

Relationship Estimated Bearing Capacity of Fine-grained Soils with Respect to the Classes of Foundation Soils

Terezie Vondráčková ¹, František Němec ², Miroslav Gombár ³, Jiří Čejka ², Ján Ližbetin ⁴

¹ VŠTE-Institute of Technology and Business in České Budějovice, Faculty Technology, Department of Civil Engineering, Okružní 517/10, 370 01 České Budějovice, Czech Republic

² VŠTE-Institute of Technology and Business in České Budějovice, Faculty Technology, Department of Informatics and Natural Sciences, Okružní 517/10, 370 01 České Budějovice, Czech Republic

³ VŠTE-Institute of Technology and Business in České Budějovice, Faculty Technology, The Department of Mechanical Engineering, Okružní 517/10, 370 01 České Budějovice, Czech Republic

⁴ VŠTE-Institute of Technology and Business in České Budějovice, Faculty Technology, Department of Transport and Logistics, Okružní 517/10, 370 01 České Budějovice, Czech Republic

E-mail address: vondrackova@mail.vstecb.cz

Abstract. Its aim is to elucidate the relationship orientation bearing capacity fine-grained soils and classes of the foundation soils. Quantification and understanding of the nature of bearing capacity in fine-grained soils is one of the basic senses of a geotechnical survey. We can know the orientation suitability of the site for the foundation. This is possible based on the knowledge of the approximate bearing capacity of field surveys. We can also assume certain complications due to demanding building foundations. Approximate estimate of the percentage of each type classes of fine-grained soil is another reason to the knowledge an indicative bearing capacity. It interests us because of its suitability or unsuitability of view the most important characteristics of foundations represented by the bearing capacity.

1. Introduction

Bearing capacity is determined using physics-mechanical approaches. Determination of bearing capacity is an essential part in the foundation for which there are two basic limit states. This is the first ultimate limit state, and the settlement is the second ultimate limit state. We are setting the so called computational bearing capacity of the foundation soil within the ultimate limit state of bearing capacity. It depends on the mechanical and physical properties of the underlying soil, the groundwater table, on the size, shape, etc. The calculation includes the calculated characteristic of foundation soil in case of fine-grained soils. It is calculated by the speed surcharging, the degree of saturation, permeability and degree of over consolidation of foundation soil.

Bearing capacity of foundation soil, which is composed of soils with a horizontal footing bottom is determined by the formula [1]:



$$R_d = c_d \cdot N_c \cdot s_c \cdot d_c \cdot i_c + \gamma_1 \cdot d \cdot N_d \cdot s_d \cdot d_d \cdot i_d + \gamma_2 \cdot \frac{b}{2} \cdot N_b \cdot s_b \cdot d_b \cdot i_b, \quad (1)$$

Where R_d represents the vertical design bearing capacity in kPa,

- γ_1, γ_2 , represents effective bulk unit weight of foundation soil above and below the level of foundations in kNm^{-3} ,
- b is the effective width or diameter of the foundation in [m].
- N_c, N_d , and N_b are bearing capacity coefficients, which depend on the design value of angle of internal friction,
- d is the depth founding in meters,
- c_d is a design value of cohesion in [kPa],
- s_c, s_d, s_b are coefficients expressing the shape of foundation,
- d_c, d_d, d_b are coefficients expressing the effect of the depth of the foundation,
- i_c, i_d, i_b are coefficients expressing the effect of skewness of resultants load [1].

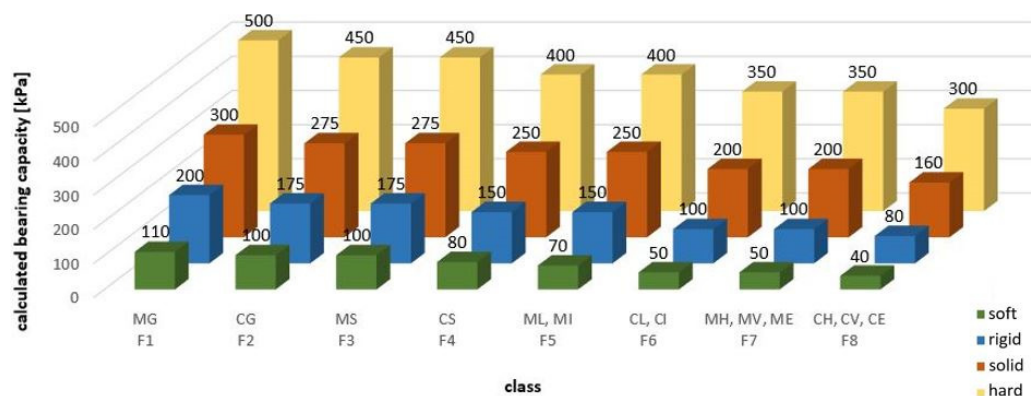


Figure 1. Graf values of calculated bearing capacity R_d in kPa for fine-grained soils to depth of foundation from 0.8 to 1.5 m for the width of foundation up to 3m according to [1]

In practice, they are also used the so called tabular values of calculated bearing capacity. Use of spreadsheets and the calculated bearing capacity depends on the class of geotechnical categories. Tabulation calculated bearing capacity is used only for the 1st geotechnical category. Here we compare the effects of the anticipated operating design loads with the tabular values of the calculated bearing capacity of foundation soil. Expected extreme the design load and calculated bearing capacity of foundation soil is compared in the 2nd and 3rd geotechnical category. It is intended to be the 2nd geotechnical category on the basis of indicative or local normative characteristics of foundation soil. The 3rd geotechnical category is determined by the normative of foundation soil characteristics, determined by tests.

2. The differences in the values of approximate bearing capacity according to consistency

Approximate calculated bearing capacity is excellent correlation characteristic for the ability of soil to carry the loads from construction through the foundations. If we compare all possible physical-mechanical properties of fine-grained soils, and each manifests itself different. Therefore, approximate bearing capacity is excellent summary of properties, which integrates the various physical-mechanical characteristics together in the ability to transmit the load of the structure (Figure 1, Figure 2). Regarding absolute values and the highest indicative bearing capacity at a fine-grained soil class F1. This is gravelly clay in hard consistency. This value is 500 kPa (100%), whereas the value of a class F8, clay with a high, very high and extremely high plasticity. Its value is 40 kPa i.e. 8% relative to the maximum value of approximate bearing capacity of fine grained soil. The reason why the first value is the highest is the fact that it is the silt in which it is gravel grains in the percentage margin of 15-35%.

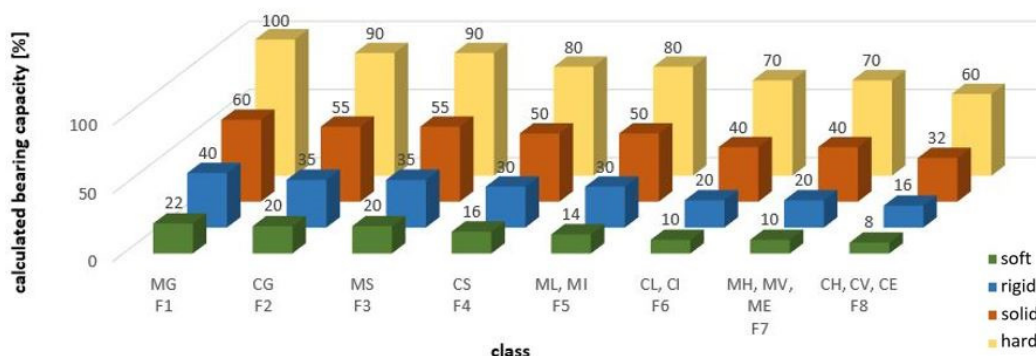


Figure 2. Graf values of spreadsheet calculated bearing capacity R_d in percentage for fine-grained soil to depth of founding from 0.8 to 1.5 m for the width of basis to 3m according to [1] (Ed. 100%, relative to the highest value of the calculated bearing capacity, i.e. 500 kPa)

This increases the shear strength and consequently the bearing capacity of this foundation soil in comparison with other types of foundation soils. Consistency plays a significant role (Table 1) as solid consistency state is only 60% (F1) this value, rigid reaches only 40% (F1) and a soft consistency state is only 22% (F1). Change of approximate bearing capacity ranges between from 60 to 100%, while the change in consistency much more degraded bearing capacity, as evidenced by previous statements, when comparing all classes F1 to F8. Thus, changing the value orientation bearing capacity in hard consistency between a class F1 to F8 ranges from 300 to 500 kPa, and this change is between 60 to 100%. This means that the difference is 40%. In the following solid consistency ranges change between 160 to 300 kPa, which is a change between 32-60%. This represents a 28% range. This means that there was a reduction in the influence of the difference of the individual classes of foundation soils between them. It is from 40 to 28%. If the moisture content is even greater and the consistency is rigid, then the range of values is between 80 and 200 kPa. This represents the difference in percentage between 16 and 40%.

This means that the difference is decreased to 24%. This decline is not as dramatic as was the case with hard consistency. For solid consistency the trend is similar to that of rigid. The only difference is in the fact that this value was 28%. Last monitored consistency is soft. Mushy consistency is not reported because it has a very negative value. For a soft consistency is of approximate ranges of bearing capacity between 40 (F8) to 110 (F1) kPa. It is the interval between 8 to 22%, representing a difference of 14% in percentage. It follows from this that with this negative consistency reduces difference F1 to F8 to 14%. This is a difference of 26% compared to a hard consistency, which was 40%. This implies that the consistency of fine-grain classes has the greatest influence inadequate bearing capacity of foundation soils. This is especially true with soft consistency, rigid and strong. The more positive state of consistency with less moisture content (hard), the more plays the role of each character classes of foundation soils.

3. Differences in the values of approximate bearing capacity according to individual classes of foundation soils

If we evaluate the differences among the various classes, so we can conclude the following findings. The greatest value has already been mentioned class F1 gravelly silt. The reason we mentioned, the impact for this class has increased shear strength due to the content of gravel grains in the range of 15 to 35% (Figure 3). However, a significant role is the fact that it is a silt, not clay. The second type of fine-grained soil is worth about 10% less (F2). A similar value as a class (F2) gravelly not clay has a sandy silt (F3). This is a very interesting finding, because the influence of admixtures of gravel in clay has the same efficacy to the loads as the sand content in the silt in the finals. What does it mean? This means that the difference between the silt and the clay (which in the previous case was 10% of the value)

is able to compensate coarser admixture at clay soils (CG) in class F2. The Class (F3) has the same value. Here is an admixture of sand but in the silt. This means that in the first case is a not clay which compensates gravel and in the second case the disadvantage content of more finely grained fraction (sand) versus gravel compensates content of silt. In the finals an approximate bearing capacity F2 and F3 has the same value for all consistencies. For hard consistency is 90% of the value, for solid consistency is 55%, for rigid is 35% and 20% in soft. A similar trend is seen between a class F4 and F5. Here we have a clay in the first case, in the second case it is clay. The value is the same but decreased compared to the previous two classes F2 and F3 in hard consistency about 10%. This means that achieves 80% of the value in hard consistency. There is equality of values caused by the fact that in the first case, the effect of sand in clay the same effect as the low and medium plasticity in silt. For all consistency F4 and F5 value is the same. The only exception is soft consistency, where the difference between these two values are 2%. A similar trend is evident in classes F6 and F7. There is a reduction of 10% in hard consistency (70% value = 350 kPa). This causes a low and medium plasticity in class F6, which contains clay. For Class F7 is silt which reduces the value of high, very high and extremely high plasticity. The worst value of all consistencies reaches F8, which is a clay with a high, very high and extremely high plasticity, which is 300 kPa (60%) for hard consistency, 160 kPa (32%) in solid and 80 kPa (16%) for rigid consistency and worst approximate bearing capacity has a soft consistency i.e. 40 kPa, which represents 8%.

Table 1. Consistency states of fine grained soil according to [1]

Consistency number	Hard (very stiff) consistency	Stiff consistency	Firm consistency	Soft consistency	Very soft consistency
	< shrinkage limit	$I_c > 1.00$	$I_c 1.0 \text{ to } 0.5$	$I_c 0.5 \text{ to } 0.05$	$I_c < 0.05$

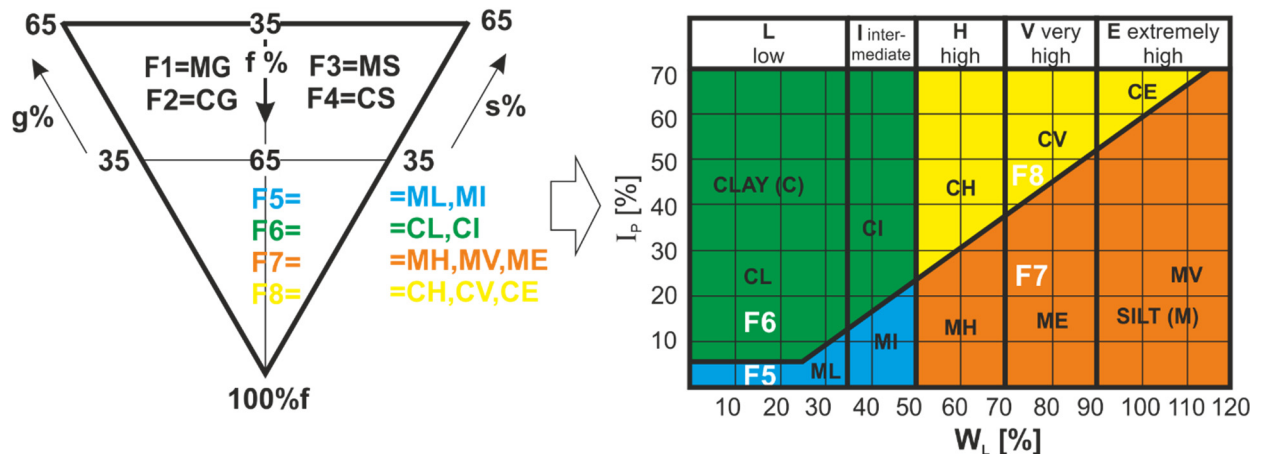


Figure 3. Classification triangle and Casagrande diagram of plasticity according to [1]

The issue of carrying capacity is an essential part of the foundation and is thus solved in a number of publications. The author [2] deals with the comparison of dynamic and static penetration at different locations. On that basis, the approximate value of the relative density and angle of internal friction were obtained, from which could be subsequently determined by the ultimate bearing capacity of the pile. The results obtained were compared with field testing. Bearing capacity were also considered [2], which mentions a survey about the bearing capacity shallow foundations of various shapes, the influence of the central vertical load, the effects of deep foundations, inclination and eccentricity, which play a significant role in the event of bearing capacity. Furthermore, the work provides information about the bearing capacity pile under vertical and diagonal load. Pile bearing capacity of depends in addition to the environment also on the type of pile. These can be in solid substrate, or a so-called floating pile, without solid support.

Consistency and plasticity plays in the event of fine-grained soil a crucial role in the event of bearing capacity and compressibility. Bearing capacity of clays dealt [3]. Many works also deal with the prediction of the bearing capacity of pile. It was examined by the authors [4] through the use of Artificial Neural Networks, where it was found that the maximum prediction error does not exceed 25%. Bearing capacity at fine-grained soils is often solved issues in publication [58] and in [9, 10].

The geological environment is inhomogeneous and determination of bearing capacity is so very problematic. Undrained bearing capacity of circular bases on double layer of clay dealt [11]. This issue is also in publications [12, 13; 14, 15] and [16].

4. Conclusions

In conclusion we can say that the biggest influence on the approximate bearing capacity of grained soils has consistency of the soil. The proof of this statement is that most positive variant with hard consistency range reaches from 300 to 500 kPa, which represents 60 to 100%. Percentages are based on the highest value for fine-grained soils. Most negative surveyed status is soft. Mushy state is not placed due to its complete inappropriateness. This soft consistency reaches values of 40 to 110 kPa, which is in percentage only 8-22%. The difference between the classes of foundation soils considerable role only in more convenient for consistency (hard consistency). Its role is gradually decreasing from 40% in hard to 14% for the soft consistency of the soil. Differences between the classes are due to three factors. The first factor is the difference between the silt and the clay for fine-grained soils. Positive values achieved silt and the second factor is the admixture of coarse grained fraction in the fine-grained soil. A distinction is made admixture of sandy and gravelly soils, with an admixture gravelly soils achieves better values approximate bearing capacity. The last factor is the plasticity. Plasticity can distinguish only in the silt or clay with a content of more than 65%. There are less suitable values are found silt and clay with low and medium plasticity and least appropriate values approximate bearing capacity is achieved at high, very high and extremely high plasticity.

References

- [1] CSN 73 1001 Subsoil under shallow foundations. Praha: Publishers Office for Standards and Measurement, 1987. (in Czech)
- [2] Meyerhof, G. G. (1956). Penetration tests and bearing capacity of cohesionless soils. *Journal of the Soil Mechanics and Foundations Division*, 82(1), 1-19.
- [3] Meyerhof, G. G. (1963). Some recent research on the bearing capacity of foundations. *Canadian Geotechnical Journal*, 1(1), 16-26
- [4] Lee, I. M., Lee, J. H. (1996). Prediction of pile bearing capacity using artificial neural networks. *Computers and geotechnics*, 18(3), 189-200
- [5] Lee, J. K., Jeong, S., Lee, S. (2016). Undrained bearing capacity factors for ring footings in heterogeneous soil. *Computers and Geotechnics*, 75, 103-111
- [6] Meyerhof, G. G. (1974). Ultimate bearing capacity of footings on sand layer overlying clay. *Canadian Geotechnical Journal*, 11(2), 223-229
- [7] Motra, H. B., Stutz, H., Wuttke, F. (2016). Quality assessment of soil bearing capacity factor models of shallow foundations. *Soils and Foundations*, 56(2), 265-276
- [8] Reddy, A. S., Srinivasan, R. J. (1967). Bearing capacity of footings on layered clays. *Journal of the Soil Mechanics and Foundations Division*, 93(2), 83-99
- [9] Salgado, R., Lyamin, A. V., Sloan, S. W., Yu, H. S. (2004). Two-and three-dimensional bearing capacity of foundations in clay. *Géotechnique*, 54(5), 297-306
- [10] Shiau, J. S., Lyamin, A. V., Sloan, S. W. (2003). Bearing capacity of a sand layer on clay by finite element limit analysis. *Canadian Geotechnical Journal*, 40(5), 900-915.
- [11] Skempton, A. W. (1951). The bearing capacity of clays
- [11] Braja, M. D., Echol, E. C., Eun, C. S., Shing-Chung, Y., Vijay, K. P. (1993). Bearing capacity of strip foundation on geogrid-reinforced clay.
- [12] Davis, E. H., Booker, J. R. (1985). The effect of increasing strength with depth on the bearing

- capacity of clays. Golden Jubilee of the International Society for Soil Mechanics and Foundation Engineering: Commemorative Volume, 185.
- [13] De Sanctis, L., Mandolini, A. (2006). Bearing capacity of piled rafts on soft clay soils. *Journal of Geotechnical and Geoenvironmental Engineering*, 132(12), 1600-1610.
- [14] Hanna, A. M., Meyerhof, G. G. (1980). Design charts for ultimate bearing capacity of foundations on sand overlying soft clay. *Canadian Geotechnical Journal*, 17(2), 300-303.
- [15] Ibrahim, K. M. H. I. (2014). Bearing capacity of circular footing resting on granular soil overlying soft clay. *HBRC Journal*.
- [16] Lee, J. K., Jeong, S., Shang, J. Q. (2016). Undrained bearing capacity of ring foundations on two-layered clays. *Ocean Engineering*, 119, 47-57.