Giang Nguyen

SENSIBILITY OF SILTY SOILS SHEAR STRENGTH PARAMETERS ON THE SIZE OF SPREAD FOUNDATION

Introduction

In designing geotechnical structures, the determination of geotechnical parameters is very important. The correct values of geotechnical parameters have big impact on safety and cost of structures. Before the introduction of Eurocode 7, part No. 1 [1] (EC7-1) and part No. 2 [2] (EC7-2), Slovakia had been using own Standards, by which the procedures of determination of geotechnical parameters were prescribed. After March 2010, the full implementation of the EC7-1 and EC7-2 and withdrawal of conflicting national Standards should be made; consequently, the EC7-1 and EC7-2 are currently being implemented in Slovakia. Concerning geotechnical parameters, the article 2.4.5.1 of EC7-1 states that the selection of characteristic values for geotechnical parameters shall be based on derived values resulting from laboratory and field tests, complemented by well-established experience and the characteristic values of a geotechnical parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state.

The ones from the geotechnical structures are spread foundations, for design of which the STN 73 1001: 1987 [3] (in the following abbreviated as the old STN) had been applied in Slovakia. From 01.04.2010, the old STN had been replaced by the new STN 73 1001: 2010 [4] (in the following abbreviated as the new STN). In the mentioned withdrawn old STN, the determination of geotechnical parameters was introduced. Even if the old STN is withdrawn, the procedure of determination of geotechnical parameters established in it is introduced now in various geotechnical literature in Slovakia (including textbooks), so in practice it is still applicable and widely used.

This paper aims to introduce the procedure of determination of the shear strength parameters of silty soils posted in the old STN and to show its sensibility on the size of spread foundations.

1. Determination of shear strength parameters of silty soils by the old STN

By the old STN, the geotechnical parameters for geotechnical structures of geotechnical category 1 and 2 could be obtained based on soil classification. The geotechnical parameters for geotechnical structures of geotechnical category 3 should be obtained from laboratory or in-situ testing.

By the old STN, soils are classified into 18 classes (5 classes for gravelly soils, 5 classes for sandy soils and 8 classes for fine-grained soils). For all soils classes, guiding standardized characteristics of Poisson´s ratio ν, conversion coefficient between deformation modulus and oedometric modulus β, unit weight γ, shear strength parameters (φ_u, c_u, φ_{ef}, c_{ef}) and deformation modulus E_{def} are introduced. In Table 1 we can see the values of mentioned parameters for silty soils (quoted from the Tables in the old STN for silty soils of soft, stiff and semi-solid consistency with $S_r > 0.8$), which we will deal with in this paper.

As can be seen in Table 1, the geotechnical parameters of silty soil are determined based on the soil class and its consistency. There is also a note in the old STN, that for cohesive soils; when choosing their standardized characteristics, soils plasticity and consistency will be taken into account.

To examine the sensibility of shear strength parameters of silty soils on the size of spread foundation; minimal, intermediate and maximal values of effective shear strength parameters in frame of soft and firm consistency as so as maximum values of effective shear strength parameters for semi-solid consistency will be used to design spread foundation by various approaches.

2. Designing spread foundation by various design procedures

When designing spread foundation, generally, the bearing capacity of foundation soils will predetermine the size of foundation. The size of foundation will be calculated from the condition that bearing capacity of soil is just satisfied (not exceeded) and then the foundation will be checked for the settlement condition [5]. The evaluation of soil bearing capacity is a matter of wide comprehension since it concerns not only the soils but also the actions and the shape of the foundation. The soils can be also non-homogenous and there is the water in the foundation soils. The soils bearing capacity can be evaluated also in drained or in undrained condition etc. More details on various spread foundation design procedures can be found in the specific documents [1, 3, 4]. Comparisons between various design approaches of EC7 can be found in [6]. In the following, we will introduce briefly the equations for calculation of designed effective bearing capacity of the foundation soils by the old STN, the new STN and EC7-1.

TABLE 1

The guiding standardized characteristics of silty soils by the old STN [3]

Symbol	Characteristics	Consistency		
		Soft	Stiff	Semi-solid (S_r > 0.8)
MG	v, β, γ [kN·m^{-3}]	v = 0.35, β = 0.62, γ = 19.0		
	E_{def} [MPa]	5 to 10	10 to 20	12 to 21
	c_u [kPa]	40	70	70
	φ_u [°]	0	0	10
	c_{ef} [kPa]	4 to 12		8 to 16
	φ_{ef} [°]	26 to 32 (also valid for solid consistency)		
MS	v, β, γ [kN·m^{-3}]	v = 0.35, β = 0.62, γ = 18.0		
	E_{def} [MPa]	3 to 6	5 to 8	8 to 12
	c_u [kPa]	30	60	60
	φ_u [°]	0	0	10
	c_{ef} [kPa]	8 to 16		12 to 20
	φ_{ef} [°]	24 to 29 (also valid for solid consistency)		
ML MI	v, β, γ [kN·m^{-3}]	v = 0.40, β = 0.47, γ = 20.0		
	E_{def} [MPa]	1.5 to 3	3 to 5	5 to 8
	c_u [kPa]	30	60	70
	φ_u [°]	0	0	5
	c_{ef} [kPa]	8 to 16		12 to 20
	φ_{ef} [°]	19 to 23 (also valid for solid consistency)		
MH MV ME	v, β, γ [kN·m^{-3}]	v = 0.40, β = 0.47, γ = 21.0		
	E_{def} [MPa]	1 to 3	3 to 5	5 to 7
	c_u [kPa]	25	50	80
	φ_u [°]	0	0	0
	c_{ef} [kPa]	4 to 10		8 to 16
	φ_{ef} [°]	15 to 19 (also valid for solid consistency)		

By the old STN, a vertical design bearing capacity R_d must be higher than design extreme loading on foundation base. To calculate R_d, we use the designed characteristics of subsoil (in total or effective parameters depending on the loading speed, permeability, degree of saturation, degree of consolidation etc.). The following condition should be fulfilled:

$$\sigma_{de} \leq R_d \tag{1}$$

where: σ_{de} [kPa] is the design extreme contact stress and it is calculated using the formulae:

$$\sigma_{de} = \frac{V_{de}}{A_{ef}} \tag{2}$$

where: V_{de} [kN] is the extreme design loading and A_{ef} [m^2] is the effective area.

The vertical design bearing capacity of subsoil R_d [kPa] is calculated as:

$$R_d = c_d\, N_c\, s_c\, d_c\, i_c + \gamma_1\, d\, N_d\, s_d\, d_d\, i_d + \gamma_2 \frac{b_{ef}}{2} N_b\, s_b\, d_b\, i_b \tag{3}$$

By the new STN, the designed bearing capacity of the foundation soils for the drained condition can be calculated by the formula:

$$R_d = \left(c'_d\, N_c\, s_c\, d_c\, i_c\, j_c + q'\, N_q\, s_q\, d_q\, i_q\, j_q + \gamma' \frac{B}{2} N_\gamma\, s_\gamma\, d_\gamma\, i_\gamma\, j_\gamma \right) / \gamma_{R,V} \tag{4}$$

By the EC7-1, the designed bearing capacity of the foundation soils for the drained condition can be calculated by the formula:

$$R_{d;d} / A' = \left(c'\, N_c\, b_c\, s_c\, i_c + q'\, N_q\, b_q\, s_q\, i_q + 0.5\, \gamma'\, B'\, N_\gamma\, b_\gamma\, s_\gamma\, i_\gamma \right) \tag{5}$$

The meanings of symbols in equations (3), (4) and (5), including meanings of dimensionless factors are well-known to geotechnical community, so we do not introduce them here. However, we would like to mention that even if the equations are quite similar, the number of parameters in the equations is not equal and equations parameters are calculated not by the same formulas. The condition posted in (1) should be also applied in the new STN and EC7-1.

From the reasons that partial factors for actions and materials are different for specific design approach, sizes of foundation designed by various design approaches will be different.

3. Example

To illustrate sensibility of shear strength parameters of silty soils on a size of spread foundation; minimal, intermediate and maximal values of effective shear strength parameters in frame of soft and stiff consistency as well as maximum values of effective shear strength parameters for semi-solid consistency will be used to design spread foundation by various approaches (see Tabs. 1 and 2). The design of spread foundation is made by design approaches mentioned in EC7-1 (DA1-C1; DA1-C2; DA2 and DA3) [1], in the old STN [3] and in the new STN [4].

TABLE 2

The sizes of spread foundation in [m] by various design procedures

Silty soils and their shear strength parameters			DA1 (C1)	DA1 (C2)	DA2	DA3	Old STN	New STN
MG	Minimal: φ = 26.0°, c = 4 kPa	(1)	1.83	2.17	2.17	2.46	2.30	2.17
	Intermediate: φ = 28.0°, c = 8 kPa	(2)	1.49	1.80	1.77	2.04	1.94	1.78
	Maximal: φ = 30.0°, c = 12 kPa	(3)	1.24	1.53	1.47	1.72	1.65	1.48
	Maximal (semi-solid): φ = 32.0°, c = 16 kPa	(4)	1.04	1.31	1.24	1.48	1.42	1.25
	Differ. in foundation size: (1) - (2)	[m]	0.33	0.36	0.40	0.42	0.37	0.39
	Differ. in foundation size: (1) - (2)	[%]	22.4	20.1	**22.7**	20.6	18.9	22.0
	Differ. in foundation size: (2) - (3)	[m]	0.25	0.27	0.30	0.31	0.29	0.29
	Differ. in foundation size: (2) - (3)	[%]	20.2	17.9	20.3	18.2	17.4	19.8
	Differ. in foundation size: (3) - (4)	[m]	0.20	0.22	0.23	0.25	0.23	0.23
	Differ. in foundation size: (3) - (4)	[%]	18.8	16.5	18.9	16.7	16.5	18.5
MS	Minimal: φ = 24.0°, c = 8 kPa	(1)	1.90	2.22	2.27	2.52	2.51	*2.29*
	Intermediate: φ = 26.0°, c = 12 kPa	(2)	1.57	1.87	1.87	2.11	2.12	1.89
	Maximal: φ = 28.0°, c = 16 kPa	(3)	1.32	1.60	1.57	1.80	1.81	1.59
	Maximal (semi-solid): φ = 29.0°, c = 20 kPa	(4)	1.18	1.44	1.40	1.63	1.65	1.43
	Differ. in foundation size: (1) - (2)	[m]	0.33	0.35	0.40	0.41	0.39	0.39
	Differ. in foundation size: (1) - (2)	[%]	21.0	18.8	21.4	19.2	18.5	20.8
	Differ. in foundation size: (2) - (3)	[m]	0.25	0.27	0.30	0.31	0.31	0.30
	Differ. in foundation size: (2) - (3)	[%]	19.0	16.8	19.2	17.1	17.0	18.8
	Differ. in foundation size: (3) - (4)	[m]	0.14	0.15	0.17	0.18	0.16	0.16
	Differ. in foundation size: (3) - (4)	[%]	11.7	10.7	11.8	10.8	**10.0**	11.4
ML MI	Minimal: φ = 19.0°, c = 8 kPa	(1)	2.39	2.67	2.88	3.06	3.21	2.91
	Intermediate: φ = 20.0°, c = 12 kPa	(2)	2.07	2.34	2.48	2.66	2.83	2.52
	Maximal: φ = 21.0°, c = 16 kPa	(3)	1.83	2.08	2.19	2.36	2.53	2.22
	Maximal (semi-solid): φ = 23.0°, c = 20 kPa	(4)	1.56	1.80	1.85	2.04	2.18	1.89
	Differ. in foundation size: (1) - (2)	[m]	0.32	0.33	0.40	0.39	0.38	0.39
	Differ. in foundation size: (1) - (2)	[%]	15.4	14.3	15.9	14.8	13.4	15.6
	Differ. in foundation size: (2) - (3)	[m]	0.24	0.26	0.30	0.30	0.30	0.30
	Differ. in foundation size: (2) - (3)	[%]	13.4	12.3	13.7	12.7	11.8	13.4
	Differ. in foundation size: (3) - (4)	[m]	0.27	0.28	0.33	0.32	0.36	0.33
	Differ. in foundation size: (3) - (4)	[%]	17.5	15.4	17.9	15.8	16.5	17.6
MH MV ME	Minimal: φ = 15.0°, c = 4 kPa	(1)	3.33	3.56	4.08	4.15	4.46	4.11
	Intermediate: φ = 16.0°, c = 8 kPa	(2)	2.77	3.00	3.36	3.46	3.78	3.39
	Maximal: φ = 17.0°, c = 12 kPa	(3)	2.38	2.61	2.87	2.99	3.29	2.90
	Maximal (semi-solid): φ = 19.0°, c = 16 kPa	(4)	1.99	2.23	2.38	2.53	2.77	2.42
	Differ. in foundation size: (1) - (2)	[m]	0.56	0.56	0.72	0.69	0.68	0.72
	Differ. in foundation size: (1) - (2)	[%]	20.3	18.7	**21.6**	20.0	18.1	21.4
	Differ. in foundation size: (2) - (3)	[m]	0.39	0.39	0.49	0.47	0.49	0.49
	Differ. in foundation size: (2) - (3)	[%]	16.3	15.0	17.0	15.8	14.8	16.8
	Differ. in foundation size: (3) - (4)	[m]	0.39	0.39	0.48	0.46	0.52	0.48
	Differ. in foundation size: (3) - (4)	[%]	19.5	17.3	20.2	18.0	18.9	19.9

The model example for the comparison of spread foundation designed by various design approaches is similar to the model introduced by Orr [6]; see Figure 1.

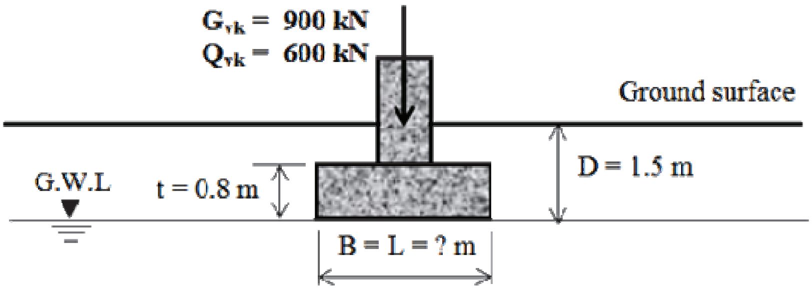

Fig. 1. Model example for the comparison of spread foundation design by various design approaches [6], foundation soil with values of shear strength parameters taken from Table 1

The sizes of spread foundation by various design procedures are given in Table 2. As we can see from Table 2, size of spread foundation is very sensitive on the values of shear strength parameters of silty soils. So e.g. a small difference in angle of internal friction (1.0°) and cohesion (4 kPa) of soil MH (or MV and ME) causes difference in foundation size up to 21.6% (designed by the DA2), see bold number in the column for DA2. A little larger difference in angle of internal friction (2.0°) and cohesion (4 kPa) of soil MG causes difference in foundation size up to 22.7% (design by the DA2), see bold number in the column for DA2. The smallest difference in foundation size is not small (10.0%) and it is reached for soil MS when difference in angle of internal friction is 1° and difference in cohesion is 4 kPa (design by the old STN), see bold number in the column for old STN.

We can also see that the size of foundation is the biggest when designed by the DA3 (for soil MG) or by the old STN (for soil ML and MI; MH, MV and ME). The size of foundation is the smallest when designed by the DA1-C1.

Concerning the old STN and new STN, for all values of silty soils shear strength parameters, the size of foundation designed by the new STN is smaller in comparison with the old STN.

Conclusions

The size of spread foundation is very sensitive on the values of shear strength parameters of silty soils. Even small difference in the values of silty soil shear strength parameters causes big difference in the spread foundation size. So the precise determination of shear strength parameters is very important and has big impact on economy of the design.

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Abstract

The paper deals with sensibility of silty soils shear strength parameters on the size of spread foundation. Minimal, intermediate and maximal values of shear strength parameters of 4 classes of silty soils (MG; MS; MI and ML; MH, MV and ME) in frame of soft and firm consistence as so as maximal values in semi-solid consistence introduced in the old Slovak Technical Standard STN 731001 (in the following abbreviated as "the old STN") had been used to design model spread foundation, similar with the one posted by Orr (2005). The foundation has square shape, thickness 0.8 m, founded in the depth D = 1.5 m. The foundation is loaded by centrically acting vertical permanent load G = 900 kN and variable load Q = 600 kN. Underground water level is at foundation base. The spread foundation was designed by design approaches mentioned in Eurocode 7, Part 1 (DA1-C1; DA1-C2; DA2 and DA3) and also by the old STN and new Slovak Technical Standard (in the following abbreviated as "the new STN"). It will be shown that for all values of silty soils shear strength parameters the size of foundation is the smallest when designed by the DA1-C1. The size of foundation is the biggest when designed by the DA3 (for soil MG) or by the old STN (for soil ML and MI; MH, MV and ME). Concerning the old and new STN, for all values of silty soils shear strength parameters, the size of foundation designed by the new STN is smaller in comparison with the one design by the old STN. It will be also shown that small difference in angle of internal friction (1.0°) and cohesion (4 kPa) of soil MH (or MV and ME) causes difference in foundation size up to 21.6% (design by the DA2). The smallest difference in foundation size (10.0%) is reached for soil MS when difference in angle of internal friction is 1° and difference in cohesion is 4 kPa (design by the old STN).

Keywords: soil mechanics, shear strength, dusty grounds

Wrażliwość parametrów wytrzymałości na ścinanie gruntów pylastych na wymiary fundamentu bezpośredniego

Streszczenie

Artykuł dotyczy wrażliwości parametrów wytrzymałości na ścinanie gruntów pylastych na wymiary fundamentu bezpośredniego. Minimalne, średnie i maksymalne wartości parametrów wytrzymałości na ścinanie 4 klas gruntów pylastych (MG; MS; MI i ML; MH, MV i ME) w obszarze konsystencji plastycznej oraz maksymalne wartości w konsystencji półzwartej, wymienione w starej Słowackiej Technicznej Normie (STN), zostały wykorzystane do projektowania modelu fundamentu bezpośredniego, podobnego do wprowadzonego przez Orra (2005). Fundament ma kwadratowy kształt, grubość 0,8 m, założony w głębokości $D = 1,5$. Fundament jest obciążony statycznie pionowo i osiowo (obciążenie stałe $G = 900$ kN; obciążenie zmienne $Q = 600$ kN). Zwierciadło wody gruntowej znajduje się w poziomie posadowienia. Fundament jest zaprojektowany według Eurokodu 7, część 1 (podejścia obliczeniowe DA1-C1, DA1-C2, DA2 i DA3), również według starej i nowej STN. Zostanie pokazane, że dla wszystkich wartości parametrów wytrzymałości na ścinanie gruntów pylastych wymiar fundamentu jest najmniejszy, gdy jest zaprojektowany według DA1-C1. Wymiar fundamentu jest największy, gdy jest zaprojektowany według DA3 (dla gruntu MG) lub według starej STN (dla gruntu ML i MI; MH, MV i ME). Jeśli chodzi o nową i starą STN, dla wszystkich wartości parametrów wytrzymałości na ścinanie gruntów pylastych wymiar fundamentu zaprojektowany według nowej STN jest mniejszy w porównaniu z tym zaprojektowanym według starej STN. Zostanie pokazane również, że mała różnica w kącie tarcia wewnętrznego (1.0°) i spójności (4 kPa) gruntu MH (lub MV i ME) powoduje różnicę w wymiarze fundamentu aż do 21,6% (projektowany według DA2). Najmniejsza różnica w wymiarze fundamentu (10,0%) zostanie osiągnięta dla gruntu MS, gdy różnica w kącie tarcia wewnętrznego jest 1,0° i różnica w spójności jest 4 kPa (projektowany według starej STN).

Słowa kluczowe: mechanika gruntów, wytrzymałość na ścieranie, grunty pylaste