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A Novel Watering System Design for the Entire Cross Section of the Tunnel Boring Machines (Case Study: Mashhad Urban Railway Line 2).

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ABSTRACT
Water conveyance system in tunnel excavation, for heat transfer of the equipment and supplying the required water of the foam system is considered essential. In water conveyance system design, the determination of the required water flow, the size of used pipe, the selection of pumps type and valves required have great importance. In this paper, design and then selection of the desired system components including the size, length and type of pipes, pumps and other required components are discussed. In addition, a case study of Mashhad urban railway line 2 is reported.

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INTRODUCTION

In fact, underground spaces have historically been created in urban areas and mainly used to host traffic ways (streets, subways, railways) and public-service utilities (water supply ducts, sewers) [1].

In this paper, firstly watering and dewatering system and the necessity of using it is explained in section 2. In section 3, the characteristics of urban railway line 2 including length of path and average of tunnel slop is mentioned. Then, the path is divided into two sections (north and south path) and for each one, the basic assumption is written based on length and volume of the water path and maximum and minimum system pressure. In the next section, based on the characteristics of the input and output water of the machine, designing of watering system is carried on. The diameter of watering and dewatering valves determined in accordance with the pressure flow of two TBMs (north and south) is calculated. In section 4, characteristics of the system including the type, size and length of valves, the flow and head of pumps and also, the type of employed valves for watering and dewatering system of two paths are presented. Finally, in the last section, the results of this study will be presented.

2. Watering and dewatering system:

In this device, three pipes were used to sweep the water, a pipe to transport water and two pipes for dewatering. Used water for watering system should be cool and with high quality. The returning waters are carried out in two pipes. First one, consist of the waters used for cooling of different parts of device which is clean and with high temperature. The waters in the second pipe are waste water caused by cement materials.

The returning cooling water is cooled again after a simple filtration and comes back to the system. However, the contaminated and waste water is collected in a tank and is transferred out of the workshop through a pump.

2.1. Necessity of watering and dewatering in tunnel boring:

During the tunnel boring, the friction between device cutters and ground leads to a heat which should be cooled by water [2]. In other words, water plays a vital role for cooling and for creating foams [3]. Cooling system needs the cool and high quality water. The temperature of the water after cooling will increase and should be transferred to the shaft for heat transferring. Also, contaminated and waste water generated from foam system should be existed from the shaft.

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3. Mashhad Urban Railway Line 2 tunnel:
3.1. Situation description:

At the current situation, the start of the northern launching shaft of the first TBM is located at approximately 432 m before station A2 (km 0-432). From this location this TBM breaks in, and it breaks out in the proximity of station F2. The construction site of station F2 will be used as the exit shaft for both TBM's boring form the Northern and Southern Launching Shafts. Station F2 will be constructed before the boring of the mechanized tunnel. The construction site of station F2 will be used as an intermediate service shaft. The length of F2 station is 100 m. The length from the northern launching shaft to station F2 amounts to 6243 m (without the length of F2 station). The length of the southern launching shaft to F2 (without the length of F2 station) amounts to 7697 m.

Table 1: Profile tunnel.

Path length	14.3 km
Path length of the non-mechanized section (BOX &U-WALL)	0.688 km
Length of thirteen station	1.063 km
Length of mechanized section	7.75 km south path + 6.35 km north path
Boring diameter	9.4 m
Outer diameter of the segment	9.1 m
Internal diameter of the segment	8.4 m
Waste volume of boring a ring	107 m^3
The number and configuration of the concrete segments in Each ring	Segment 7+ Segment key + invert segment
Ring step	1.5 m

Figure 1 shows a view of the inlet pipe tunnel:

Fig. 1: Tunnel entrance.

The lengths of the sections and the average tunnel inclinations are given in Table 2:

Table 2: Section lengths and average tunnel inclination.

Section	Section Length [m]	Phi av [deg]	Phi av [%]
Northern Launching Shaft – A2	432	0.12	0.20
A2 – B2	1467	0.40	0.69
B2 – C2	814	0.50	0.88
C2 – D2	1256	0.46	0.80
D2 – E2	788	0.18	0.32
E2 – F2	1486	0.24	0.42
F2 – G2	1561	-0.06	-.0.11
G2 – H2	778	0.46	0.81
H2 – I2	1298	0.29	0.50
I2 – J2	864	0.77	1.35
J2 – K2	1165	0.86	1.50
K2 –L2	1357	0.91	1.60
L2 – Southern Launching Shaft	674	0.56	0.98

3.2. Basic assumptions:

1. The length of pipe for the transfer of water is 7697m for southern TBM and 6243m for northern TBM
2. The inlet water quality is good condition for both TBM use
3. Water use from the tank is 48 m^3/hr continuous and 65 m^3/hr instantaneous
4. Maximum pressure for inlet to TBM: 3bar
5. The amount of return flow of water from cooling system of TMB: 61.9 m^3/hr
6. The amount of consumable flow of water for foam system: 24 m^3/hr
7. Minimum Head for outlet to tunnel: 10 m (assumed value, to be confirmed by client)
8. Maximum capacity for system: 61.9 m^3/hr

3.3. Fundamentals of water system design:

3.3.1. System design:

The water pipes in the tunnel and the tunnel is shown below (Figure 2).

Fig. 2: View tunnels and water pipes.

Specifications water inlet:
Pipes diameter: 6" (150 mm)
Inlet water quality: temperature: < 25°C
Instantaneous volume requirement: 65 m3/hr

Specifications dewater outlet:
Pipes diameter: 4" (100 mm)
Outlet dewaters quality: temperature: > 25°C
Instantaneous: 61.9 m^3/hr

3.3.2. Concept:

The TBM uses water for two means:
1) Cooling system
2) Foam system

The cooling system requires cold water with good condition. After the cooling of the TBM, the water temperature is high and the water therefore should return to shaft for heat transfer. The dewatering system is designed based on the amount of return water from the cooling system .The design of the water supply system is performed with the calculation of the flow (Q) and the pressure head (H) according to the following steps:
Step 1: Calculation of flow (Q). The flow of water depends on the end users. In this case the main end user is the TMB. Water is also used for cleaning purposes.
Step 2: Calculation of head (H_{total}). The head of circuit consists of three types:
I) Primary pressure
II) Static head (H_s)
III) Frictional head loss (H_f)

In this case, the primary pressure is 3 bar (30 m). The static heads for each section are calculated and given in Table 3.The frictional head loss is calculated based on the Darcy-Weirsbach Equation (see section 3.3.3). These calculations help to select pump, pipe and valves for the water circuit.

Table 3: Static head water supply.

Section	Section Length [m]	Hs [m]	Phi av [/.]
Northern Launching Shaft – A2	432	0.00 – 0.85	0.20
A2 – B2	1467	0.85 – 11.0	0.69
B2 – C2	814	11.0 – 18.2	0.88
C2 – D2	1256	18.2 – 28.25	0.80
D2 – E2	788	28.25 – 30.77	0.32
E2 – F2	1486	30.77 – 37.01	0.42
F2 – G2	1561	70.50 – 68.78	-.0.11
G2 – H2	778	64.20 – 70.50	0.81
H2 – I2	1298	57.71 – 64.20	0.50
I2 – J2	864	46.05 – 57.71	1.35
J2 – K2	1165	28.58 – 46.05	1.50
K2 –L2	1357	6.87 – 28.58	1.60
L2 – Southern Launching Shaft	674	0.00 – 6.87	1.02

3.3.3. Design calculations:

3.3.3.1. Calculation of water supply system:

3.3.3.1.1. Calculation of flow (Q):

The water use from tank is 48 m3/hr continuous and 65 m3/hr instantaneous. The water circuit is designed for 65m3/hr (flow), so that it may also be used for other types of applications in the tunnel such as cleaning.

$Q = 65$ m3/hr $= 1.708 \times 10^{-2}$ m^3/s

Corresponding to DIN-NORMS, the velocity of water in a pipe with a diameter less than 500 mm should remain below 2.0 m/s.

D = 6" = 0.1524 m

$A = 1.824 \times 10^{-2}$ m²

$$V = \frac{Q}{A} = \frac{1.708\times 10-2}{1.824\times 10-2} = 0.9364\frac{m}{s} < 2.0\frac{m}{s} \quad (1)$$

The water velocity remains below 2.0 m/s, thus the pipe diameter of 6" is suitable.

$$\mathrm{Re} = \frac{VD}{\nu} = \frac{0.9364\times 0.1524}{1.3\times 10-6} = 0.1097\times 106 \quad (2)$$

3.3.3.1.2. Calculation of head (H):

$$H_{total} = H_s + H_f + 30m \quad (3)$$

3.3.3.1.3. Calculation of static head (H_s):

Regarding Table 3, two sections are to be considered:

1) From launching shaft to F2, with a length of 6243 m

2) From exit shaft to F2, with a length of 7697 m

The static head values for the two sections are:

1) H_S (Northern launching shaft - F2) = 37.01 m

2) H_S (Southern launching shaft - F2) = -68.78 m

3.3.3.1.4 Calculation of frictional head (H_f):

a) For southern TBM:

The frictional head (H_f) is determined by the Darcy-Weisbach Equation:

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$$H_f = f\ \frac{L}{D} \times \frac{V^2}{2g} \quad (4)$$

Where:
"L" is the length of the pipe
"D" is the diameter of pipe
"V" is the average velocity of the fluid flow
"g" is the local acceleration to gravity
"f" is a dimension coefficient called the Darcy friction factor that is determined with the Colebrook formula.

$$\frac{1}{\sqrt{f}} = 2 \times \log[(3.71 \times D)/K] \quad (5)$$

Equivalent sand roughness (K) for Polyethylene pipe is:

$K = 0.1mm = 0.1 \times 10^{-3} m$
$f = 1.775 \times 10^{-2}$
$H_f = 39.57$

Thus H (total) plus 10% loss for bending is:
H (total) = (39.57-68.78+30) × 1.1 = 0.87 m
b) For northern TBM:
Equivalent sand roughness (K) for Polyethylene pipe is:

$K = 0.1mm = 0.1 \times 10^{-3} m$
$f = 1.775 \times 10^{-2}$
$H_f = 32.01$
H_{total} = (32.01 + 37.01 +30) ×1.1=108.92 m

3.3.3.2. Calculation of water back system:
3.3.3.2.1. Calculation of flow (Q):

The return flow from the TBM cooling system amounts to 61.9 m^3/h

Q = 61.9m^3/hr = 1.72 × 10^{-2} m^3/sec

Corresponding to DIN-NORMS, the velocity of water in a pipe with a diameter less than 500 mm should remain below 2.0 m/s

D = 6" = 0.1524 m

A =1.824 × 10^{-2} m²

$$V = \frac{Q}{A} = \frac{1.72 \times 10-2}{1.824 \times 10-2} = 0.9429 \frac{m}{s} < 2.0 \frac{m}{s} \quad (6)$$

$$\mathrm{Re} = \frac{VD}{\nu} = \frac{0.9429 \times 0.1524}{1.3 \times 106} = 0.11053 \times 10-6 \quad (7)$$

3.3.3.2.2. Calculation of head (H)

$$H_{total} = H_s + H_f + 10m \quad (8)$$

3.3.3.2.3. Calculation of static head (H_s):

Regarding Table 3, there are two sections that are considered:
1) From the launching shaft to F2, with a length of 6243 m
2) From the F2 to the TBM exit shaft to F2, with a length of 7697 m
Table 3 shows the static head:

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1) H_s (F2 - Northern launching shaft) = -37.01 m
2) H_s (F2 - Southern launching shaft) = 68.78 m

3.3.3.2.4. Calculation of frictional head (H_f):

Darcy-Weisbach Equation:

$$H_f = f\,\frac{L}{D}\times\frac{V^2}{2g} \tag{9}$$

where:
"L" is the length of the pipe
"D" is the diameter of pipe
"V" is the average velocity of the fluid flow
"g" is the local acceleration of gravity
"f " is a dimension coefficient called Darcy friction factor that is determined with the Colebrook formula:

$$\frac{1}{\sqrt{f}} = 2\times\log[(3.71\times D)/K] \tag{10}$$

Equivalent sand roughness (K) for PVC pipe is

$$f = 1.775\times10^{-2}$$
$$K = 0.1mm = 0.1\times10^{-3}m$$

a) For northern TBM:

$$H_f = 31.89m$$

H_{total} = (-37.01 + 31.89 +10) ×1.1=5.36 m

b) For southern TBM:

$$H_f = 0.01775\times\frac{7597}{0.1524}\times\frac{(0.9347)^2}{2\times9.8} = 39.44m$$

Thus H_{total} plus 10% loss for bending is:

H_{total} = (68.78+39.44+10) ×1.1 = 130.04 m

4. Specification of component:

4.1. Pipe:

On the basis of user classification the specifications of pipe are:
Type: PVC-u pipe, specifications according to European Standard EN-1329 Size of pipe: 6"
Single pipe length: 6 m

4.2. Pump:

The pump is selected based on the required flow and head. It is advisory that at least two pumps are available: one main unit and another for reserve.
The required pump power is calculated with the formula:

$$N = \frac{\gamma\times Q\times H}{\eta} \tag{11}$$

Where:
"N" is the required pump power
"γ" = 9806.65 N/m³
"Q" = 1.72 × 10^{-2} m³/sec
"H" (southern)= 130.04 m
"η" = 75%
So the pump power required is:
a) For Water supply system
"N" (northern) = 24.32 KW

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"*N*" (southern) = 0.223 KW
b) For Dewatering
N (southern) = 29.24 KW

4.3 Valves:

Directional control valves should be used in the water circuit. The type of valve is: shut-off valve. (Fig 3).

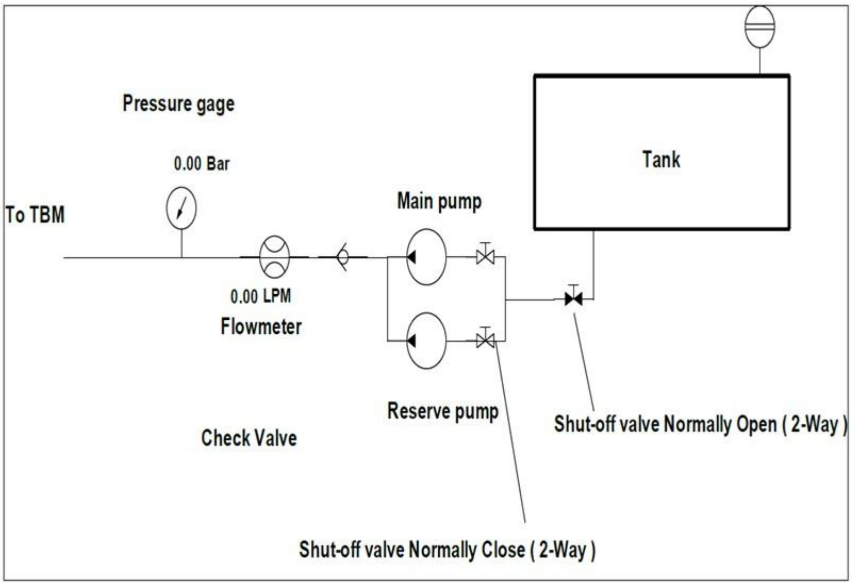

Fig. 3: Water Diagram.

5. Conclusion:

The distance between the southern shaft and the output shaft F2 station, is a critical path for equipment selection. Therefore, reducing the length of the path can lead to economical optimization and energy saving. According to system design calculations, a high pressure pump can be a proper selection for watering system. Also, for dewatering system, a high pressure pump and a centrifugal pump can be used for south TBM and north TBM, respectively. Due to the downward slope of the south shaft to TBM, the tunnel length has no influence on the selection of required equipment. The valves should be a breaker type so that in an emergency condition can be interrupted.

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