Albanian Design Practice of pile foundation compared to other international practices

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ABSTRACT

The calculation of the axial bearing capacity for pile foundations vary widely from one country to another, depending on the methods that each country use or on the building codes that has adapted in the legislation. In Albania, a legislation nor a building code exist for this purpose, but during years a design practice for pile foundations is consolidated. In this paper the calculation of the axial bearing capacity of a pile using Albanian Design Practice is shown in comparison with 3 other methods, which are: analytical method based on SPT data; analytical method based on CPTu data; method based on Japanese Design Practice. In order to have a satisfactory comparison between the results of the used methods, the calculations are carried out for both driven and cast-in-place piles, considering for each case several values for pile length and diameter. Analysis of the complete results enables to compare the method described in Albanian Design Practice with other proposed methods. The calculated bearing capacities show that the differences between the methods are apparent.

Keywords: pile, design practice, CPTu, SPT, bearing capacity, toe resistance, shaft resistance

1 INTRODUCTION

Although numerous investigations, both theoretical and experimental, have been conducted in the past to predict the behavior and the load-bearing capacity of piles in granular and cohesive soils, the mechanisms are not yet entirely understood and may never be. The design and analysis of pile foundations may thus be considered somewhat an art as a result of the uncertainties involved in working with some subsoil conditions [1].

During years several methods and practices for the design of pile foundations have been developed. Among other issues, they differ from each other from the data used in the calculations and also from the level of safety. In each country, depending on the tradition or on the legislation, certain methods are in use which are more familiar for their engineers. In Albania a design code for this purpose doesn't exist, but in years a method for the calculation of pile foundations is consolidated, to which we can refer as Albanian Design Practice (ADP).

It is clear that if we use various methods for the calculation of the bearing capacity of a pile we will obtain different results. The comparison of the results of the used methods can be seen as a way to compare these methods. In this paper the bearing capacity of a pile is calculated using ADP and 3 other methods: method based on Japanese Design Practice (JDP); analytical method based on CPTu data (AMCPTu); analytical method based on SPT data (AMSPT).

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In this way the differences between these methods can be understood and what is more important, it can be seen how the results of ADP stand in front of the results of the other methods. The calculation process of each method is briefly summarized in the sequent headings.

2 ALBANIAN DESIGN PRACTICE

According to ADP [2] the allowable bearing capacity of a pile P_a (kN), for driven and cast-in-place piles, is calculated with the formula that follows

$$P_a = m \cdot k_{dw} \cdot (m_\sigma \cdot q_t^{'} \cdot A_t + m_f \cdot \sum f_s A_s) \qquad (1)$$

Where m is the pile working conditions coefficient; k_{dw} the coefficient for downward loading (equal to 0.7); m_σ the pile toe working conditions coefficient; q'_t the unit resistance on the pile toe (kPa); m_f the pile shaft working conditions coefficient; f_s the unit frictional resistance (kPa); A_t the area of the cross section of the pile (m^2); A_s the area of the pile shaft (m^2). The values of the coefficients m, m_σ and m_f are in Table 1 [2] according to the pile type. To obtain q'_t, are available tables and the value of q'_t is selected depending on the pile type (driven or cast-in-place), soil type (cohesive or granular soil) and on the depth of the pile tip [2].

Table 1. Working conditions coefficients

Pile type	m_σ	m_f	m
Driven pile	1.0	1.0	1.0
Cast-in-place pile without/with ground water	1.0 / 0.9	0.7 / 0.6	0.65

For the calculation of the frictional resistance it is necessary to divide the soil in layers and for each layer we calculate f_s and A_s. For sands q'_t and f_s depend on the coarseness of the sand and for cohesive soils they depend on the consistency index I_c [2].

The allowable upward bearing capacity of a pile $(P_{upward})_a$ (kN) is calculated considering only the friction resistance on the pile shaft, by neglecting the weight of the pile [2]. The calculation formula is

$$(P_{upward})_a = m \cdot k_{uw} \cdot (m_f \cdot \sum f_s A_s) \qquad (2)$$

where k_{uw} is the coefficient for upward loading (equal to 0.4). The values of the other parameters derive in the same way as for downward loading.

As can be seen ADP doesn't use a clear factor of safety in the calculations. Anyway, the combinations between the coefficients m, m_σ, m_f, k_{dw} and k_{uw} somehow provide a safety factor.

3 JAPANESE DESIGN PRACTICE

The calculation of the bearing capacity for pile foundations is given from The Building Standard Law of Japan, Standard of Japanese Geotechnical Society. As the allowable bearing capacity is chosen the lowest value between the result of the analytical method and from the pile load tests [3]. Analytically P_a (kN) is calculated as follows

$$P_a = \frac{1}{3}(P_t + P_s) \qquad (3)$$

where P_t is the ultimate bearing capacity on the pile toe (kN) and P_s the ultimate bearing capacity from the friction on the pile shaft (kN). The value of P_t is calculated by multiplying the unit resistance on the pile toe with the area of the cross section of the pile, as below

$$P_t = q'_t \cdot A_t \qquad (4)$$

The unit resistance on the pile toe is calculated according to Table 2 [3]. In this table N represents the average number of blows during the SPT test for the soils near the pile toe. If N is greater than 60 it should be taken 60. The value of P_s is defined as follows

$$P_s = \left(\frac{10}{3} \cdot N_s \cdot L_s + \frac{1}{2} \cdot q_u \cdot L_c \right) \cdot \phi \qquad (5)$$

where N_s is the average number of blows during the SPT test for sandy soils that are part of the soils around the pile (if N_s is greater than 30 it should be taken 30); L_s is the length of the pile that is in contact with sandy soils (m); q_u = average unconfined compression strength for clay soils that are part of the soils around the pile (kPa); L_c is the length of the pile that is in contact with clay soils (m) and ϕ the perimeter of the pile (m).

Table 2. Unit resistance on the pile toe q'_t [kPa]

Pile type	q'_t
Driven pile	300·N
Cast-in-place pile	150·N

The allowable upward bearing capacity $(P_{upward})_a$ (kN) consider the resistance on the pile shaft and the weight of the pile [3]. The calculation formula is

$$(P_{upward})_a = \frac{4}{15} \cdot P_s + W_f \tag{6}$$

In this formula, W_f is the weight of the pile (kN) (calculated considering the buoyancy effect) and P_s the same as for downward loading.

4 ANALYTICAL METHOD USING CPTU DATA

The bearing capacity of a pile can be calculated using the data that derive from the CPTu test in field, using various methods. The method used in this paper [4] imposes the same calculations for both driven and cast-in-place piles. The data, before used in the calculations, need to be corrected by substracting the pore water pressure from the cone resistance. In this way we obtain the effective cone resistance q_E (kPa), as follow

$$q_E = q_T - u \tag{7}$$

where q_T is the cone resistance measured during CPTu test (kPa); u is the pore water pressure measured at the cone (kPa). From q_E we can calculate the average effective cone resistance q_{Eg} (kPa), that represents the average value of the effective cone resistance for one soil layer [4]. With the use of q_{Eg} is possible to calculate the unit resistance on the pile toe and the unit frictional resistance on the pile shaft

$$q'_t = C_t \cdot q_{Eg} \tag{8}$$

$$f_s = C_s \cdot q_{Eg} \tag{9}$$

Where C_t is the toe correlation coefficient (equal to 1); C_s is the shaft correlation coefficient that depends on the soil type (Table 3) [4]. In formulas (8) and (9) q'_t and f_s are in kPa. In (8) q_{Eg} is for the layer where is positioned the toe of the pile and in (9) q_{Eg} is calculated for every layer of the soil around the pile. The allowable bearing capacity P_a and the allowable upward bearing capacity $(P_{upward})_a$ are calculated with the formulas below

$$P_a = \frac{q'_t \cdot A_t + \sum f_s A_s}{F} \tag{10}$$

$$(P_{upward})_a = \frac{W_f + 0.75 \cdot \sum f_s A_s}{F} \tag{11}$$

For P_a, the factor of safety F is 2.5 and for $(P_{upward})_a$ it is 5. For upward loading the friction is considered only 75% and for the weight of the pile is taken into account the buoyancy effect.

Table 3. Values of the coefficient C_s

Soil type	C_s
Soft sensitive soils	0.080
Clay	0.050
Stiff clay or mixture of clay and silt	0.025
Mixture of silt and sand	0.010
Sand	0.004

5 ANALYTICAL METHOD USING SPT DATA

From the SPT test we obtain the N value, that represents the required number of blows to penetrate the spoon by 30cm, at a specific depth. With the necessary corrections for field procedures, is calculated the value N_{60} and is used in the calculations. The allowable bearing capacity P_a and the allowable upward bearing capacity $(P_{upward})_a$ are calculated according to (10) and (11). The factors of safety are also the same as above. The difference is in the calculation of q'_t and f_s.

5.1 *Driven piles*

The unit resistance on the pile toe is calculated using (12) for toe in sand and using (13) for toe in clay.

$$q'_t = B \cdot \gamma \cdot N_\gamma^* + \sigma'_{zD} \cdot N_q^* \quad (12)$$

$$q'_t = s_u \cdot N_C^* \quad (13)$$

Where B is the pile diameter (m); γ the unit weight of the soil (kN/m^3); σ'_{zD} the effective vertical stress at the depth of the pile toe (kPa); s_u the undrained shear resistance of the soil (kPa); N^*_C, N^*_γ and N^*_q are bearing capacity factor. The values of N^*_C are in Table 4, for s_u values up to 250 kPa.

Table 4. Values of the factor N^*_C

s_u [kPa]	N^*_C
25	6.5
50	8.0
>100	9.0

For intermediate values of s_u is used the interpolation. The other bearing capacity factors N^*_γ and N^*_q are obtained from graphics according to the values of the friction angle and from the rigidity index I_r of the soil [5]. The rigidity index is defined as below

$$I_r = \frac{E}{2 \cdot (1+\nu) \cdot \sigma'_{zD} \cdot tg\varphi} \quad (14)$$

$$E = \beta_0 \cdot \sqrt{OCR} + \beta_1 \cdot N_{60} \quad (15)$$

where E is the equivalent modulus of elasticity of the soil (kPa); OCR the overconsolidation ratio; β_0 and β_1 are correlation factors (Table 5); ν is Poisson's ratio. The unit frictional resistance for each layer, is obtained from the β-method, by the following formula

$$f_s = \beta \cdot \sigma'_{zD} \quad (16)$$

Table 5. Values of the correlation factors β_0 and β_1

Soil type	β_0 [kPa]	β_1 [kPa]
Clean sands	5000	1200
Silty sands and clayey sands	2500	600

For clays β can be obtained from graphics, depending on the value of OCR and on the friction angle [6]. On these graphics β are in the range of 0.25 to 0.35. For sands β depends on the relative density D_r (%) [7] as follows

$$\beta = 0.18 + 0.0065 \cdot D_r \quad (17)$$

5.2 *Cast-in-place piles*

The unit resistance on the pile toe for sands is shown in (18) [8].

$$q'_t = 57.5 \cdot N_{60} \leq 2900 \text{ kPa} \quad (18)$$

The unit frictional resistance in sandy layers is also calculated with β-method and β depends on the depth of the layer z (m), as in (19) [9]. The value of β is between 0.25 and 1.20.

$$\beta = 1.5 - 0.245 \cdot \sqrt{z} \quad (19)$$

For toe in clay is the same as for driven piles.

6 RESULTS AND CONCLUSIONS

In order to have a complete comparison between the methods used in this paper, the calculations of the bearing capacity are made for several cases. The soil is investigated until the depth of 30m and contains 5 layers. The geotechnical parameters of each layer necessary for the calculations are shown in Table 6. The ground water table is located 2m below the ground surface.

The bearing capacity is calculated for both driven piles and cast-in-place piles. In order to present the results of the calculations in graphical form (it is easier to compare the methods used) various values for the pile diameter B (m) are considered. For driven piles the used diameters are 30, 40, 50 and 60cm. For cast-in-place piles the used diameters are 60, 80, 100 and 120cm. For all the above cases are considered two values for the pile length D (m): 12m and 22m. In this way the pile toe is once in clay and once in sand. The results of all the calculations are presented in the graphs in Figures 1 to 4.

Table 6. Geotechnical parameters of soil determined from laboratory tests (unit weight, γ, friction angle, φ, consistency index, I_c, relative density, D_r, and undrained shear strength, s_u) and field tests (q_{Eg} and N_{60}).

Layer	Description	Thickness [m]	γ [kN/m³]	φ [°]	I_c	D_r [%]	s_u [kPa]	q_{Eg} [kPa]	N_{60}
1	Fine medium sand	2.5	17.2	30	-	33	-	3183	7
2	Fine medium sand with silt	3.5	17.5	28	-	31	-	1953	8
3	Soft clay with silt	10.0	18.1	21	0.4	-	44	313	7
4	Fine sand with silty clay	4.0	17.7	29	-	36	-	2940	14
5	Silt with loose sand	10.0	18.3	28	-	21	-	604	11

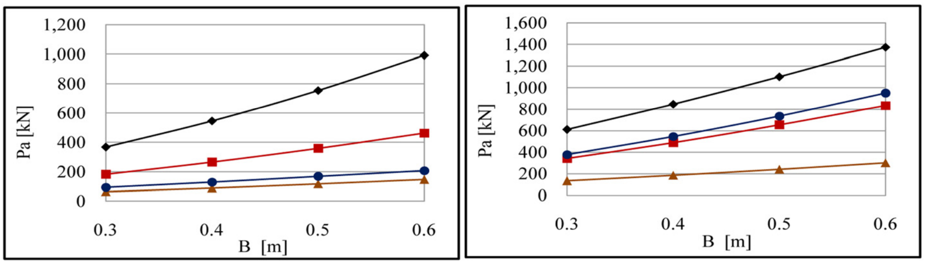


Figure 1. Allowable axial bearing capacity for driven piles (D = 12m; D = 22m)

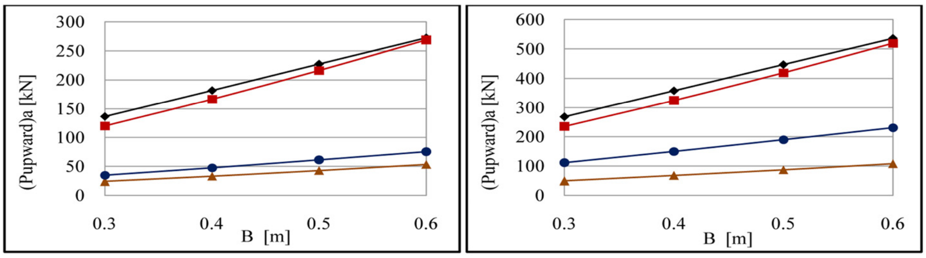


Figure 2. Allowable upward axial bearing capacity for driven piles (D = 12m; D = 22m)

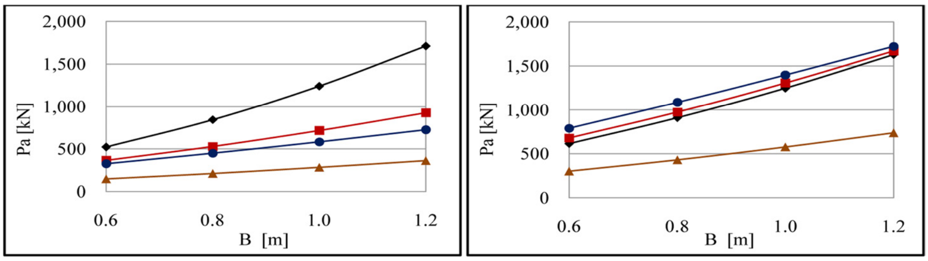


Figure 3. Allowable axial bearing capacity for cast-in-place piles (D = 12m; D = 22m)

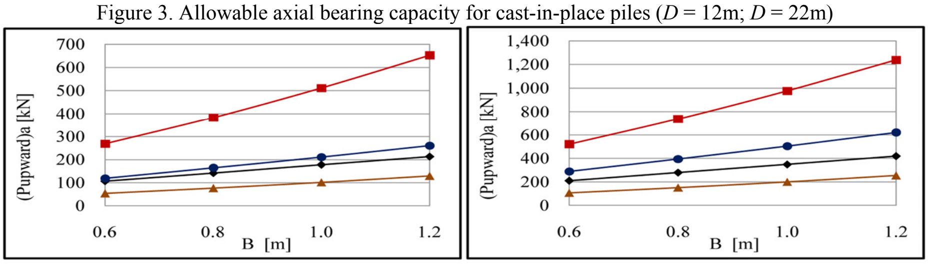
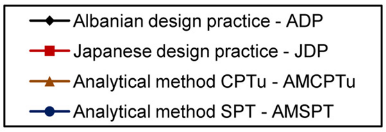


Figure 4. Allowable upward axial bearing capacity for cast-in-place piles (D = 12m; D = 22m)



Legend for Figure 4

If we refer to the results of the calculations, a comparison between the used methods can be made. It is clear that this comparison applies only for the specific soil conditions that are given in Table 6. Therefore the conclusions are valid only for orientation and can't be generalized.

According to the graphs, the bearing capacity moves through a big range of values and the differences between the four methods are apparent. In all the cases, the AMCPTu gives the more conservative results, so gives the lowest values of the allowable bearing capacity.

For driven piles ADP gives less conservative results compared to all the other methods. For the allowable bearing capacity P_a it gives values much larger than the other methods and the values of P_a are 2 to 4 times larger than for the other methods. For the allowable upward bearing capacity $(P_{upward})_a$ the results are almost the same as for JDP, but a little larger. In comparison with AMCPTu and AMSPT the results are 2 to 4 times larger.

For cast-in-place piles with the toe positioned in clay (D = 12m), the values of the allowable bearing capacity P_a using ADP are larger than those that derive from the other methods, approximately 2 to 3 times larger. When the pile toe is positioned in sand (D = 22m) the results are very similar with those of JDP and AMSPT. Regarding the allowable upward bearing capacity $(P_{upward})_a$ the results are similar to the results of AMSPT. The values of $(P_{upward})_a$ are approximately 1/3 of those of JDP.

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