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# Bearing Capacity Analysis of Shallow Foundations Supported on an Artificial Fill (Substation at Kashari, Tirana)

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**Abstract:** The paper presents conclusions related to the design of shallow foundations, at the site where the Substation at Kashari, in Tirana is foreseen to be constructed. The project includes buildings with small to medium structures with 1-3 stories. The geological survey works include 6 boreholes of a depth 20.0 m, 90 SPT (Standard Penetration Tests) tests, and laboratory works include 13 direct shear tests, 27 unconfined and compressive strength tests, 7 CU (consolidated undrained) tests and 9 UU (unconsolidated undrained) tests, etc. The foundation design must fulfill both, bearing and settlement criteria, but in this case the settlements of foundations are not possible to be calculated, since the laboratory works do not include any consolidation test. So, the local bearing capacity is expected to control the design in terms of bearing capacity and settlements. The local bearing capacity of shallow square foundations is evaluated by using Terzaghi's formula, based on reduced shear strength parameters of soils below the bottom of foundations. The results are compared with the bearing capacity values calculated by using Burland and Burbdige (1984) method, based on the data of SPT tests. This method is used for checking the settlement (serviceability) criterion in the foundation design, when the direct settlement calculation is missing. The paper presents some conclusions related to local bearing capacity foundation-based design.

**Key words:** Bearing capacity, ultimate/allowable bearing capacity, local bearing capacity, bore hole, standard penetration test.

## 1. Introduction

In this paper a bearing capacity analysis of shallow foundations, at the construction site where the company "EnBI POWER" has the intention to build Substation at Kashari, Tirana is performed. The construction site is near the village Kashari, at the North West of the Tirana city, located in Tirana County, Tirana prefecture in Albania.

Bearing capacity analysis is based on the field and laboratory data reported on the geotechnical study of the site, which has been conducted by "ALTEA & GEOSTUDIO 2000" [1]. A plan of construction site with geological survey works is shown in Fig. 1. The geological survey works include: 6 boreholes of a depth 20.0 m, 90 SPT (Standard Penetration Tests) tests, 6 piezometers of a depth 20.0 m, etc. The laboratory works include: description and identification of soil (visual manual procedure), 46 granulometry analyzes, 46 analyze Atterberg limits, 13 direct shear tests, 27 unconfined and compressive strength tests, 7 CU (consolidated undrained) tests and 9 UU (unconsolidated undrained) tests.

The project provides 1-3 stories buildings, but detailed information about the foundation is not available. These buildings may be well supported on *shallow spread foundations* (*spread footings*). The foundation design must fulfill both, bearing and settlement criteria, but in this case only the bearing

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capacity is used to control the design. Settlement control is not possible to be applied, since the data of consolidation test are missing. So, to control the settlements, local bearing capacity of foundations, by using Terzaghi's formula, is computed. Because of the expected large settlements, it is decided to support the foundations on an artificial constructed fill, to be constructed using the gravels from "Mati River".

The bearing capacity analysis is based on the data of laboratory tests, which means on the shear strength parameters of constructed fill and soils below the bottom of foundations. Bearing capacity analyses based on the data of SPT tests are considered also. The Burland and Burbdige (1984) method [2] is used in order to check the bearing capacity values, which are expected to control the foundation design.

The computed values of bearing capacities can help to decide for the type and dimensions of foundations at the final stage design, but it is important to mention that the final solution considers also many other factors, like structural strength, serviceability, constructability and economic requirements of foundations.

## 2. Theoretical Background

In this part both methods (Terzaghi's formula [3] and Burland & Burbdige method [2]) used to obtain allowable bearing capacity of shallow square foundations (spread footings), foreseen to be constructed for the buildings of Substation at Kashari, in Tirana, are described. Both methods, especially the Terzghi's formula, are well-established in the engineering practice of construction.

The bearing capacity analysis is based on the data of laboratory and in-situ tests, which are reported in the geological study. Thereupon, the described analytical method uses the data of these laboratory tests, like unit weight, friction angle and cohesion and Burland & Burbdige method uses the data of SPT tests of the artificial fill and soils underlain this fill.

### *2.1 Terzaghi's Formula*

Bearing capacity of *shallow square foundations* (*spread footings*) is evaluated by using Terzaghi's formula [3]. This formula is given below:

$$q_{ult} = 1.3c'N_c + \sigma'_{zD}N_q + 0.4\gamma BN_\gamma$$

where:

$q_{ult}$ = ultimate bearing capacity.

$c'$ = effective cohesion for soil beneath foundation.

$\varphi'$ = effective friction angle for soil beneath foundation.

$\sigma'_{zD}$ = vertical effective stress at depth $D$ below the ground surface ($\sigma'_{zD} = \gamma D$ if depth to groundwater table is greater than $D$).

$\gamma'$ = effective unit weight of the soil ($\gamma = \gamma'$ if groundwater table is very deep).

$D$ = depth of foundation below ground surface.

$B$ = width (or diameter) of foundation.

$N_c$, $N_q$, $N_\gamma$ = Terzaghi's bearing capacity factors = $f(\varphi')$.

Terzghi's formula is presented in terms of effective stresses [3]. The values of $c'$ and $\varphi'$ represent the soils between the bottom of the footing and a depth $B$ below the bottom. However, it also may be used in a total stress analysis by substituting $c_T$, $\varphi_T$ and $\sigma_{zD}$ for $c'$, $\varphi'$ and $\sigma'_{zD}$. Allowable bearing capacity, $q_a$, used in geotechnical foundations design, is obtained by dividing ultimate bearing capacity, $q_{ult}$, by a factor of safety, as below:

$$q_a = \frac{q_{ult}}{F}$$

where:

$q_a$ = allowable bearing capacity.

$F$ = factor of safety.

Typical values of the factor of safety used in bearing capacity analyses of shallow foundations are between 2.5 and 3.5. A factor of safety $F = 3$ is selected to perform bearing capacity analyses shown in this paper.

### *2.2 Burland and Burbdige (1984) Method*

Bearing capacity of *shallow square foundations* (*spread footings*) is evaluated also by using Burland and Burbdige (1984) method [2]. This method is used

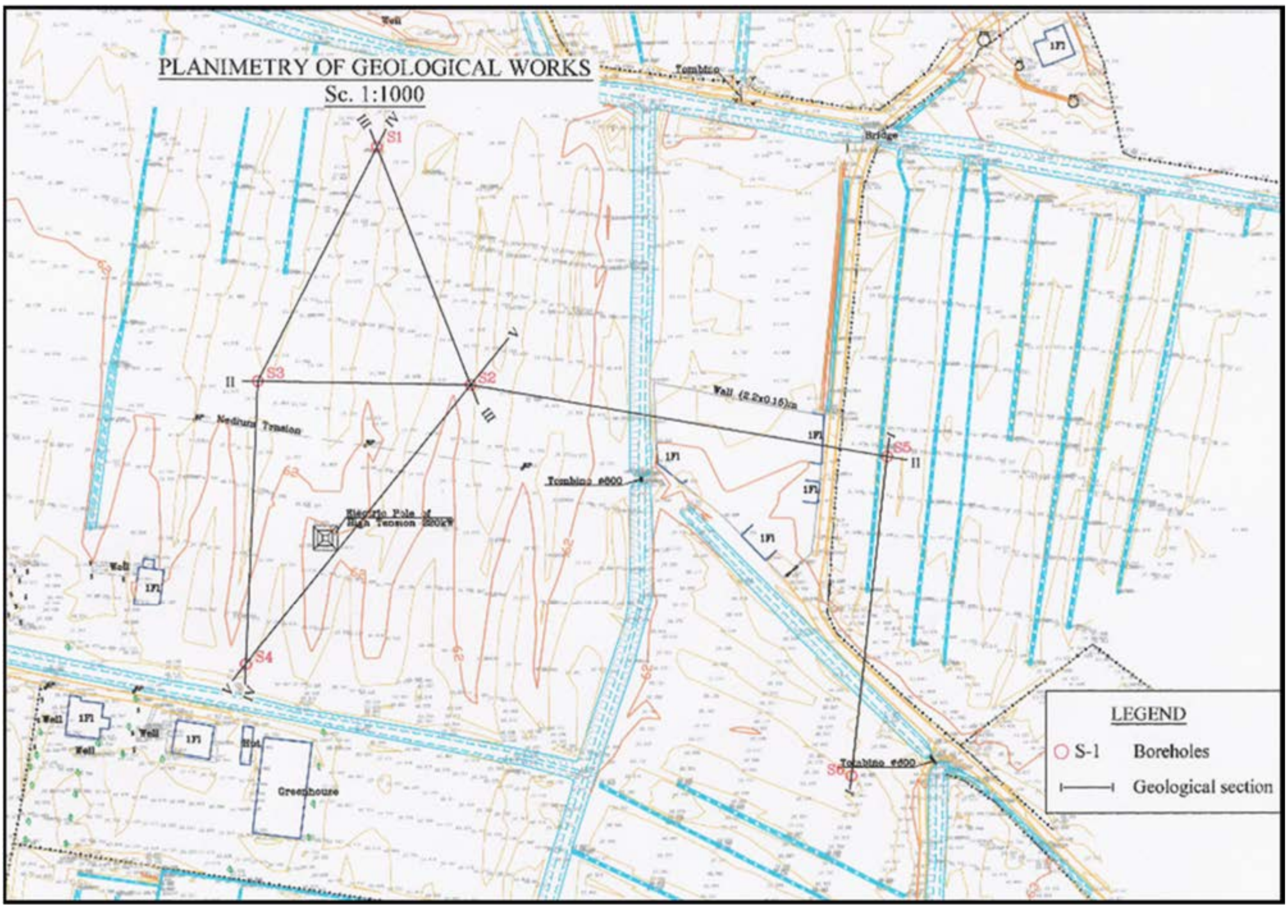


**Fig. 1 Plan of geological works (reproduced by Ahmetaj and Allkja [1]).**

for checking the settlement (serviceability) criterion in the foundation design.

The Burland and Burbidge method is an empirical relationship between average SPT blow count, foundation width, and foundation subgrade compressibility. The immediate settlement of a footing on granular soil is given by the following:

$$S = f_s f_l f_t \left[ \left( q' - \frac{2}{3}\sigma_0' \right) B^{0.7} I_c \right]$$

where:

$f_s$ = shape correction factor.

$f_l$ = correction factor for thickness of sand or gravel layer.

$f_t$ = time factor, used if $t$ is > 3 years.

$q'$ = average gross applied pressure.

$I_c$ = compressibility index.

The soil compressibility index, $I_c$, is calculated from the SPT blowcounts as:

$I_c = 1.71/(N_{60})^{1.4}$ (for normally consolidated soils)

$I_c = 0.57/(N_{60})^{1.4}$ (for over consolidated soils)

where:

$N_{60}$ = average adjusted blowcounts.

The blowcount values between the base of the footing and the depth of influence are used and should be corrected for energy only to give $N_{60}$. No overburden correction is applied. If the soil is a submerged dense very fine or silty sand with $N_{60} > 15$, $N_{60}$ should be adjusted using the correction factor proposed by Terzaghi and Peck (1948) [4]. If the soil is gravelly sand or sandy gravel, Burland and Burbidge (1985) [5] recommend multiplying $N_{60}$ by an adjustment factor of 1.25.

Calculations are performed by using an Excel spreadsheet. The $N$-value in this method is the average $N$-value over the depth of influence below the footing, approximately, 1.5 times the width of the foundation. This is a statistical method, and for that reason, the mean + sigma and mean - sigma ranges are also shown.

Corrections need to be made in the SPT blowcount, according to the recommendations of Youd et al [7], for the type of sampler, the rod length, the borehole diameter, the energy transmitted to the sampler and the overburden stress.

According to Coduto [6], the raw SPT data are improved by applying certain correction factors, thus significantly improving its repeatability. The variations in testing procedures may be at least partially compensated by converting the $N$-value recorded in the field to $N_{60}$ as follows:

$$N_{60} = \frac{E_m C_B C_s C_R N}{0.60}$$

where:

$N_{60}$ = SPT $N$-value corrected for field procedures.

$E_m$ = hammer efficiency (it is used $E_m$ = 0.45).

$C_B$ = borehole diameter correction (it is used $C_B$ = 1.05).

$C_s$ = sampler correction (it is used $C_s$ = 1.00).

$C_R$ = rod length correction (it is used $C_R$ = 0.85).

$N$ = SPT $N$-value recorded in the field.

Many of the SPT-based design correlations are developed using hammers with an efficiency of 60 percent, so the above equation corrects the results from other hammers to that which would have been obtained if a percent efficient hammer was used.

## 3. Results of Calculations and Discussions

In this part the results of calculations are shown, related to allowable bearing capacity of foundations for the buildings, which are to be constructed at this site. Because of the fact that analytical method is related to the data of laboratory tests, at first the authors deal with the results of these tests, which are reported in the geological study.

Note that bearing capacity analysis of *shallow foundations* is conducted considering *square spread footings*. In all the cases, the bearing capacity is evaluated using weighted average values of $c'$, $\varphi'$ and $\gamma$ based on the relative thickness of each stratum in the zone between the bottom of the footing and a depth $B$ below the bottom.

In order to design foundations which satisfy both bearing capacity and settlement criteria, it was decided to excavate the upper stratum, until a depth of 3.0-3.5 m and after that to construct an artificial fill, using gravels from "Mati River". The recommended thickness of this artificial fill is $D_{\text{fill}}$ = 1.5-2.0 m and the maximum recommended dry density to be achieved in the construction site for the fill is $\gamma_d$ =22.5 kN/m$^3$.

The shear strength parameters of the constructed fill ($c'$ and $\varphi'$) are determined by laboratory tests (the direct shear test) on specimens compacted to the proposed dry density and are shown in the geological study [1].

A settlement analysis of foundations is not possible, because geological study does not present data of one-dimensional consolidation tests. So, to control settlements, local bearing capacity of foundations is computed, using Terzaghi's formula [3] with the reduced values of $c'$ and $\varphi'$:

$$c'_{adj} = 0.67c'$$

$$\varphi'_{adj} = tg^{-1}(0.67tg\varphi')$$

where:

$c'_{adj}$ = adjusted effective cohesion.

$\varphi'_{adj}$ = adjusted effective friction angle.

Table 1 shows the weighted average adjusted shear strength parameters and unit weights of soils inside the failure zone, which are involved in the bearing capacity analysis.

### *3.1 Bearing Capacity of Shallow Foundations*

All the bearing capacity analyses of shallow foundations are performed by using an excel spreadsheet, like the one shown in Fig. 2, which is based on the analytical methods described in the previous theoretical part [3].

Based on the request, authors have analyzed foundations underlain an artificially constructed fill, with thickness caps $D_{\text{fill}}$ = 1.5, 1.75 and 2.0 m. This artificial fill is considered to be constructed at the construction areas of each Substation's building at Kashari, in Tirana. It is realized through an excavation of the upper part of soils

**Table 1 Design values of cohesion, friction angle, and unit weight.**

| $D_{fill}$ (m) | | Constructed fill | Layer 3 | $B$ (m) | $c_d$ (kPa) | $\varphi_d$ (°) | $\gamma_d$ (kN/m$^3$) |
|---|---|---|---|---|---|---|---|
| 1.5 | $c_{adj}$ | 1.5 | 13 | 2 | 4.38 | 28.00 | 21.50 |
| | $\varphi_{adj}$ | 34 | 10 | 3 | 7.25 | 22.00 | 20.50 |
| | $\gamma$ | 22.5 | 18.5 | 4 | 8.69 | 19.00 | 20.00 |
| | $N$-value | 10 | 9 | 5 | 9.55 | 17.20 | 19.70 |
| | | | | 6 | 10.13 | 16.00 | 19.50 |
| 1.75 | $c_{adj}$ | 1.5 | 13 | 2 | 2.94 | 31.00 | 22.00 |
| | $\varphi_{adj}$ | 34 | 10 | 3 | 6.29 | 24.00 | 20.83 |
| | $\gamma$ | 22.5 | 18.5 | 4 | 7.97 | 20.50 | 20.25 |
| | $N$-value | 10 | 9 | 5 | 8.98 | 18.40 | 19.90 |
| | | | | 6 | 9.65 | 17.00 | 19.67 |
| 20 | $c_{adj}$ | 1.5 | 13 | 2 | 1.50 | 34.00 | 22.50 |
| | $\varphi_{adj}$ | 34 | 10 | 3 | 5.33 | 26.00 | 21.17 |
| | $\gamma$ | 22.5 | 18.5 | 4 | 7.25 | 22.00 | 20.50 |
| | $N$-value | 10 | 9 | 5 | 8.40 | 19.60 | 20.10 |
| | | | | 6 | 9.17 | 18.00 | 19.83 |

(excavation includes layers No. 1 and No. 2) until a depth of 3.0-3.5 m, and, after that placing the compacted gravels from the "Mat River".

Two cases are considered during the evaluation of bearing capacities for shallow foundations of the buildings in this site:

Case 1: Square spread footings with a depth $D$ = 1.0 m, from the ground surface.

Case 2: Square spread footings with a depth $D$ =1.5 m, from the ground surface.

In both cases, thickness of the constructed fill is accepted 1.5, 1.75 and 2.0 m and, because of the excavation, it always underlay layer No. 3 (layer No. 2 is neglected). Foundation width is varied in the interval $B$ = 2.0-6.0 m.

During the exploration works of the subsurface conditions at the construction site [1], groundwater table is located at a depth 0.5-0.9 m, from the natural ground surface. It is reported in the geological study. During bearing capacity calculations, the worst case (highest level = 0.5 m) is considered. In order to satisfy bearing capacity criteria, but also to control the settlement of the foundations, adjusted and weighted averages values of shear strength parameters c' and φ' are considered.

Results of all calculations, for allowable bearing capacities $q_a$, are shown in charts related to the considered foundation width $B$ (see Fig. 3).

In order to check the design of foundations related not only to bearing capacity but also related to their settlements the Burland and Burbdige (1984) method [2] is applied.

The bearing capacity analyses are performed by using an excel spreadsheet, like the one shown in Fig. 4, which is based on Burland and Burbdige (1984) method described in the theoretical part.

The $N$-values of SPT tests are taken from the geological study, considering the average $N$-value over the depth of influence below the footings, approximately 1.5 times the width of the foundation. Considering that the foundation width is varied in the interval $B$ = 2.0-6.0 m, the depth of influence varies in the interval 3.0-9.0 m in the footing area. The $N$-value is found as an arithmetical average value for the Layer No. 3, considering the results of investigations through 6 boreholes, and it is shown in Table 1. The accepted field $N$-value is corrected, by applying certain factors, to convert the field $N$-value to $N_{60}$ value [6].

The results of bearing capacity analyses of shallow foundations are shown in Fig. 4.

**BEARING CAPACITY OF SHALLOW FOUNDATIONS**
**Terzaghi Method**

Date June 21, 2009
Identification SUBSTATION - KASHAR

**INPUT**

Units of Measurement
SI SI or E

Foundation Information
Shape SQ SQ, CI, CO, or RE
B = 3 m
L = m
D = 1.5 m

Soil Information
c = 5.33 kPa
phi = 26 deg
gamma = 21.17 kN/m^3
Dw = 0.5 m

Factor of Safety
F = 3

***Terzaghi Results***

***Bearing Capacity***
**q ult = 646 kPa**
**q a = 215 kPa**

***Allowable Column Load***
**P = 1,618 kN**

**Fig. 2 Bearing capacity of square shallow foundations, according to Terzaghi (Excel spreadsheet developed from Donald P. Coduto, 2001).**

**Allowable Bearing Capacities, $q_a$.**

| | Depth of foundation D = 1.0 m. | | | | Depth of foundation D = 1.5 m. | | |
|---|---|---|---|---|---|---|---|
| $D_{fill}$ (m) | 1.50 | 1.75 | 2.00 | $D_{fill}$ (m) | 1.50 | 1.75 | 2.00 |
| B (m) | $q_a (kN/m^2)$ | $q_a (kN/m^2)$ | $q_a (kN/m^2)$ | B (m) | $q_a (kN/m^2)$ | $q_a (kN/m^2)$ | $q_a (kN/m^2)$ |
| 2.0 | 204 | 273 | 382 | 2.0 | 239 | 324 | 460 |
| 3.0 | 137 | 159 | 193 | 3.0 | 153 | 180 | 215 |
| 4.0 | 117 | 130 | 145 | 4.0 | 128 | 143 | 161 |
| 5.0 | 108 | 117 | 127 | 5.0 | 117 | 128 | 140 |
| 6.0 | 103 | 110 | 118 | 6.0 | 111 | 119 | 128 |

**Note:** $D_{fill}$ = *Thickness of constructed fill below the bottom of the foundation.*

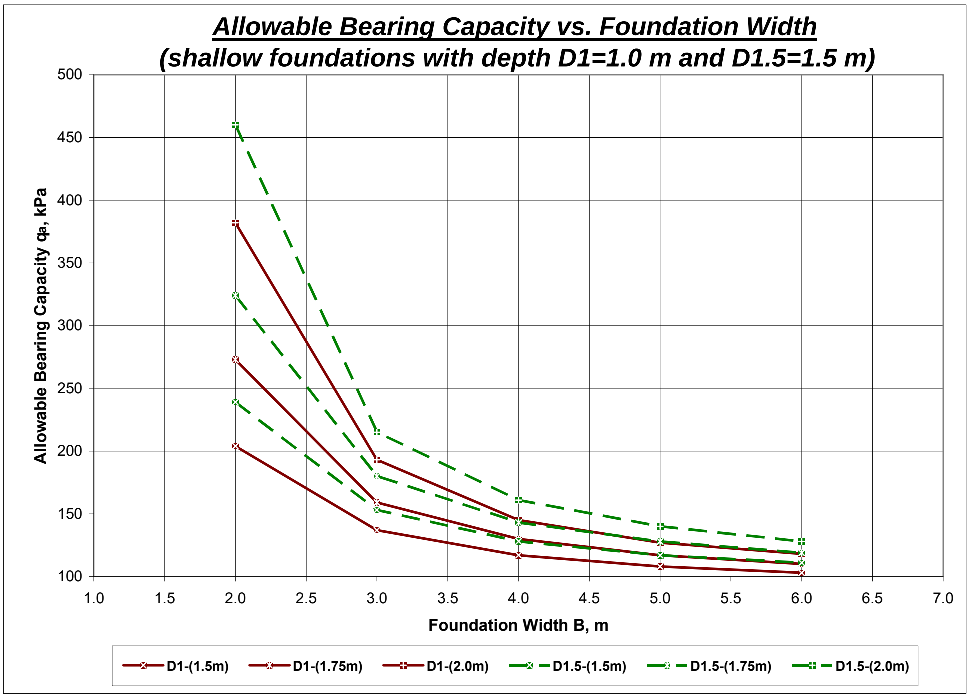


**Fig. 3 Allowable bearing capacity of foundations underlain the constructed fill (for the different values of foundation width).**

**DEFORMATION CRITERION**

**Using Burland & Burbridge (1984) Approach**

| | | | | | |
|---|---|---|---|---|---|
| Allowable settlement (mm) | 50 | | | | |
| Inducing mean-σ stress (KPa) | 89.6 | 67.5 | 55.2 | 47.2 | 41.5 |
| Inducing mean stress (kPa) | 163.1 | 122.8 | 100.4 | 85.9 | 75.6 |
| Inducing mean+σ stress (KPa) | 296.8 | 223.5 | 182.7 | 156.3 | 137.6 |

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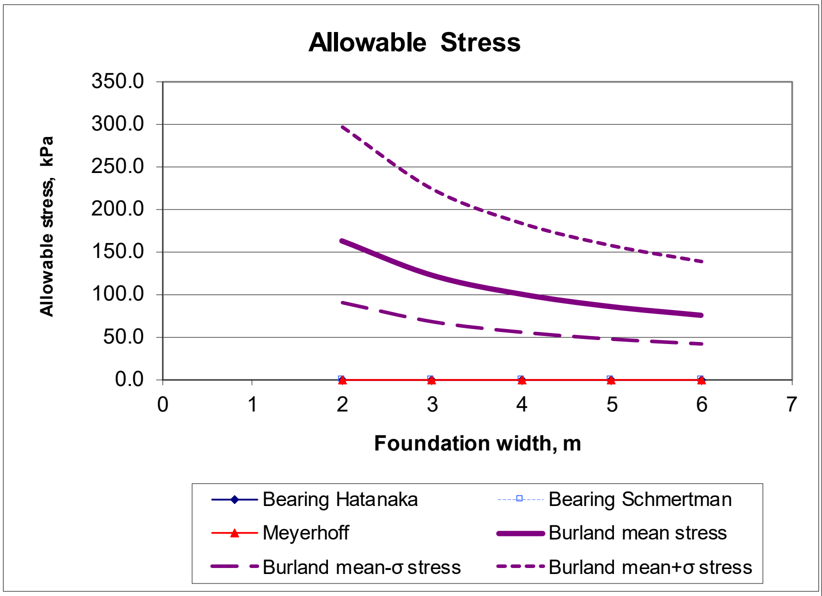


**DEFORMATION CRITERION**

**Using Burland & Burbridge (1984) Approach**

| | | | | | |
|---|---|---|---|---|---|
| Allowable settlement (mm) | 75 | | | | |
| Inducing mean-σ stress (KPa) | 134.4 | 101.2 | 82.8 | 70.8 | 62.3 |
| Inducing mean stress (kPa) | 244.6 | 184.2 | 150.6 | 128.8 | 113.4 |
| Inducing mean+σ stress (KPa) | 445.2 | 335.2 | 274.0 | 234.4 | 206.3 |

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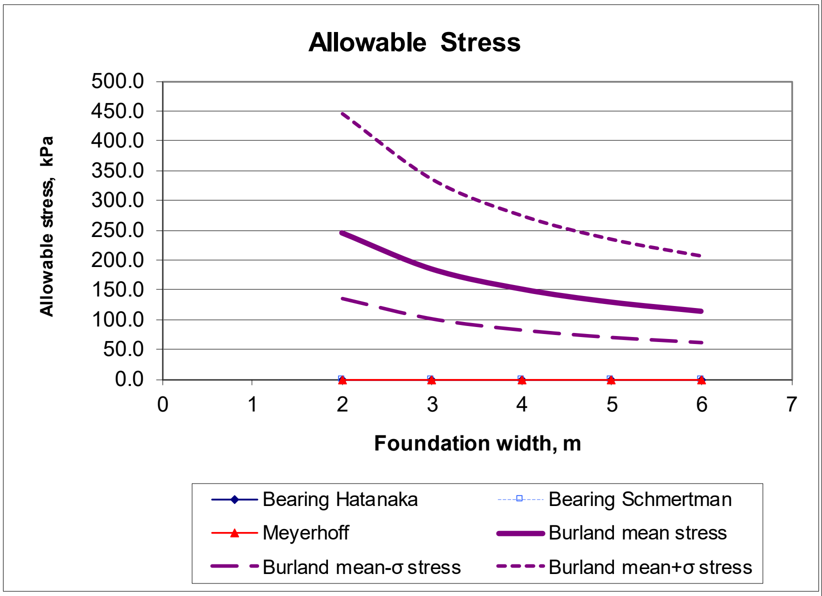


**Fig. 4** **Bearing capacity of square shallow foundations, according to Burland and Burbdige (developed by Dimitris P. Zeccos).**

The bearing capacity analyses are realized for the accepted/allowable settlement of 50 mm and 75 mm.

## 4. Discussion of Results

Above contents showed the results of allowable bearing capacity analysis for *shallow square footings* at the construction site of Substation at Kashari, in Tirana.

As it is mentioned, allowable bearing capacities are calculated for shallow foundations supported on an artificial compacted fill, which underlies layer No. 3. In order to control the settlement of foundations, bearing capacity of foundations is evaluated based on adjusted shear strength parameters of constructed fill and layer No. 3. Calculated values are reported for two cases, Case 1 and Case 2, and are related to different values of foundation width *B*. All these results are shown graphically in Fig. 3.

As it is observed from these charts, the bearing capacities values are high for foundation's width smaller than fill's thickness ($B < D_{\text{fill}}$). But they decrease rapidly when foundation's width $B$ is increased. This is because of layer No. 3. When foundation's width $B$ increases, failure zone (the zone below the bottom of foundation equals to foundation's width $B$) is also increased and includes layer No. 3, which has lower values of $c'$ and $\varphi'$. As it is mentioned above, in all the bearing capacities analysis weighted average values of $c'$, $\varphi'$ and $\gamma$ are used in accordance with relative thickness of each stratum within the failure zone. That is why bearing capacities values, in this case, are decreased.

The bearing capacity values are compared with the values of bearing capacity calculated based on Burland and Burbdige (1984) method [2], which is used to control also the settlement of foundations.

The results of bearing capacity analyses, based on Burland and Burbdige (1984) method [2], show almost the same values as the calculated local bearing capacity values. So, as a conclusion in order to control the settlements during the foundation design, local bearing capacity values calculated by using Terzaghi's formula may be applied.

The calculated local bearing capacity values are a good prediction for the foundation's design of small and medium structures, like buildings of Substation at Kashari, Tirana. But it is not advised to use them for the design of foundations of important structures, which transmit very high pressures on the ground. In this case it is necessary to make a settlement analysis, based on the data of consolidation tests or on the data of SPT tests.

## 5. Conclusions

Bearing capacity analysis of shallow foundations for the construction site, located in Tirana County, Tirana prefecture in Albania, where the company "EnBI POWER" has the intention to build Substation at Kashari village, in Tirana, is discussed in this paper. From the results of calculations and their discussion, the below conclusions have resulted:

(1) The foundations of buildings, at the mentioned site of construction, must be safely supported on an artificial fill with a thickness $D_{\text{fill}}$ = 1.5-2.0 m and constructed with gravels from "Mati River", as it is described above.

(2) The geotechnical design of shallow foundations, may be based on the reported values of allowable local bearing capacities $q_a$ = 100-250 kPa., without any need to conduct a settlement analysis.

(3) If the geotechnical design of shallow foundations is based on the allowable bearing capacities, $q_a > 250$ kPa, then it is advised to conduct a detailed settlement analysis.

(4) Both methods (Terzaghi's formula [3] and Burland & Burbdige method [2]) are used to obtain allowable bearing capacity of shallow square foundations, and results are in a very good agreement between them.

(5) Local allowable bearing capacity values calculated by Terzaghi's formula [3] using the reduced values of $c'$ and $\varphi'$ may control the settlements and are very suitable for the practical design of shallow foundations.

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