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Professional paper

THE SCOPE OF THE CONDUCTED FIELD INVESTIGATIONS SUFFICIENTLY DEFINES THE SOIL ENVIRONMENT WHERE THE BUILDING FOUNDATION WILL TAKE PLACE.

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Abstract

The task is to show the calculations of statistics and dimensional strip foundations and foundation slab of the building. We also analyzed the impact of the various modules of subgradel reaction on the base plate and strip foundations of the building.

The methodology of the research work and laboratory tests is in accordance with the technical regulations, current standards, as well as the guidelines and recommendations from the literature that are common in practice in the country and abroad for this type of buildings.

According to the soil failure criterion, the soil load bearing capacity is determined according to the Tercaghi formulation:

- Rectangular single spread footing: $qf = 1.3cNc + \gamma_1 DfNq + 0.4\gamma_2 BN\gamma$
- Rectangular wall footing: $qf = cNc + \gamma_1 DfNq + 0.5\gamma_2 BN\gamma$
- Slab foundation: $qf = (1+0.3n)\ cNc + \gamma_1 DfNq + 0.5\gamma_2 BN\gamma$

For the purposes of structural analysis, in addition to the allowable load bearing capacity of the foundation, the modulus of the soil reaction was calculated according to the method of Bowles, $Ks = Fs \times 40 \times \sigma_{all}$ (kN/m^3).

Keywords: physical - chemical characteristics, geomechanical characteristics, Ks., φ, c, γ1.

1 Introduction

The considered industrial building (G-industrial), with floor levels B+GF+1 (Po+Pr+1) is located in the immediate vicinity of E65 road “Gostivar – Ohrid”, on KP 4106/5 and KO Kicevo 5.

In order to determine the essential physical-mechanical and deformable characteristics of the soil where the buildings footing will lay, all the necessary engineering, geological and geo-mechanical field research works and laboratory examinations were properly undertaken.

The undertaken geotechnical investigations were intended to determine the litho logical composition of the soil layers in depth, i.e. to determine the field conditions for construction of the building, to determine the groundwater level (if there is any), to determine the deformable characteristics of the soil where the building will be footed, as well as to understand other relevant data needed for the most optimal funding along with the functionality and stability of the facility during construction and operation.

The methodology of the research work and laboratory tests is in accordance with the technical regulations, current standards, as well as the guidelines and recommendations from the literature that are common in practice in the country and abroad for this type of buildings.

The results of the field research works and laboratory tests are presented through appropriate graphic attachments, spreadsheets and diagrams, whereas their interpretation is given in the textual part.

2 Field investigation

The field investigation includes the following activities:

- Engineering-geological and hydro geological mapping of the terrain where the considered building is located;
- Mechanical excavation of exploration wells;
- Geotechnical mapping of the material from the wells;
- Taking disturbed samples for laboratory examination.

Samples from the exploration wells are taken regularly according to the applicable standards and are submitted to the laboratory for further testing.

Table 1. Properties of samples taken from the exploration wells

Number of well	Depth (м’)	Groundwater level/appearance (м’)	Note
B-1	4.6	- 4.3	June ‘20
B-2	3.9	/	June ‘20

Table 2 Seismicity coefficient

Intensity according to MKZ	Кs
VII	0.025
VIII	0.050
IX	0.100

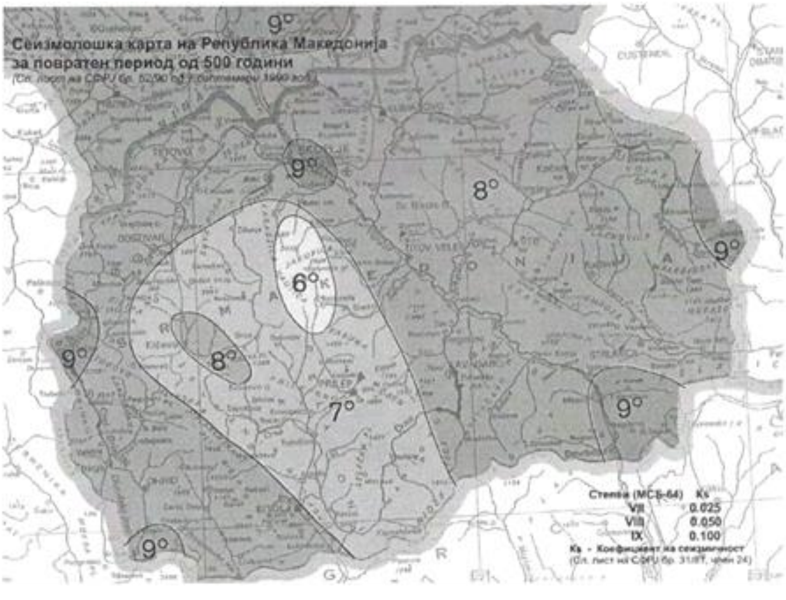


Figure 1. Seismic map of RNM for a return period of 500 years

Regarding the structural elements, the cases given in table 1 and 2 are considered.

The data on the physical-mechanical and strength characteristics of the represented materials make it possible to calculate the allowed load-bearing capacity of the soil where the building will be funded.

The soil load bearing capacity is calculated using:

- The soil failure criterion.

3 Methods

Soil failure criterion

According to the soil failure criterion, the soil load bearing capacity is determined according to the Tercaghi formulation:

- Rectangular single spread footing: $qf = 1.3cNc + \gamma_1 DfNq + 0.4\gamma_2 BN\gamma$ (1)
- Rectangular wall footing: $qf = cNc + \gamma_1 DfNq + 0.5\gamma_2 BN\gamma$ (2)
- Slab foundation: $qf = (1+0.3n)\ cNc + \gamma_1 DfNq + 0.5\gamma_2 BN\gamma$ (3)

Where: qf – load bearing capacity (kPa); c – cohesion (kPa); γ_1, γ_2 – volume weight above and below the foundation level (kN/m^3); Df – effective foundation depth (m); B – footing width (m); Nc, Nq, Nγ - load factors depending on the angle of internal friction (φ).

For the purposes of structural analysis, in addition to the allowable load bearing capacity of the foundation, the modulus of the soil reaction was calculated according to the method of Bowles, $Ks = Fs \times 40 \times \sigma_{all}$ (kN/m^3).

Tercaghi formulation

When determining the allowable load bearing capacity, an internal friction angle of φ - 18.4^o is adopted.

The calculation of the allowable load is given in the following table 3 for single foundations.

$qf = 1.3cNc + \gamma 1DfNg + 0.4\gamma 2BN\gamma$ (4)

Table 3. φ, c, γ_1

Φ	18.4	^{o}
C	15	kPa
γ_1	19.2	kN/m^3
γ_2	19.2	
N_c’	11.42	
N_q’	4.25	
N_γ	1.73	
Fs	3	

The calculation of the allowable load is given in table 4 for rectangular (strip) foundations.

$qf = cNc + \gamma_1 DfNq + 0.5\gamma_2 BN\gamma$ (5)

Table 4. Fs.

Φ	18.4	º
C	15	kPa
$\gamma_{1/2}$	19.2	kN/m^3
N_c’	11.42	
N_q’	4.25	
N_γ	1.73	
Fs	3	

Df [m]	B [m]		σ_{all} [kN/m^2]	Ks [kN/m^3]
0.8	1.0		84.40	10127.5
1.0	1.0		89.84	10780.3
1.2	1.0		95.28	11433.1
1.5	1.0		103.44	12412.3
0.8	1.2		85.50	10260.4
1.0	1.2		90.94	10913.2
1.2	1.2		96.38	11566.0
1.5	1.2		104.54	12545.2
0.8	1.5		87.16	10459.7
1.0	1.5		92.60	11112.5
1.2	1.5		98.04	11765.0
1.5	1.5		106.20	12744.5
0.8	1.8		88.82	10659
1.0	1.8		94.26	11311.8
1.2	1.8		99.70	11964.6
1.5	1.8		107.86	12943.8
0.8	2.2		91.04	10924.7
1.0	2.2		96.48	11577.5
1.2	2.2		101.92	12230.3
1.5	2.2		110.08	13209.5

The calculation of the allowable loads for a two-layered environment is given in Table 5 for rectangular (strip) foundations.

$$qfI = 2/3cNc' + \gamma_1 DfNq' + 0.5\gamma_2 BN\gamma' \qquad (6)$$

$$qfII = 2/3cNc' + \gamma_1 DfNq' + 0.5\gamma_2 BN\gamma' \qquad (7)$$

$$qf=qfII+((qfI-qfII)/0.8*(t/B-0.2)) \qquad (8)$$

Table 5. k_s.

Φ	38	o		φ	18.4	o
C	0	kPa		c	15	kPa
$\gamma_{1/2}$	22.5	kN/m^3		$\gamma_{1/2}$	19.2	kN/m^3
N_c’	41.28			N_c’	11.42	
N_q’	29.99			N_q’	4.25	
N_γ	37.98			N_γ	1.73	
			t = 0.6			
			k_s = 3.0			

Df [m]	B [m]	qfI [kN/m^2)	σ_{all} [kN/m^2]	Ks [kN/m^3]
0.8	1.0	322.37	65.36	193.87
1.0	1.0	367.35	70.80	219.08
1.2	1.0	412.34	76.24	244.29
1.5	1.0	479.81	84.40	282.11
0.8	1.2	350.86	66.47	173.12
1.0	1.2	395.84	71.91	193.38
1.2	1.2	440.82	77.35	213.65
1.5	1.2	508.30	85.51	244.06
0.8	1.5	393.59	68.13	149.50
1.0	1.5	438.57	73.57	164.82
1.2	1.5	486.56	79.01	180.15
1.5	1.5	551.03	87.17	203.14
0.8	1.8	436.32	69.79	130.88
1.0	1.8	481.31	75.23	142.91
1.2	1.8	526.29	80.67	154.94
1.5	1.8	593.76	88.83	172.99

The impact of the **buffer material**is the same as a layer of the same material with infinite lateral expansion. In addition to that, the width of the buffer layer B' is adopted as the width between the line drawn from the lower edge of the foundation at an angle of 45°, which should be provided so that the buffer layer on both sides has expansion equal to the thickness H of the buffer layer.

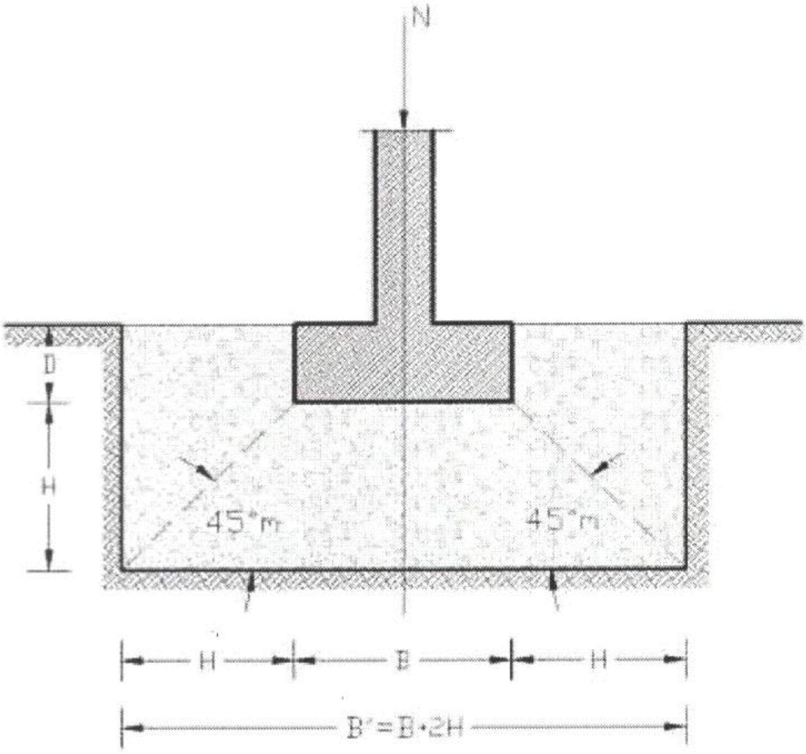


Figure 3. Width of the replaced buffer layer

The calculation of the **allowable load** is given in table 6 for slab foundation.

$$q_f = (1+0.3n)\, cN_c + \gamma_1 D_f N_q + 0.5\gamma_2 B N_\gamma \qquad (9)$$

Table 6. qf

Φ	18.4	^{o}
C	15	kPa
$\gamma_{1/2}$	19.2	kN/m^3
N_c’	11.42	
N_q’	4.25	
N_γ	1.73	
Fs	3	

Df [m]	B [m]	L [m]	σ_{all} [kN/m^2]	Ks [kN/m^3]
2.2	13.0	28.0	196.86	23623.3
2.5	13.0	28.0	205.02	24602.5
2.8	13.0	28.0	213.18	25581.7
3.0	13.0	28.0	218.62	26234.5
3.2	13.0	28.0	224.06	26887.3
3.5	13.0	28.0	232.22	27866.5
3.8	13.0	28.0	240.38	28845.75
4.0	13.0	28.0	245.82	29498.5

4 Deformation calculation (subsidence)

From the performed analysis for foundation strips on a bonified substrate with dimensions 1.0x2.0m and for a foundation slab on a non-bonified substrate, it is found that only small subsidence within the permissible limits are obtained.

However, due to the weak characteristics of the considered soil materials and the proposed soil replacement (bonification) at the foundation level, the consolidation (laying) of the foundation will be done almost instantly with the application of each load rate and they will end to a large extent in construction phase due to the favorable consolidation characteristics of the foundation.

Table 7. Deformation calculation

$\sigma_{zo.} = \sigma_{doz} - \gamma t =$ 193,87 - (19,2 x 3.0) = 136,3 kN/m^2

Слој	γ	z	a=L/2	b=B/2	n = z/b	m = a/b	k	σ_{zi}	P_γ	H_i	M_{si}	ω_i
	(KN/m3)	(m)	(m)	(m)				(kN/m^2)	(kN/m^2)	(m)	(kN/m^2)	(m)
1	2	2	3	4	5	6	7	8	9	10	11	12
		0,00						*136,3*	*57,6*			
1	**21,00**	***-0,40***	**1,0**	**0,50**	**0,80**	**2,00**	**0,218**	***118,6***	***66,0***	**0,80**	**22000**	***0,00431***
2	**21,00**	***-1,40***	**1,0**	**0,50**	**2,80**	**2,00**	**0,080**	***43,9***	***87,0***	**1,20**	**22000**	***0,00239***
3	**19,20**	***-2,25***	**1,0**	**0,50**	**4,50**	**2,00**	**0,039**	***21,4***	***104,4***	**0,50**	**12000**	***0,00089***
4	**19,20**	***-2,75***	**1,0**	**0,50**	**5,50**	**2,00**	**0,028**	***15,1***	***114,0***	**0,50**	**12000**	***0,00063***
5	**19,20**	***-3,25***	**1,0**	**0,50**	**6,50**	**2,00**	**0,021**	***11,2***	***123,6***	**0,50**	**12000**	***0,00047***
											$\Sigma\omega_i$	***0,00869***

Активна длабочина на слегање: $\sigma_{zi} = \max 20\% \, P_\gamma$

$\sigma_{zi}/P_\gamma =$ 9%

$\rho = 3/4\Sigma\omega_i =$ ***0,007*** m

L= 2,00 (m)

B= 1,00 (m)

$\sigma_{zo.} = \sigma_{doz} - \gamma t =$ 240,38 - (19.2 x 6) = 125,18 kN/m^2

Слој	γ	z	a=L/2	b=B/2	n = z/b	m = a/b	k	σ_{zi}	P_γ	H_i	M_{si}	ω_i
	(KN/m3)	(m)	(m)	(m)				(kN/m^2)	(kN/m^2)	(m)	(kN/m^2)	(m)
1	2	2	3	4	5	6	7	8	9	10	11	12
		0,00						*125,2*	*115,2*			
1	**19,20**	***-0,50***	**14,0**	**6,50**	**0,08**	**2,15**	**0,250**	***125,2***	***124,8***	**1**	**12000**	***0,01043***
2	**19,20**	***-1,50***	**14,0**	**6,50**	**0,23**	**2,15**	**0,249**	***124,5***	***144,0***	**1**	**12000**	***0,01038***
2	**19,20**	***-2,50***	**14,0**	**6,50**	**0,38**	**2,15**	**0,245**	***122,5***	***163,2***	**1**	**12000**	***0,01021***
2	**19,20**	***-3,50***	**14,0**	**6,50**	**0,54**	**2,15**	**0,237**	***118,7***	***172,8***	**1**	**12000**	***0,00989***
2	**19,20**	***-4,50***	**14,0**	**6,50**	**0,69**	**2,15**	**0,227**	***113,5***	***182,4***	**1**	**12000**	***0,00946***
											$\Sigma\omega_i$	***0,05037***

Активна длабочина на слегање: $\sigma_{zi} = \max 20\% \, P_\gamma$

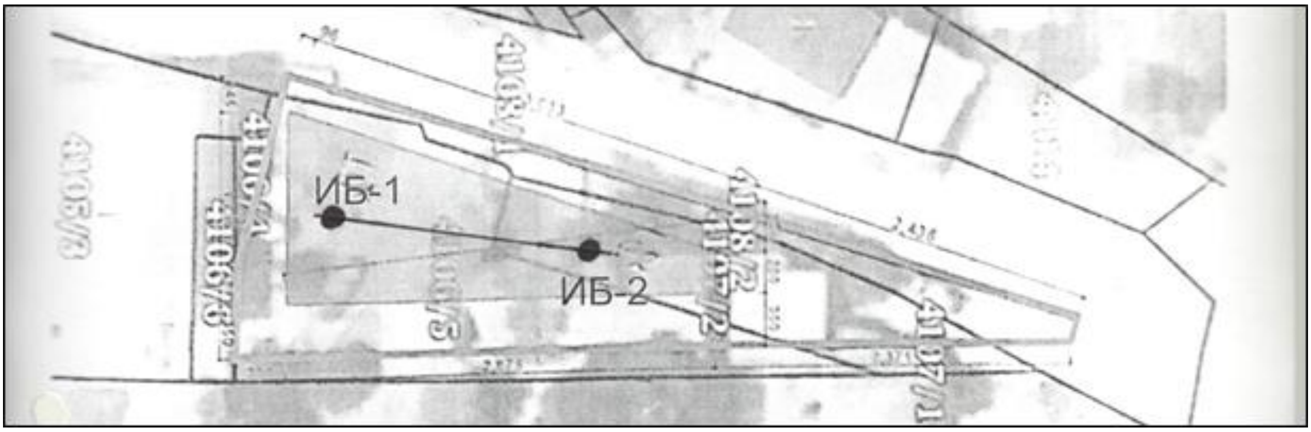
$\sigma_{zi}/P_\gamma =$ 62,2%

$\rho = 3/4\Sigma\omega_i =$ ***0,038*** m

L= 28,00 (m)

B= 13,00 (m)

5 Graphical part



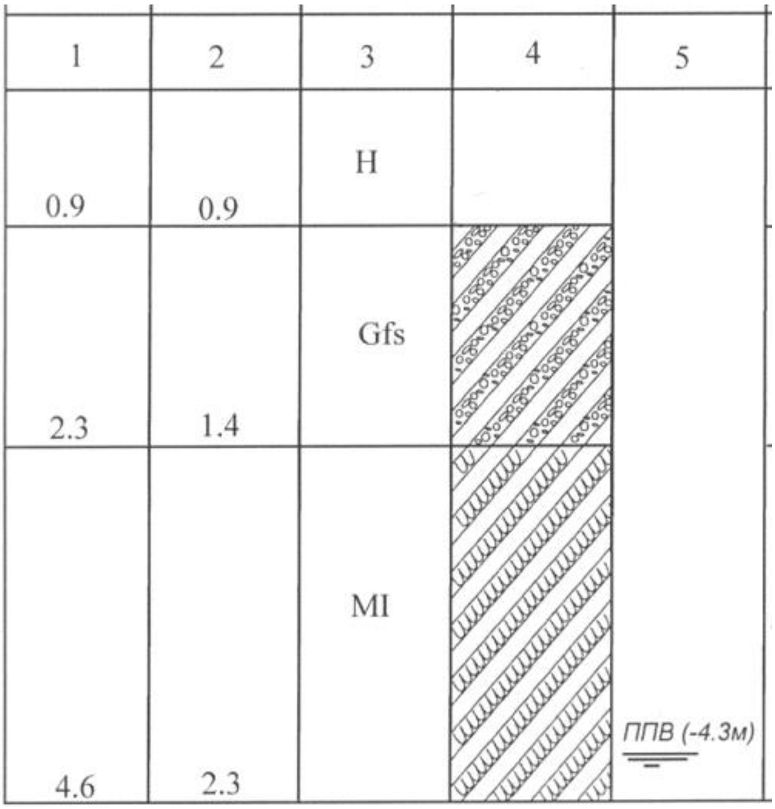


Figure 4.1. Lithological description

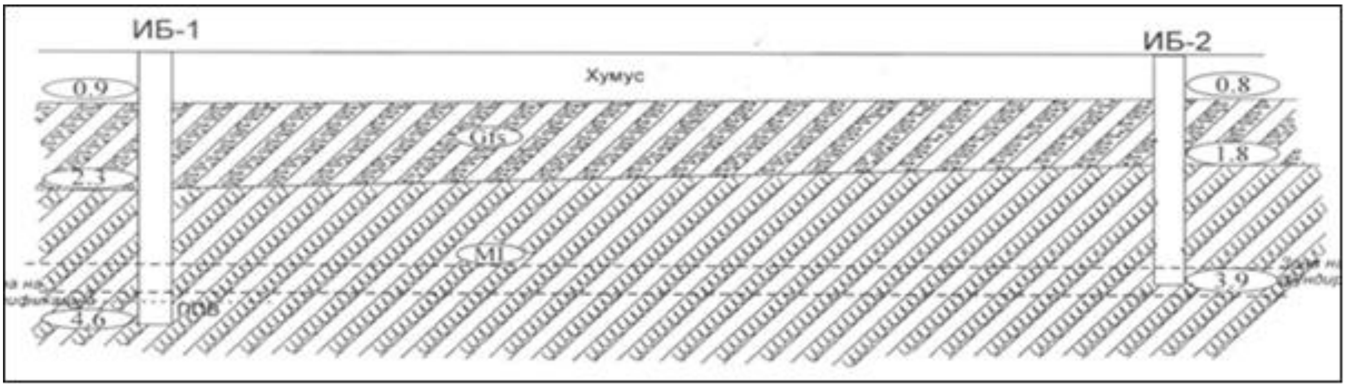


Figure 4.2. Geomechanical profile

6 Conclusions and recommendations

Based on the performed field and laboratory tests, the following recommendations and conclusions can be made:

- During the field investigations (digging wells), in June 2020, the occurrence of groundwater was ascertained (Table 1).
- At the observed location, from a geological point of view, proluvial deposits are present.
- According to the categorization of buildings and depending on their importance in society and the number of users, this building belongs to the II category of buildings.
- In terms of geo-mechanical considerations, at the foundation level the following layer is found: medium compacted, low-plastic sand dust with geo-mechanical designation (MI), with relatively good bearing characteristics.
- After excavation of the foundation pit to the level of the foundation, engineering-geological mapping of the pit should be performed in which the conditions of the foundation will be determined by a geo-mechanical engineer.

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