Analytical Study to Assessment the Stability of the Al-Askarian Underpass in Najaf

Zaid N. ALKhayat[1, a*] and Mohammed K. Fakhraldin[1, b]

[1] Department of Civil Engineering, University of Kufa, Al-Najaf, Iraq

[a] zaid81en@gmail.com and [b] mohammed.fakhruddin@uokufa.edu.iq

*Corresponding author

Abstract. This study studied the most important problems that may be exposed to the Al-Askarian underpass in the province of Najaf. The length of the tunnel is 507 m. It is divided into two parts according to the number of test pits, and each part is divided into 17 parts depending on the locations of the joints in the tunnel. During the construction process, the problem of height-water level appeared at the construction site, so four wells were drilled to control the groundwater level. The highest groundwater level was recorded at a depth of 1 m below the ground level. The analytical study showed that the stability of the origin, depending on the safety factor, is as follows: Safety coefficient against overturning from 3.5 to 10.4. Safety coefficient against sliding from 1.23 to 25.6. Safety coefficient against bearing capacity from 6.4 to 108.7. Calculations were also made to find out the resistance of the tunnel against the ascending forces in the event that the groundwater level rises to the ground level and to suggest appropriate treatments for such a case.

Keywords: Al-Askarian underpass; overturning; bearing capacity; sliding; factor of safety; finite element.

1. INTRODUCTION

Recently, the need to establish facilities below the natural ground level has increased in Iraq in general, and in the holy city of Najaf in particular, for several reasons, including The social nature of human beings that drives them to live within population clusters in limited land areas where food and work are available, in addition to migration that took place from rural areas to cities for reasons related to work, study, access to medical care, housing, etc. In addition, the province of Najaf is an important religious center. These increasing population numbers were accompanied by an increase in the need to establish some facilities necessary for the livelihood of these residents. Because of the nature of the soil of Najaf, which cannot bear large weights produced from vertical buildings towering above it without conducting economically costly treatment operations, and also because of the urban planning of the city that determined the heights of buildings in Al-Najaf Al-Ashraf Governorate, with a specific height, with the presence of adjacent properties that do not allow to transgress its borders, these reasons combined forced the designers to go to the construction of underground facilities.

Failure occurs in the underpass for several reasons, the most prominent of which is lateral pressure, which often leads to overturning [1,9] in the ground corridor, in addition to weak soil resistance under the foundation of the tunnel, which leads to slipping [2] in the tunnel or shearing in the soil itself, so it is necessary to Knowing the chemical and physical properties of the soil [5,6,7,8] for its importance in calculating the bearing capacity [3,4], with the necessity of calculating the resistance of the tunnel to the ascending forces.

2. SOIL PROPERTIES

On-site investigations of the site of the Al-Askarian underpass before its construction were conducted by the construction laboratory in Babel Governorate, where the LSPT examination, as shown in Table (1), represented by two test holes with a depth of 20 m, was carried out at the site specified for the construction of the underpass, as shown in Figure 1. This shows that the soil contains an impressive percentage of (so3), which must be taken into account by the presence of ground water that interacts with it, and also shows that the soil is generally sandy.

Figure 1: Borehole location.

Table 1: Chemical and physical properties for soil.

Samples				Index properties		Particle size distribution				SP. GR. (GS)	S.P.T."N" value	Chemical Tests				
Number	Type	Depth (m)														
Field		From	To	L.L %	P.I %	Clay %	Silt %	Sand %	Gravel %			SO_3 %	T.S.S. %	Gypsum %	$CaCO_3$	CL%
1	D	0.0	1.5									7.49	17.1	16.1	10	0.023
2	S.S	1.5	2.0			29		71	0		12					
3	D	2.5	3.0			8		91	1							
4	S.S	3.0	3.5			7		87	6		57 / 7"					
5	D	4.0	5.0			29		64	7							
6	S.S	5.0	5.5			29		54	17		50 / 4"	1.87	5.1	4.03	20	0.0355
7	D	6.0	7.0			29		54	17							
8	S.S	7.0	7.5			14		84	2		50 / 2"	1.89	5.1	4.02	10	0.0213
9	D	8.0	9.0			46	3	49	2	2.69						
10	S.S	9.5	10.0			11		89	0		50 / 4"					
11	D	10.5	11.5			40	9	51	0	2.69						
12	S.S	12.0	12.5								54	0.37	0.91	0.79	13	0.0195
13	S.S	14.5	15.0			12		85	3		63					
14	D	16.0	17.0	97.3	59.9											
15	S.S	17	17.5			15		77	8		>50	0.54	2.4	1.16	11	0.0284
16	D	18.0	19.0	103.7	74.3											
17	S.S	19.5	20.0	65.3	36.7	15		84	1		58	0.84	2.1	1.03	15	0.0248

3. UNDERPASS ANALYSIS

Based on the locations and number of joints in the underpass, it was divided into 17 parts for each side, including half of the covered part for each side, as shown in Figure 2. Each part was approximately 12 m long, except for the first parts at the ends of the underpass, where the lengths were 33 m for the first hole and 25 m for the second hole, and to perform calculations on all parts of the underpass from U to B, the underpass was divided into two main parts based on the test excavation site, where it was There are some differences in the distances between the joints and the slope, the amount of which was in the part of the first hole equal to 0.0325 and the part of the second hole equal to 0.033.

Figure 2: Underpass parts.

3.1 Underpass Failure Analysis

3.1.1 Origin Stability Analysis

Failure is generally divided into three types:

- The overturning failure.
- Sliding failure.
- Bearing capacity failure.

3.1.2 The Overturning Failed

In this case, the wall of the underpass is the resistance to the lateral forces of the soil, where the lowest value of the safety coefficient was recorded as 3.5 in the parts P (BH1) as shown in Figure 3: a and b while the required safety coefficient is 2 to 3. Hence, the underpass was safe for agents overturning.

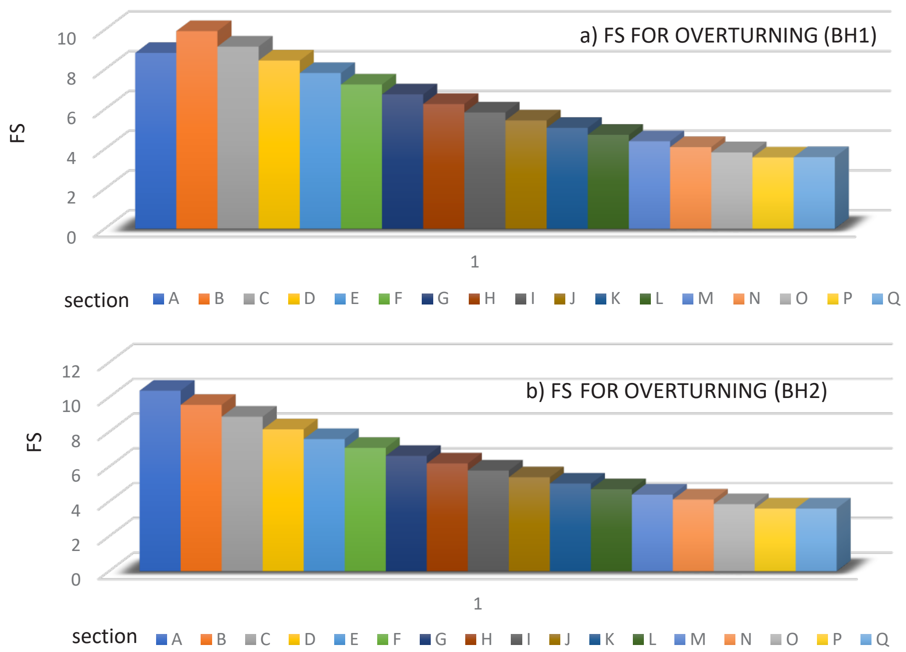


Figure 3: Factor of safety against overturning (F.S) (a) for BH1 (b) for BH2.

3.1.3 Sliding

This failure is considered one of the most common cases in the underpass, as it occurs when the amount of friction forces between the foundation of the underpass and the soil is less than the amount of lateral forces applied to the underpass, where the lowest value of the safety coefficient was recorded as 1.1 in the part P (BH2) as shown in Figure 4 (a and b), while the required safety coefficient is >3 so the underpass was safe agents overturning.

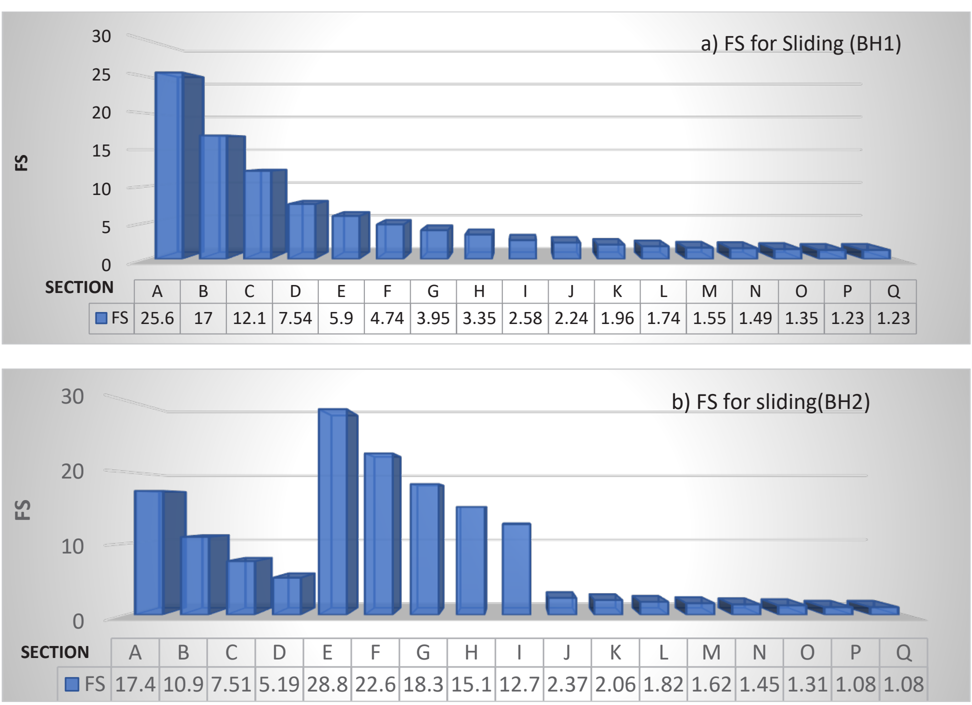
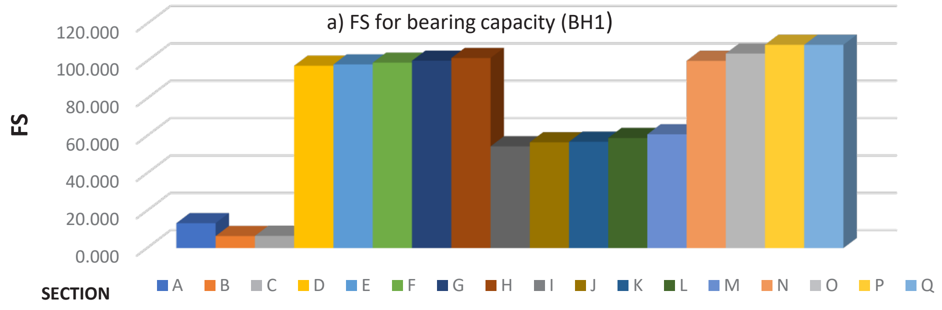


Figure 4: Factor of safety against sliding (F.S) (a) for BH1 (b) for BH2.

3.1.4 Bearing Capacity

The bearing capacity is the ability of the soil to bear the loads placed on it by the structures above it without failure. The weight of the underpass was calculated with the external loads placed on the soil with the calculation of the stresses at the ends of the foundation, (q) max and (q) minim, to calculate the safety coefficient, where the lowest value was recorded equal to (6.4), as shown in Figure 5 (a and b) While the required to be >3 this means that the underpass was safe agents Bearing capacity.



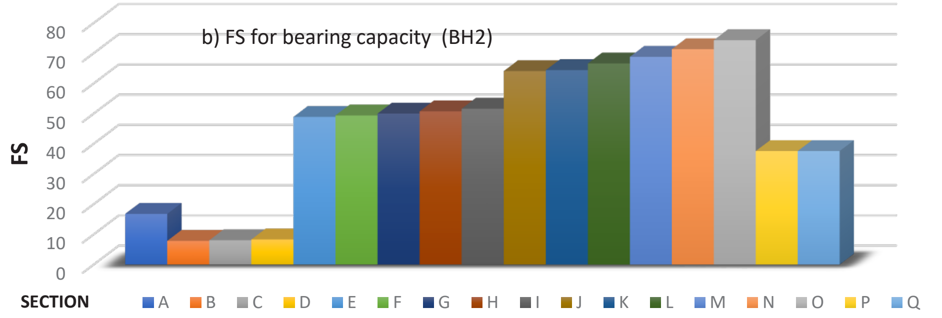
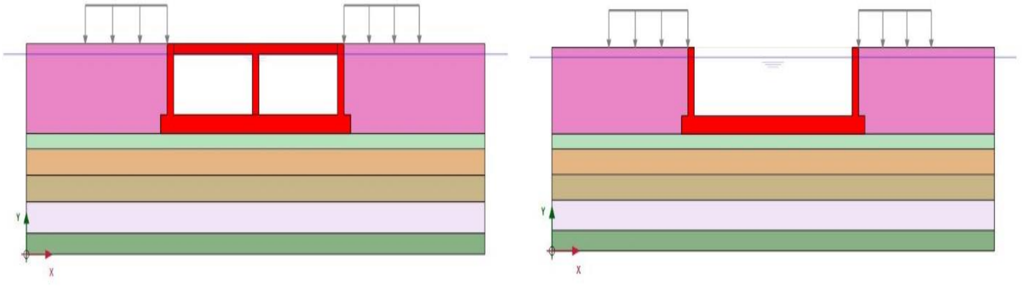


Figure 5: Factor of safety for bearing capacity (F.S) (a) for BH1 (b) for BH2.

4. FINITE ELEMENT PROGRAM (PLAXIS)

The dimensions of the real underpass parts were represented in the finite element program as follows: the width of the underpass foundation is 29 m, the width of the passages is 25 m, with the middle island in the unroofed parts and the wall in the covered part, with the width of the walls 1 m for each wall, with the width of each part approximately 12 m, except for the parts at the outskirts of the underpass, depending on the locations joints in the underpass. The representation of the underpass in the Finite Elements Program 2D is shown in Figure 6 (a and b), where the measurements were adopted from the accurate field surveys of the underpass. It is a program developed by a Dutch company working in software development, where it uses the finite element method (FEM) to represent geotechnical problems in a three-dimensional or two-dimensional form. The program works on the basis of three theories: deformation and water flow and standardization of deformation and water flow together, in addition to the presence of an attached program for dynamic calculations.



a b

Figure 6: (a) covered part in the underpass (b) open part in the underpass part within (BH2).

5. UPLIFT PRESSURE

The weight of the underpass is the main force that resists the uplift pressure. See Tables 2 and 3 for underpass weight details.

Table 2: Weight of underpass (BH 1).

Section	H_{av}(m)	Width (m)	Cantilever (m^3)	Base (m)	V total (m^3)	Hole H	Hole W	Hole B	Hole V (m^3)	Part V (m^3)	$\gamma_{concrete}$	Roof W (kN)	Mid wall W (kN)	Part W (kN)
A	2.727	27	32.752	9.2	710.139	0.947	25	9.2	217.810	492.329	25	0	0	12308.220
B	3.072	27	42.720	12	1037.948	1.292	25	12	387.508	650.441	25	0	0	16261.015
C	3.462	27	42.720	12	1164.450	1.682	25	12	504.639	659.811	25	0	0	16495.277
D	3.856	27	43.432	12.2	1313.538	2.076	25	12.2	633.125	680.414	25	0	0	17010.349
E	4.253	27	43.432	12.2	1444.292	2.473	25	12.2	754.192	690.099	25	0	0	17252.484
F	4.651	27	43.788	12.3	1588.495	2.871	25	12.3	882.934	705.561	25	0	0	17639.019
G	5.040	27	41.296	11.6	1619.868	3.260	25	11.6	945.441	674.427	25	0	0	16860.682
H	5.427	27	43.432	12.2	1831.192	3.647	25	12.2	1112.434	718.759	25	0	0	17968.967
I	5.816	27	41.652	11.7	1878.968	4.036	25	11.7	1180.569	698.399	25	0	0	17459.987
J	6.200	27	42.364	11.9	2034.444	4.420	25	11.9	1314.968	719.475	25	0	0	17986.886
K	6.589	27	42.720	12	2177.514	4.809	25	12	1442.661	734.853	25	0	0	18371.322
L	6.979	27	42.720	12	2304.015	5.199	25	12	1559.792	744.223	25	0	0	18605.584
M	7.371	27	43.076	12.1	2451.302	5.591	25	12.1	1691.389	759.913	25	0	0	18997.828
N	7.762	27	42.364	11.9	2536.232	5.982	25	11.9	1779.587	756.645	25	0	0	18916.124
O	8.144	27	41.296	11.6	2592.030	6.364	25	11.6	1845.591	746.439	25	0	0	18660.982
P	8.526	27	42.364	11.9	2781.899	6.746	25	11.9	2007.057	774.843	25	0	0	19371.063
Q	8.72	27	153.080	43	10277	6.94	24	12	1998.72	8278.28	25	38947.25	7460.5	253364.750

Table 3: Weight of underpass (BH 2).

Section	H_{av}(m)	Width (m)	Cantilever (m^3)	Base (m)	V total (m^3)	Hole H	Hole W	Hole B	Hole V (m3)	Part V (m^3)	γ concrete	Roof W (kN)	Mid wall W (kN)	Part W (kN)
A	2.61	27	2.74	1.54	111.27	0.83	25	1.54	31.96	79.31	25	0	0	1982.75
B	2.83	27	21.43	12.04	942.62	1.05	25	12	316.12	626.50	25	0	0	15662.53
C	3.23	27	21.15	11.88	1058.18	1.45	25	12	435.91	622.26	25	0	0	15556.61
D	3.67	27	25.60	14.38	1451.07	1.89	25	12.2	576.89	874.18	25	0	0	21854.49
E	4.12	27	21.81	12.25	1383.17	2.34	25	12.2	712.48	670.69	25	0	0	16767.30
F	4.52	27	21.54	12.10	1499.04	2.74	25	12.3	843.32	655.72	25	0	0	16393.00
G	4.92	27	21.00	11.80	1588.99	3.14	25	11.6	911.03	677.96	25	0	0	16948.96
H	5.32	27	21.28	11.96	1737.86	3.54	25	12.2	1079.10	658.76	25	0	0	16469.03
I	5.72	27	21.36	12.00	1874.14	3.94	25	11.7	1151.86	722.28	25	0	0	18057.05
J	6.12	27	21.61	12.14	2028.46	4.34	25	11.9	1291.46	737.01	25	0	0	18425.13
K	6.53	27	21.82	12.26	2182.86	4.75	25	12	1424.52	758.33	25	0	0	18958.35
L	6.93	27	20.98	11.79	2226.59	5.15	25	12	1544.96	681.63	25	0	0	17040.82
M	7.33	27	21.30	11.97	2388.33	5.55	25	12.1	1677.79	710.54	25	0	0	17763.55
N	7.72	27	20.92	11.75	2471.04	5.94	25	11.9	1767.85	703.19	25	0	0	17579.79
O	8.12	27	21.29	11.96	2643.26	6.34	25	11.6	1838.08	805.18	25	0	0	20129.56
P	8.52	27	21.44	12.04	2791.47	6.74	25	11.9	2004.84	786.63	25	0	0	19665.73
Q	8.72	27	76.54	43.00	10200.46	6.94	24	12	1998.72	8201.74	25	37033.75	14921	256998.25

The weight of the underpass is (1059.783409) MN, and the uplift force is (681.82051) MN.

F.S = weight of the underpass/uplift force should be more than (1).
F.S = 1059.783409 / 681.82051 = 1.55 > 1
Because of that, the underpass was stable but in a critical failure zone. Because the tunnel can float if the water rises to the ground level.

5.1 Groundwater Level Rise

The most important problem facing the underpass is the rise in the groundwater level, which leads to an increase in the amount of uplift forces, which in turn leads to the buoyancy of the underpass and, thus, its complete failure. The effect of these forces depends on the depth of the water penetration of the underpass and the width of its foundation, as shown in Figure 7.

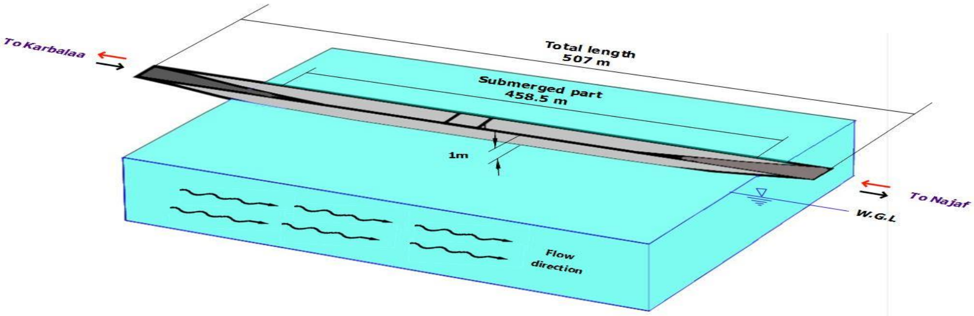


Figure 7: Water under the underpass.

According to the on-site investigation report, the groundwater level changes depending on the season, where the maximum height was recorded by (1) m below the natural ground level, as this depth was adopted in the calculations as it is the most dangerous case. To overcome these forces, one must:

a) Calculate the weight of the structure accurately.
b) Carry out piles at the bottom of the base tunnel.
c) Carry out the Cantilever sideways to increase the downward forces.
d) Increase friction between the walls and the soil.
e) Lower the groundwater level.

5.2 The Final Stage

After the implementation of the project by the executing company, four wells were working to lower the groundwater level continuously. When these wells stopped working, the underpass was filled with water, which led to an increase in the possibility of underpass failure, so it was necessary to do treatments to avoid such problems, including:

- Increasing the thickness of the concrete forming the underpass parts.
- Adding a cement wall above the middle carrot in the non-roofed parts increases the underpass's weight.
- Burying the sides of the underpass increases the lateral friction forces (TU), increasing the structure's stability, as shown in Tables 4 and 5.

Table 4: Tensile force when water level = 1m BH (1).

Section	Depth (m)	D (m)	L (m)	γ_{sub}	Ø	kp	sf	sf max	c_u	W (kN)	Tu (kN)
A	2.33	0.55	33.7	10	26	1.4	1.60	1.36	23.3	44413.63	45396.80
B	3.07	1.29	12	10	26	1.4	2.42	1.36	23.3	16261.02	17251.37
C	3.46	1.68	12	10	26	1.4	2.85	1.36	23.3	16495.28	17866.79
D	3.86	2.08	12.2	10	26	1.4	3.28	1.36	23.3	17010.35	18831.83
E	4.25	2.47	12.2	10	26	1.4	3.72	1.36	23.3	17252.48	19546.33
F	4.65	2.87	12.3	10	26	1.4	4.16	1.36	23.3	17639.02	20468.11
G	5.04	3.26	11.6	10	26	1.4	4.59	1.36	23.3	16860.68	20060.32
H	5.43	3.65	12.2	10	26	1.4	5.01	1.36	23.3	17968.97	21893.84
I	5.82	4.04	11.7	10	26	1.4	5.44	1.36	23.3	17459.99	21833.60
J	6.20	4.42	11.9	10	26	1.4	5.86	1.36	23.3	17986.89	23059.98
K	6.59	4.81	12	10	26	1.4	6.29	1.36	23.3	18371.32	24165.29
L	6.98	5.20	12	10	26	1.4	6.72	1.36	23.3	18605.58	25122.85
M	7.37	5.59	12.1	10	26	1.4	7.15	1.36	23.3	18997.83	26334.06
N	7.76	5.98	11.9	10	26	1.4	7.58	1.36	23.3	18916.12	26936.97
O	8.14	6.36	11.6	10	26	1.4	8.00	1.36	23.3	18660.98	27296.03
P	8.53	6.75	11.9	10	26	1.4	8.42	1.36	23.3	19371.06	29055.05
Q	8.72	6.94	43	10	26	1.4	8.63	1.36	23.3	253364.75	287150.83

Table (5): Tensile force when water level = 1m BH (2).

Section	Depth (m)	D (m)	L (m)	γ_{sub}	Ø	kp	sf	sf max	c_u	W (kN)	Tu (kN)
A	2.21	0.43	25.54	10	26	1.4	1.47	1.36	23.3	30192.85	30765.15
B	2.83	1.05	12.04	10	26	1.4	2.16	1.36	23.3	15662.53	16441.56
C	3.23	1.45	11.88	10	26	1.4	2.60	1.36	23.3	15556.61	16689.46
D	3.67	1.89	14.38	10	26	1.4	3.08	1.36	23.3	21854.49	23733.06
E	4.12	2.34	12.25	10	26	1.4	3.57	1.36	23.3	16767.30	18901.81
F	4.52	2.74	12.1	10	26	1.4	4.02	1.36	23.3	16393.00	19010.94
G	4.92	3.14	11.8	10	26	1.4	4.46	1.36	23.3	16948.96	20034.25
H	5.32	3.54	11.955	10	26	1.4	4.89	1.36	23.3	16469.03	20159.21
I	5.72	3.94	12.001	10	26	1.4	5.33	1.36	23.3	18057.05	22374.81
J	6.12	4.34	12.143	10	26	1.4	5.78	1.36	23.3	18425.13	23455.81
K	6.53	4.75	12.26	10	26	1.4	6.22	1.36	23.3	18958.35	24754.47
L	6.93	5.15	11.788	10	26	1.4	6.66	1.36	23.3	17040.82	23362.48
M	7.33	5.55	11.966	10	26	1.4	7.10	1.36	23.3	17763.55	24937.46
N	7.72	5.94	11.751	10	26	1.4	7.54	1.36	23.3	17579.79	25429.71
O	8.12	6.34	11.962	10	26	1.4	7.97	1.36	23.3	20129.56	28948.59
P	8.52	6.74	12.043	10	26	1.4	8.41	1.36	23.3	19665.73	29436.67
Q	8.72	6.94	43	10	26	1.4	8.63	1.36	23.3	256998.25	290784.33

Total weight = weight of the underpass + Tensile force (Tu)
Total weight = 1059.783409 + 1331.489831 = 2391.27324 MN
F.S = 1.2 to 4
Use F.S = 1.7
Wa = $\frac{W}{FS}$ = $\frac{2391.27324}{1.7}$ = 1406.631317647 MN **>** 681.82051 MN
So, the underpass was safe if the water level was still 1 m under the ground level.

6. CONCLUSIONS

- There is a possibility that the tunnel will be exposed to the danger of slipping in the areas close to the center of the tunnel, so it is necessary to work in these areas.
- The tunnel is safe against the risk of overturning.
- From the analysis results, it was found that the underpass is unsafe if the groundwater rises to the ground level.
- A high safety coefficient should be used to calculate the bearing capacity due to the high proportion of gypsum that interacts with water, and this interaction will lead to some parts of the underpass being unsafe.
- Keep the current water level and try to reduce it in the future.

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