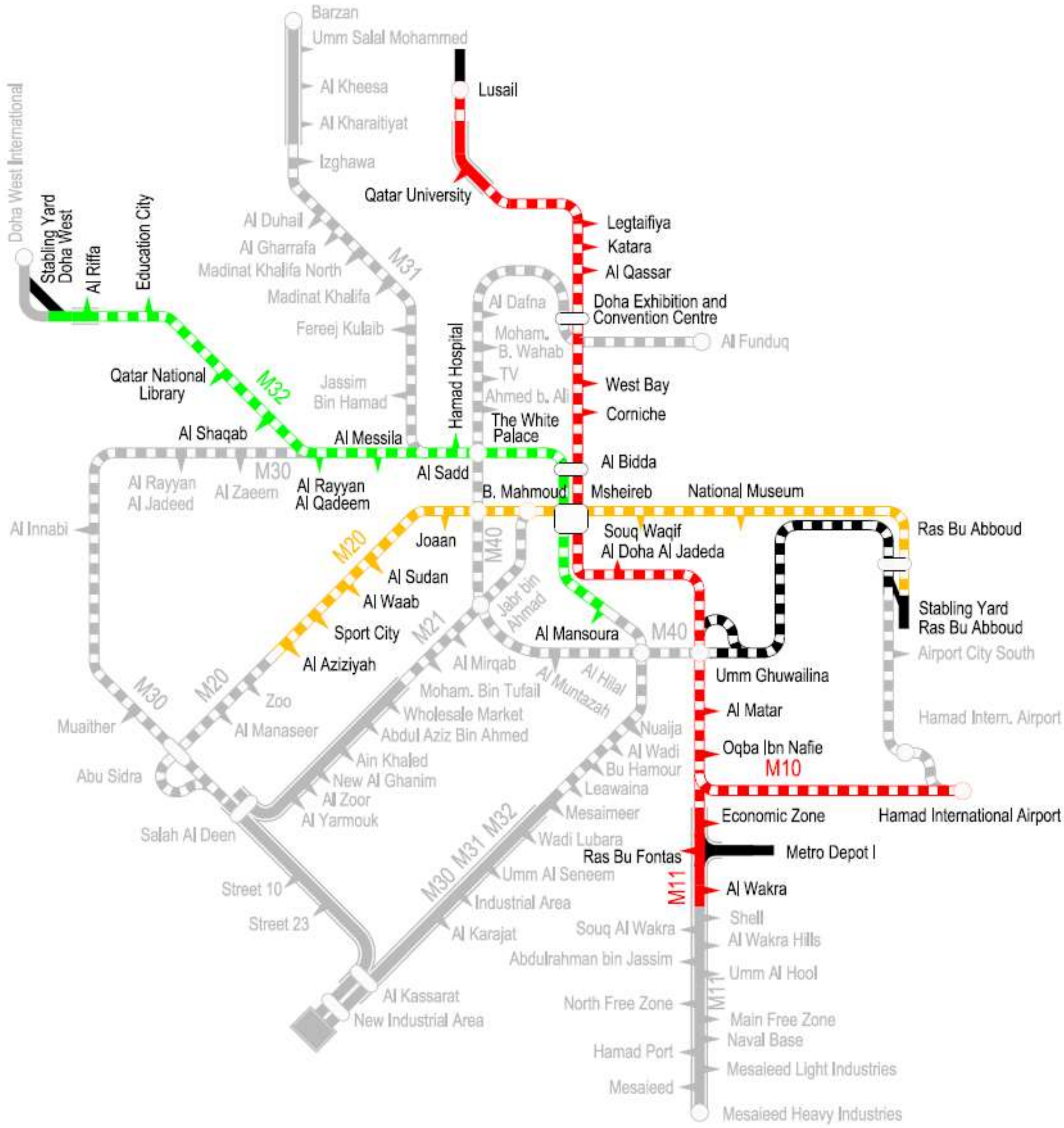
Due to the most advanced design work and regulations, we focused in this article on the metro in Doha.

1. Map of Qatar

Subway

During the design, detailed geological studies were made along the planned track axes. It was made 123 holes with the diameter of 84 mm to the depth of 25 to 70 m, together with measurement of the level of groundwater. The study showed the presence of limestone (Limestone Simsim), slate (Midrash Shale) and the so-called rusu (Rus Formation - limestone with interbeds of clay and plaster). It was noted that the limestone formations have an irregular layout and the large number of voids caused by karst phenomena, very unfavourable for the tunnelling works. A water-bearing layer was observed at the depth of 5 to 15 m. These waters contain high levels of sulphates and chlorides, and are extremely corrosive to steel and concrete. The average water temperature is as high as 28ºC.

Subway building was divided into two phases. Phase 1 is to be completed for the World Cup in 2022, while phase 2 is scheduled to begin at a later date. In phase 1, there are three metro lines - the Red Line, running along the coast and having an arm to the airport, and Gold and Green Line passing from west to east. It is planning to build an operating segment, which in the next phase will be the part of the Blue Line. All three lines are connected at two levels in Msheireb station, which is the heart of the system. It was also planned building four delivery-repair stations, one for Green and Gold Lines and two for the Red Line, of which one of them will be located underground. Figure 2 shows the lines of phase 1 in the corresponding colours and lines of phase 2 are shown in grey. Table 1 includes the length of sections and the number of stations of phase 1.



2. Diagram of metro network in Doha (phase 1 and 2)

Table 1. The length of each line and the number of stations in phase 1

Line	Length	Station number
Red	43 km	18
Green	22 km	9
Gold	16 km	10
Operational	4 km	0

In addition to the extending all lines, in phase 2, is provided an additional line Blue, running around the city centre as well as the subsequent lines Green and Gold. It will be built also the next big delivery-repair station. Table 2 shows the length of sections and the number of stations provided in phase 2. The length of different types of structures is shown in Table 3 and the percentage share in Figure 3. In phase

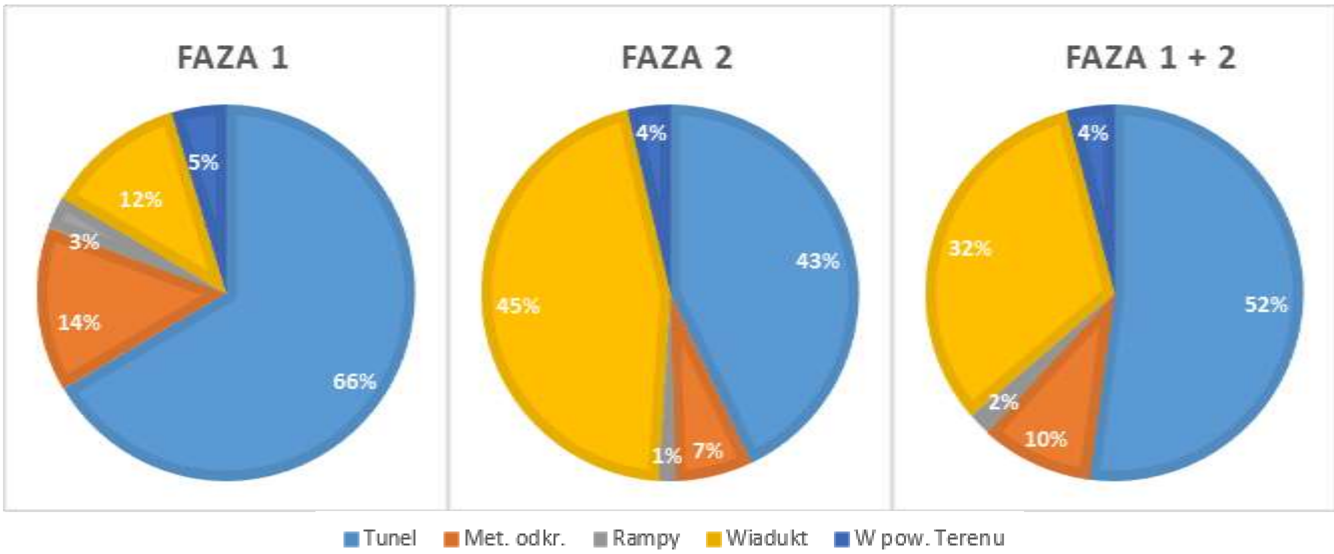
1, 66% of the total length of all lines is two tunnels build up by machines TBM. Subsequently, the tunnels are made by open pit (14%) - mainly stations and adjacent sections and viaducts (12%). In phase 2, viaducts have the largest contribution (45%) and next TBM tunnels (44%), whereas the length of other segments is insignificant. After completing all the planned sections of the phase 1 and 2, the percentage contribution of structures is: TBM tunnels - 52%, viaducts - 32%, the remaining tunnels - 10%, segments at the ground level - 4% and ramps - 2%.

Table 2. The length of each line and the number of stations in phase 2

Line	Length	Station number
Red	27 km	12
Green	63 km	31
Gold	21 km	11
Blue	20 km	9

Table 3. Types of objects in phase 1 and 2

	Tunnels	Pit method	Ramps	Viaducts	At the ground level
Phase 1	56 km (x 2)	12 km	2 km	10 km	4 km
Phase 2	57 km (x 2)	9 km	2 km	60 km	5 km
Phase 1 + 2	113 km (x 2)	21 km	4 km	70 km	9 km



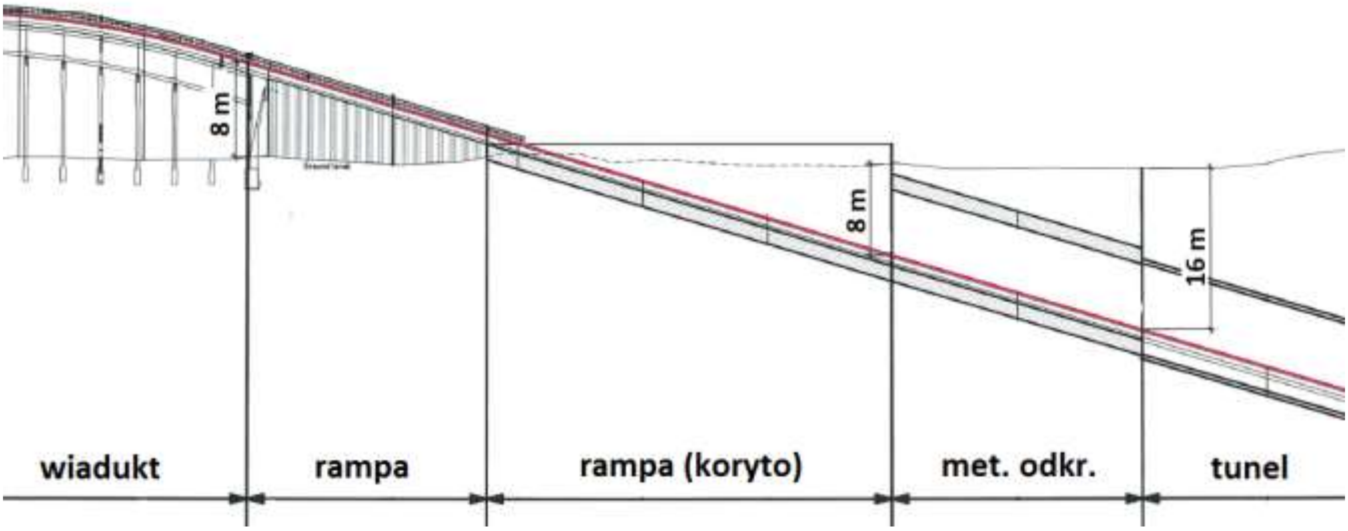
3. Percentage contribution of various construction types

Each line was designed as a dual track in the spacing of 4.0 m in the open field and viaducts, and nominally 15.7 m in separate tunnels. Underground stations spacing was increased to 17.5 m, to obtain the width of the platform two-edge equal to 14.4 m. The trains are powered by a third rail track located on the side of track. The length of each train, depending on the configuration, is 60 m (three units of 20 m) and 120 m (two connected short trains) and the axle load is 16 t. The track surface will consist of rails type 60E1 combined in a contactless track, elastic fastenings and prefabricated concrete slab. Due to the occurring sandstorms, ballast pavement was not included. It was estimated that rapidly proceeding contamination of the ballast will require frequent maintenance, which makes such surface thriftless.

Since the construction takes the load of track subway and thus due to the type of subtrack, metro line can be divided into the following sections:
- tunnels,
- underground objects made by open pit (stations, junction chambers and shallow tunnels)
- viaducts,

- ramps (both connecting tunnel with the surface and the surface with the viaduct)
- tracks running at the ground level (or in small embankments or trenches).

The height relationships between individual sections are shown in Figure 4.

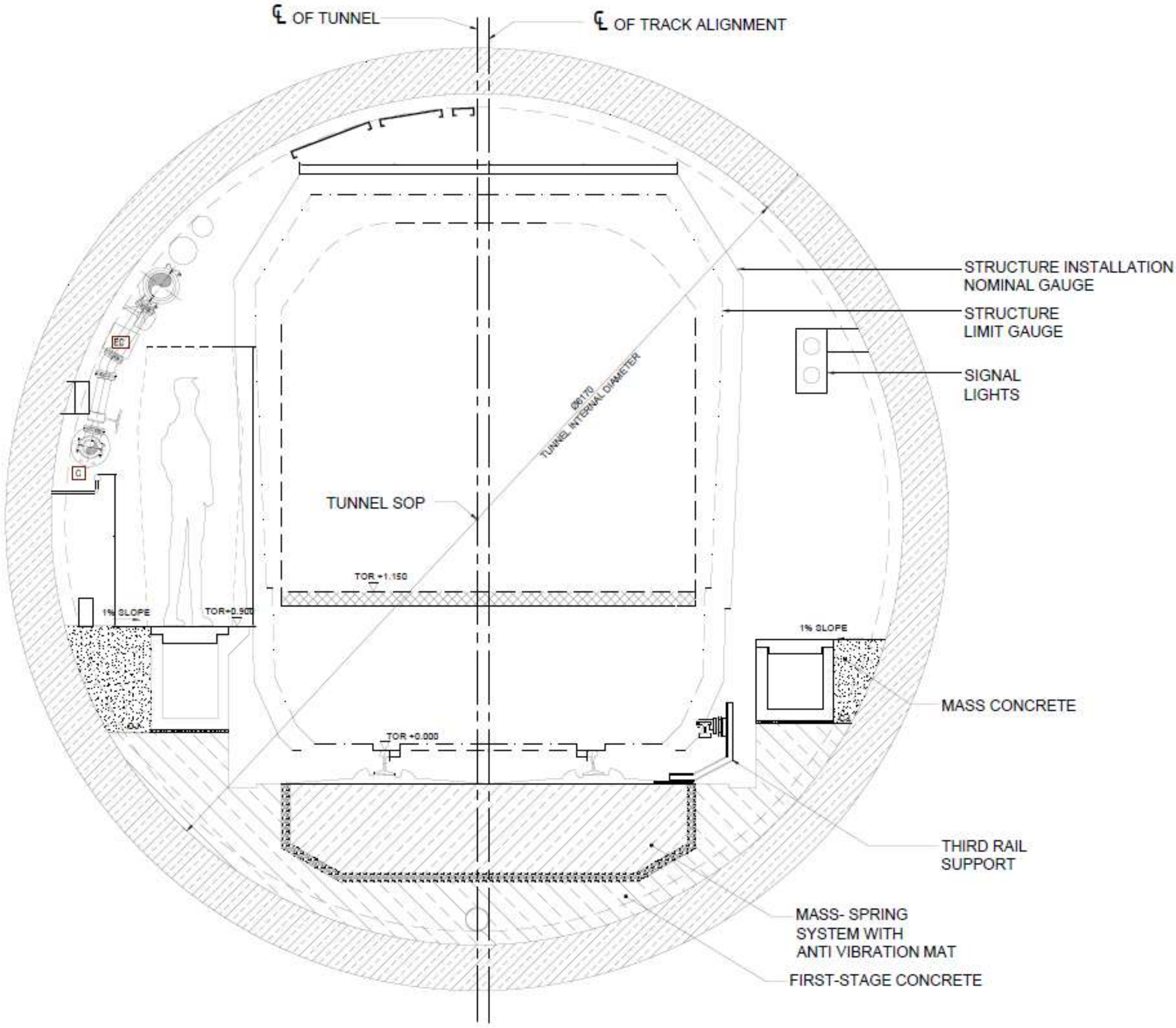


4. Sectioning track sections for structural reasons

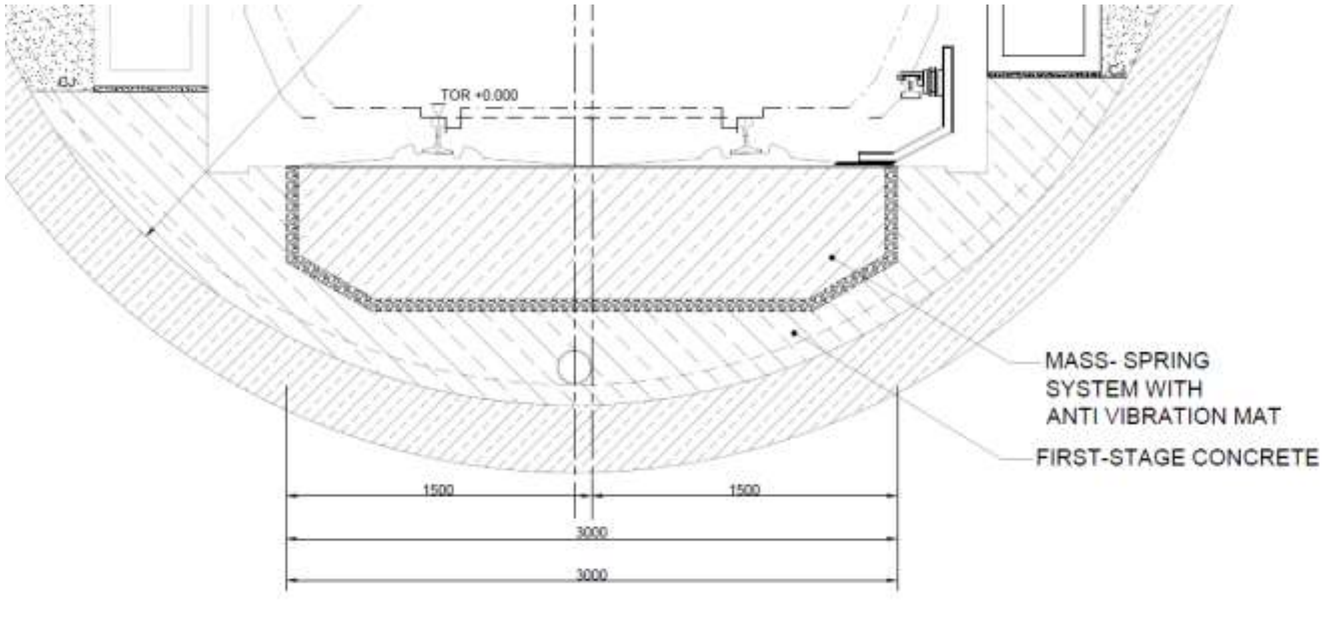
All sections of the tunnels from phase 1 were completed in August 2016, and currently are carried out finishing and installation works in tunnels and sections outside tunnels. The geometry of the track shall be checked whether some changes are required. On some stretches, changes in track geometry in the plan and profile are necessary because, despite the assumed tunnelling tolerance equal to ± 100 mm, it was not able to avoid some major deviations. For this purpose, it was designed a new geometry of the track which was a part geometry of the tunel so-called *wriggle alignment*.

Tunnelling was done by machine TBM (Tunnel Borring Machine) of type EPB (Earth Pressure Ballance), providing a balancing by the machine of ground pressure. Although tunnelling by this method is relatively slow (about 13 m per day), it is a very favourable method for large cities active whole day. Subways in Doha have the inner diameter of 6170 mm, and the thickness of the tunnel elements (tubing) is 330 mm. Tubes are placed automatically by the machine tunnelling immediately after opening the cavity in a given location. They are secured from the outside by anti-corrosion substance because of the high position of the groundwater and its high aggressiveness. In addition, between the subsoil and the outer surface of the tunnel is introduced under pressure a special mix of the cement. At the bottom of the tunnel, there is a trough made of concrete C25/30 called the first step concrete. In so made trough are laid mats with specially selected properties to supress vibration coming from the passing trains. On mats are made concrete slab of track. The entire system is called mass-spring system. The required level of stiffness of the substructure is in this case carried out by the anti-vibration mat because it must be assumed that both the stiffness of concrete elements and the whole tunnel are so large that their movement resulted from the passing subway train are very small and thus negligible.

In September, 2015, a new Guinness world record has been established in Doha. This time were simultaneously working 21 discs drilling TBM tunnels under one communication project. The Figures 5 and 6 show sections of the track in the tunnel.



5. The cross-section of the track subway tunnel



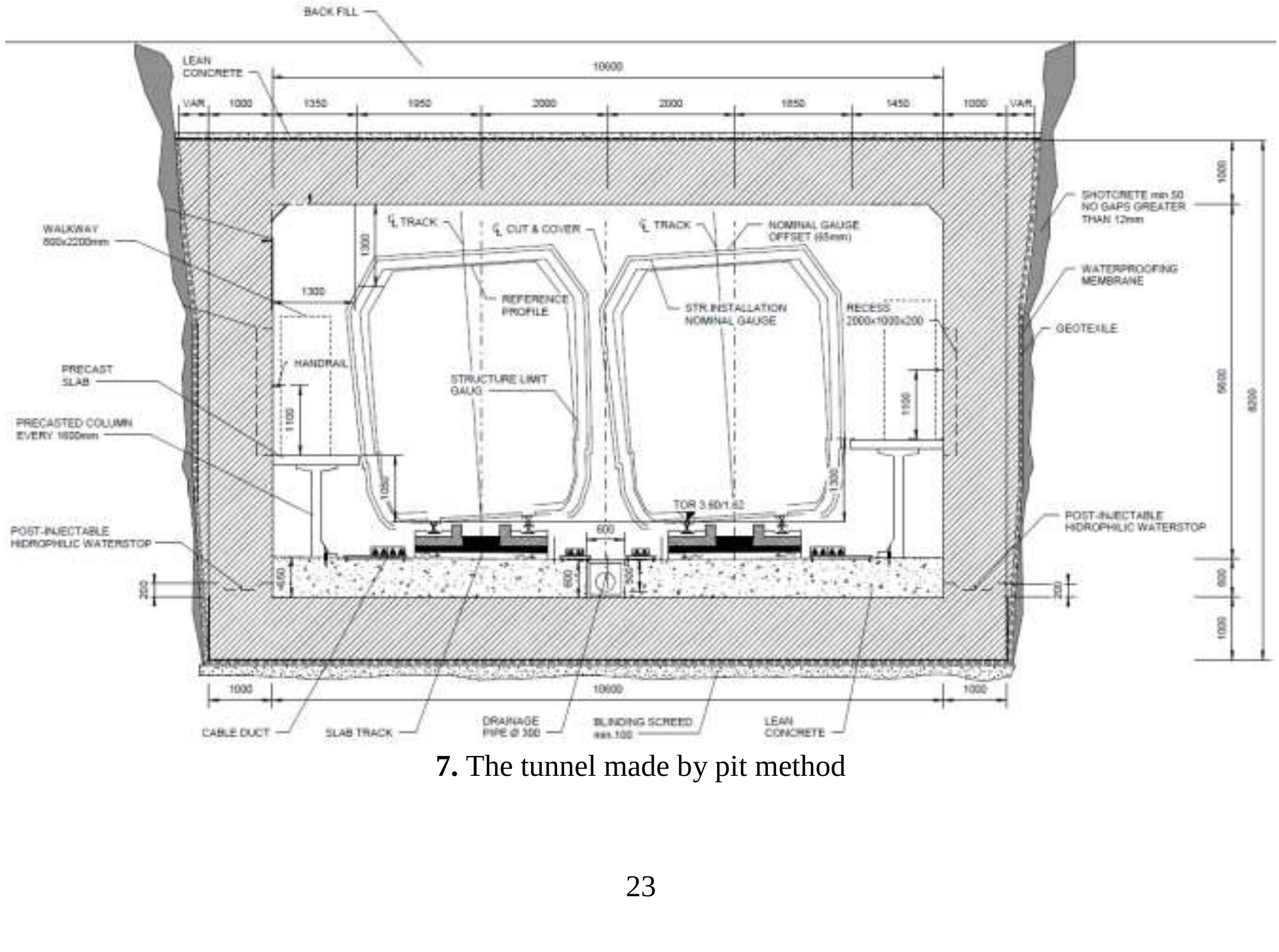
6. Detail foundation of the track in the tunnel

In order to optimize the location of the track in the tunnel, a pattern calculating offset of the tunnel axis with respect to the track centre was applied, depending on the track slope and the position of the escape route. Two escape routes are designed in the inside of the tunnel, i.e. the escape route is on the right side of the track in the left tunnel, and on the left side in the right tunnel. It facilitates evacuation through the connection between the tunnels. In the case of the road on the outside of the arc, equations for calculation of the horizontal S_H and vertical S_V movements are as follows:

$S_H = 85 – 0.75 \cdot C$,
$S_V = 1675 + 0.75 \cdot C$,
whereas, the road is on the inside side of the arc is:
$S_H = 85 + 0.75 \cdot C$,
$S_V = 1675$.

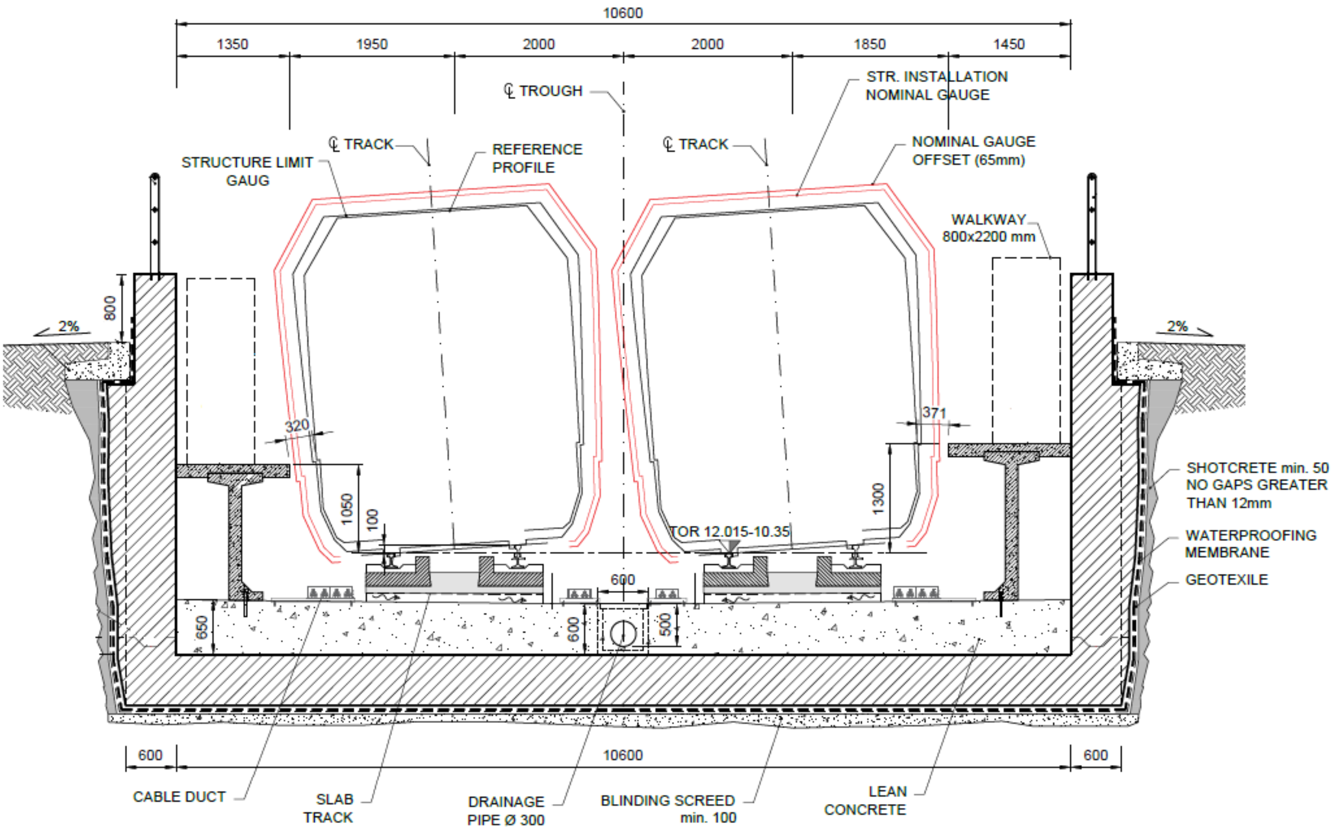
In the above formulas, C is a track tilt in millimetres. The result of the shift is also expressed in millimetres. You can notice that in straight sections of the tunnel, axis is spaced horizontally by 85 mm to the left or right depending on the position of the escape route and 1676 mm in height. The maximum track tilt was determined to 100 mm and for this reason, the maximum movement of the tunnel in the horizontal plane is 160 mm. Therefore, the load of the track is not aligned axially with the geometric axis of the tunnel. However, it is not a problem for the using the tunnel.

Tunnels made by cast methods (cut and cover) are provided in places where the track profile is designed shallowly below the surface, and then works from the surface can be perform. A principle was assumed that the secure tunnelling with machines TBM can be carried out only when in the upper surface of the tunnel is still soil layer with a thickness equal to the diameter of the tunnel, otherwise the tunnel should be performed by pit method. In tunnels of this type, the surface in the form of a track is based on a concrete slab by a layer of a special self-compacting concrete in a layer of concrete with a thickness of about 0.6 m laid on the bottom panel structure. The prefabricated concrete slab track is equipped with mats with special properties suitable to supress vibration and giving a suitable elasticity for the whole system. Figure 7 shows a typical cross-section of the tunnel constructed in this way.



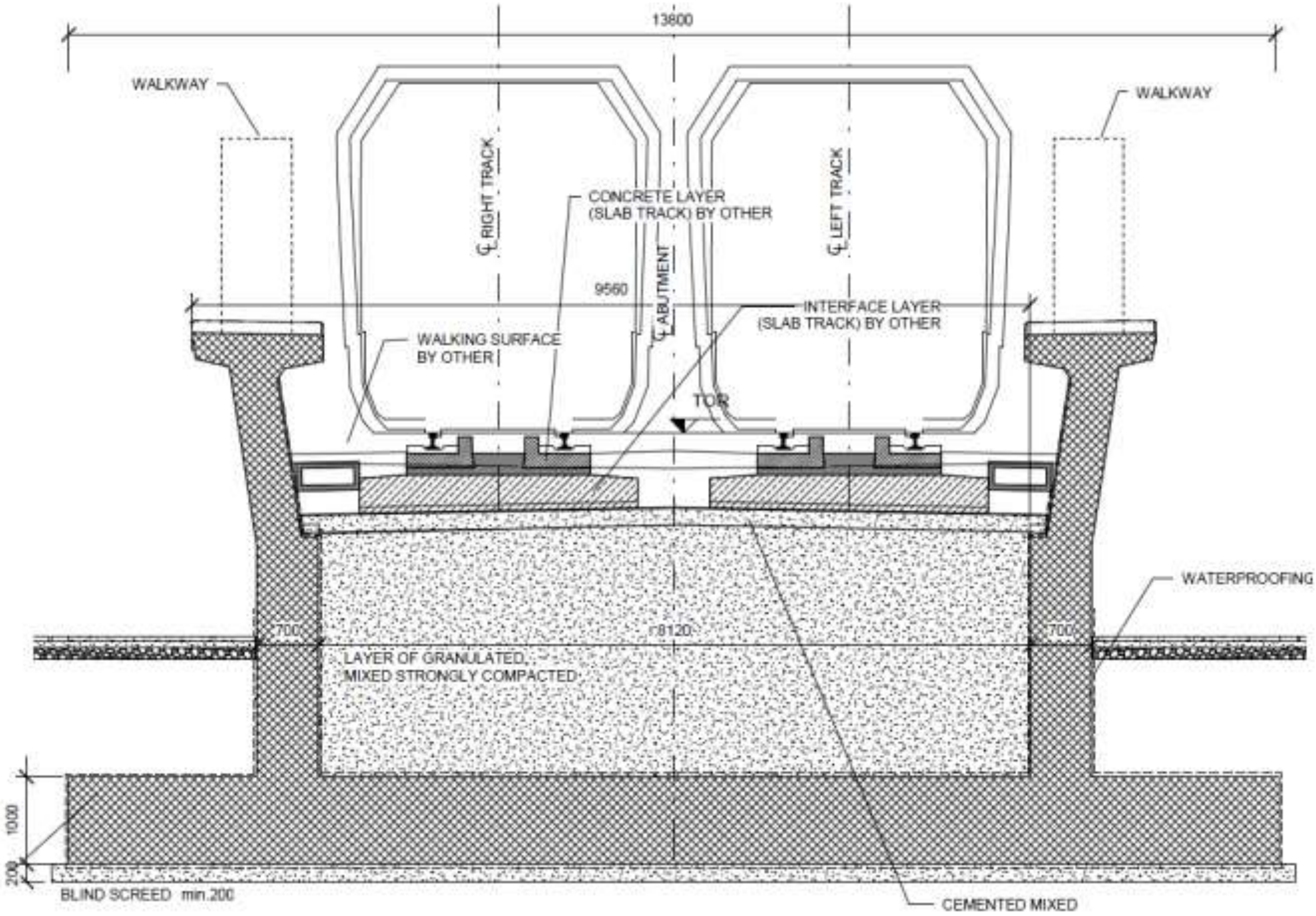
7. The tunnel made by pit method

The transitions between sections and tunnels in the ground level or viaducts are realized by two types of ramps. The ramps leading from the ground level down to the tunnel are made as a trough with reinforced concrete walls and bottom plate with the thickness of about 1 m (Figure 8). The layout surface - substructure is here basically the same as in tunnels made by pit method. On construction of plate is provided the arrangement of the plain concrete layers and fixing the track surface on the concrete slab.



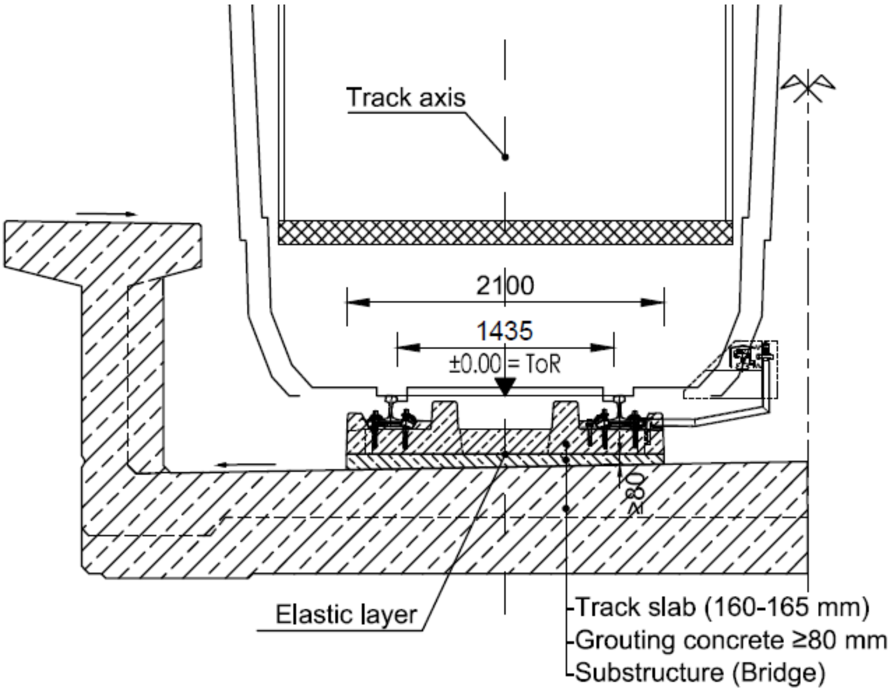
8. The ramp leading to the tunnel

Ramps leading to bridges (Figure 9) are made as parallel retaining walls filled with layers with appropriate bulk materials, which guarantee the achievement of a density equal to 1.0. The upper layer having the thickness of 20 cm is stabilized with cement. For such filling made between the resistant walls is installed the plate made of reinforced concrete with a thickness of 35-40 cm, and only on it, the surface of the track is laid in the form of a prefabricated concrete slab. Considering the structures of these ramps, it is very important a proper density laid layers. Secondary deformation module in the upper surface of the protective layer equals 120 MPa.



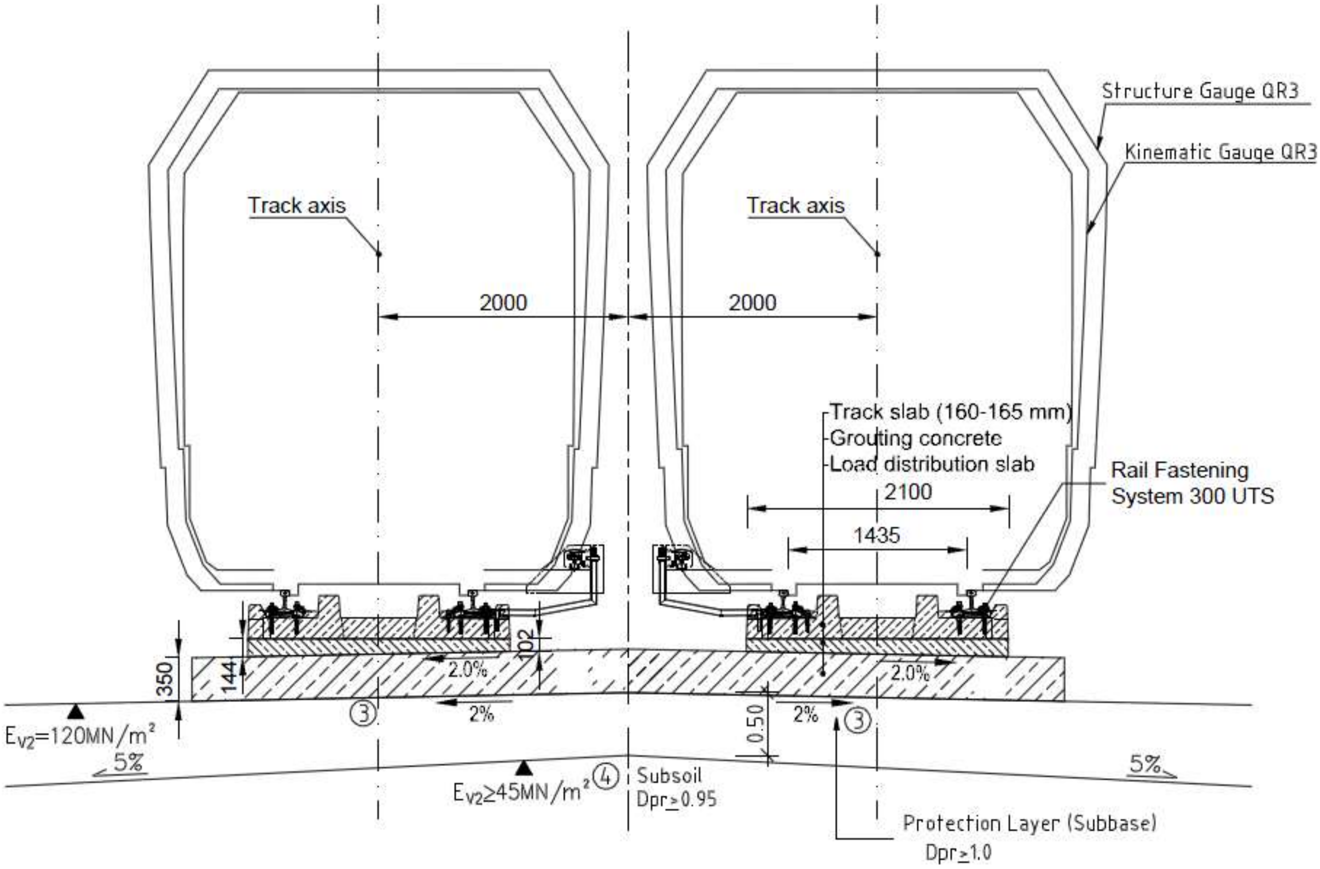
9. The ramp leading to the viaduct

On the bridges (Figure 10), their surface in the form of a track on a concrete slab rests also directly on the structural plate of the object. The standard viaduct span is 32 m, the longest span completed in phase 1 reaches 80 m. In phase 2, it is proposes to lead the Golden Line under the viaduct in the belt separating the main road of the city. It causes the necessity to build series of four viaducts with spans of 140 m passing above the two-level road junctions.



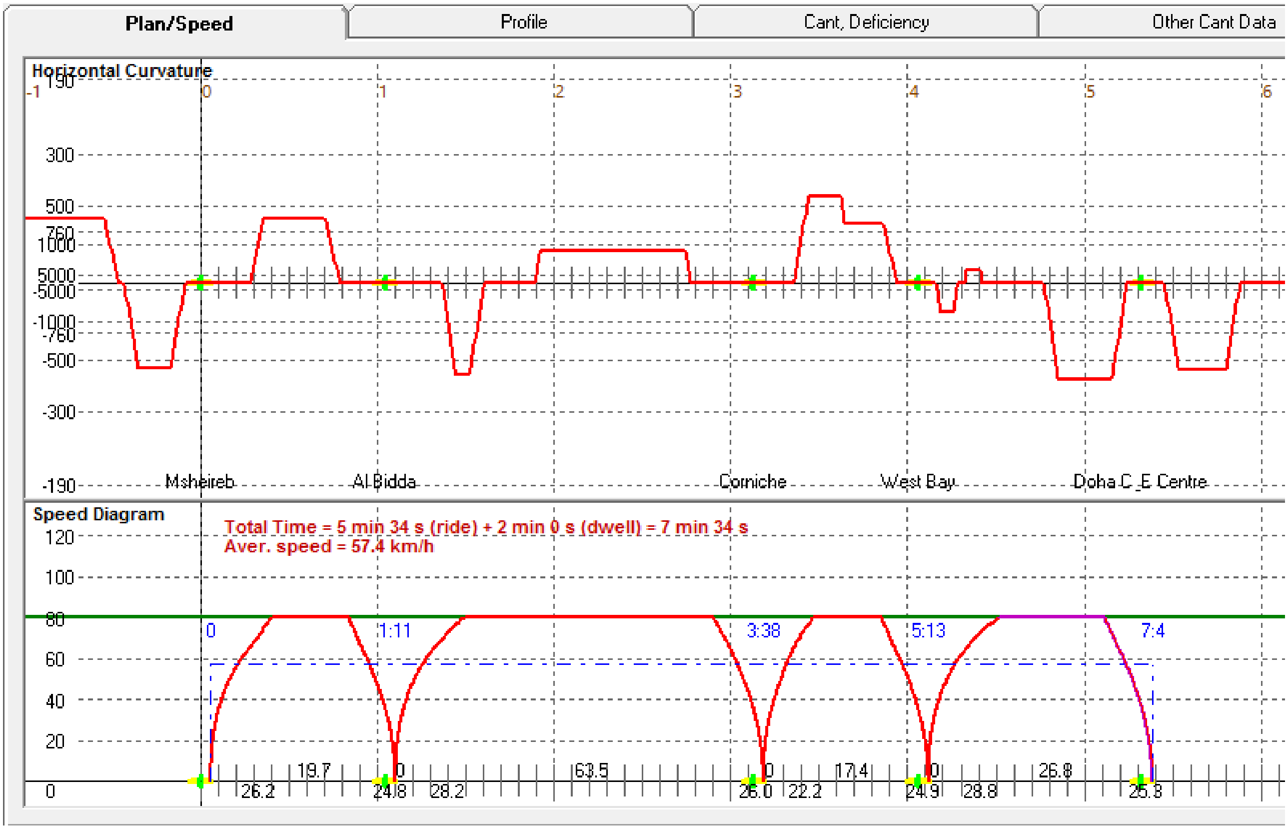
10. The cross-section of the track on the viaduct

As for other sections, the track surface on prefabricated concrete slab is also expected for the tracks at ground level (Figure 11). In this case, the concrete slab rests on the concrete layer with the thickness of 35 cm that is intended to distribute loads over a larger area respectively for existing ground conditions of the layers. The upper layer thickness of 50 cm should be compacted to a density index equal to 1.0, and the secondary deformation modulus should be at least 120 MPa. Subsoil should be characterized by density indicator equal to 0.95 and secondary deformation module equal 45 MPa. It should also be shaped to the slope to 5%, because of the dehydration.



11. The cross-section of the track at ground level

The assumed design speed is 80 km/h in tunnels and up to 130 km/h outside them. Due to the limitations caused by the existing infrastructure, both underground and ground, in some places not achieve the assumed design speed. Similarly, short distances between stations near the centre of the city do not allow reaching 130 km/h on sections outside tunnels. In some cases, the speed was reduced to 60 km/h. Figure 12 shows a part of a preliminary analysis of the movement of the train between the stations of the Red line. The average distance between stations in this case is about 1.3 km, and the average travel time from station to station is 90 s. The average (commercial) speed on the analysed section was 58 km/h, including stop times at stations amounting 30 sec. It is clear from the plots that the design speed is chosen properly, and its increase to 100 km/h would not yield significant benefits. The analysis was made in the original computer program Railab.



12. Plot of train motion for the section of Red line

Tram network in Lusail (Lusail Light Rail Transit)

Writing about the subway in Doha, it is impossible to not mention about building the tram network in Lusail. Both the networks, despite they are independent, they converge on common stations. LLRT network consists of four lines with the total length of 30 km, of which about 8 km run in tunnels made by opencast. Stops are designed in a variety of configurations - the insular, external and separated platforms. The total number of planned stations/stops is 32, of which 8 are underground. It is planned to increase the designed network with further 11 km and a dozen stops. Train power is designed from the top lines (in tunnels) and from the third rail localized in the canter of the track (except for tunnels).

Because of the many intersections with roads and other existing restrictions, the speed established to 70 km/h, as predicted, has not been reached on the part of the route, and thus the expected commercial speed in some sections will be about 30 km/h. The average travel time between successive stops will be 1-2 minutes. It is expected that the daily use of the tram will be about 50 thousand passengers.

The same Lusail is also a very interesting project. It is a completely new city built for 200 thousand residents north of Doha. It will have residential and office centres, schools, hospitals, shopping centres etc.

The railway network of long-range

The planned network of long-range passenger-freight railway will not only connect the capital with other cities, but also with other countries in the GCC (Gulf Cooperation Council) such as Saudi Arabia, Bahrain, Kuwait, the United Arab Emirates and Oman. It is planned to construct five major lines: freight from the port of Ras Laffan to Mesaieed, with mixed traffic from Doha to Dukhan, Doha to Al Shamal and Doha to Saudi Arabia, and high-speed passenger line from Doha to Bahrain through the undersea tunnel. The construction of these lines is also divided into phases. In the first phase, it is expected to build 143 km double-track sections, more than 30 turnouts on the main tracks, one passenger station, three freight stations, one intermodal station and about 100 engineering objects (including 60 bridges). In subsequent phases, it is planned to construct additional 350 km of double-track lines. A large part of the line passing through urban areas will be built in tunnels made by TBM machines with an internal diameter of 9 m. The entire network has to be adapted to passenger trains at speeds of 220 - 270 km/h and 120 km/h for freight trains. All works are divided into four phases and should be completed by 2030.

Summary

Since several years, Qatar has been developing very quickly, and this is indicated by the construction of modern transport systems, including rail networks. At the same time, there are conducting intensive design and construction works on three different systems of railway transport - subway, tram network and the network of long-range line. The article was focused on the subway project and discussed various types of structures depending on the position of the track relative to the existing ground. With the vast lengths of tunnels and viaducts and with quite homogeneous geological conditions in Qatar, problems of railway subgrade do not seem to be most important, but in any case cannot be underestimated.

Source materials

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