BEARING CAPACITY OF CONE SHAPED FOUNDATIONS WITH SEMI ANGLE β VARIATION AND DIFFERENT ROUGHNESS

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ABSTRACT

A properly designed foundation throughout the soil without overstressing the soil. Overstressing the soil can result in either excessive settlement or shear failure of the soil, both on which cause damage to the structure; thus, geotechnical and structural engineers who design foundations must evaluate the bearing capacity of soils. Depending on the structure and soil encountered, various types of foundation are used. The problem of bearing capacity of cone shaped foundation with semi angle β variation; 15°, 30°, 45°, 60°, 90° and different roughness; perfectly smooth and perfectly rough, in homogeneous soil and subjected to axial load, is analyzed on the basis of plastic theory. The soil is considered as a perfectly rigid plastic material obeying the MOHR-COULOMB failure criterion. An experimental investigation was made to obtain penetration resistance for estimating the ultimate bearing capacity of cone foundation with various semi angle β and different roughness in sands (c = 0) and clays (ϕ = 0). The Mangatasik Dry Sand and Wenwin Soft Clay were used in this tests. The experimental values were found to agree well with theoretical bearing capacity of cone shaped foundations.

Keywords : bearing capacity, cone shaped foundation, semi angle β, roughness, sand, clay.

INTRODUCTION

Every civil engineering structure must have a proper foundation. Foundation is very important element of the construction, and should be design to be able to give safety to construction above. In practice the civil engineer has many diverse and important encounters with soil and construction, so that a knowledge of the right available types and methods of constructing foundations is essential for a through understanding of the science of their behavior. In the design of any foundation system, the central problems are to prevent bearing capacity failures and settlements large enough, to damage the structure, or impair it’s function. The supporting power of soil is referred to as its bearing capacity.

The method of designing foundation is based on the concept of bearing capacity. The bearing capacity of cone shaped foundation under axial load, with the various semi angle β and different roughness, can generally be estimated with sufficient accuracy based on plastic theory.

The primary objective of this paper is to present the influence of semi angle β variation and different roughness to cone bearing capacity in homogeneous soils; under central vertical load. This investigation to obtain cone bearing capacity of foundation with the various semi angle β and different roughness through the characteristic of homogeneous soils in sands (c = 0) and clays (ϕ = 0), assumption. The cone shaped foundation is schematically presented in Fig. 1.

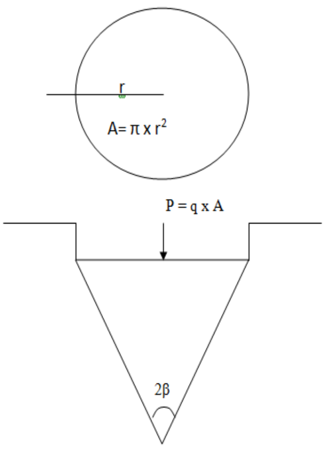

Fig. 1 Cross section of cone shaped foundation

METHODOLOGY

Analysis of cone bearing capacity with the various semi angle β; 15°, 30°, 45°, 60°, 90° and different roughness; perfectly smooth and rough surface, were carry out by use as follows methods :

Literature Study

The methods to use in theoretical calculation, as basis and references for the following analysis, these are Mohr-Coulomb theory of rupture to used for defined shear force; Terzaghi and Meyerhoff theory of ultimate bearing capacity; Tresca methods for define maximum shear stress in soft clay; Hansbo methods for define undrained shear strength in soft clay; J.E.R Sumampow and T. Koumoto theory and investigation of wedge bearing capacity of foundations; T. Koumoto theory and investigation of cone bearing capacity of foundations in sands and clays.

Experimental Investigation

This research take the advantage experiments methods in laboratory to use main and support apparatus; program of research consists:

- Soil sampling; sands and clays.
- Preparation of materials and tests apparatus; specific gravity, unit weight, moisture content, loading and penetration test with modified CBR apparatus, direct shear test apparatus, fall cone test apparatus.
- Data analysis; ease to evaluate test results and then will behave in graphs and tables, to take conclusion.

TEST RESULT AND DISCUSSION

Direct Shear Test Result

The results of direct shear test have analysed in graphs to determine the shear strength parameters of a soil, and it can be obtained in relationship between shear strength (s) versus normal force (σ) behavior for each unit weight of sands (c = 0); in loose sand (γ = 1,35 gr/cm^3), the angle of internal friction (ϕ) was obtained about 30°, in medium sand (γ = 1,45 gr/cm^3), the angle of internal friction (ϕ) was obtained about 37° and in dense sand (γ = 1,55 gr/cm^3), the angle of internal friction (ϕ) was obtained about 42°. This may be exhibited in equation form by Coulomb-Mohr's equation:

$$s = c + \sigma \tan \phi \qquad (1)$$

This relationship as shown in Fig.2

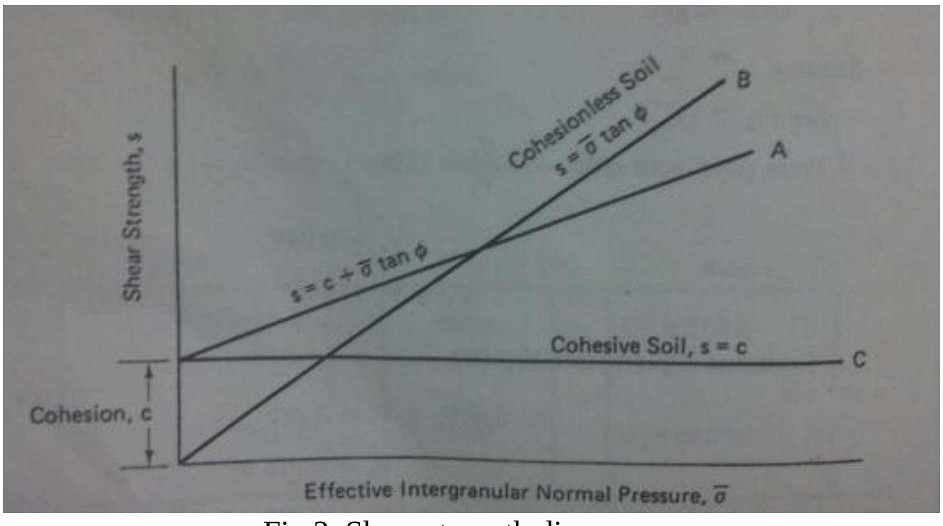

Fig.2. Shear strength diagram

Fall Cone Test Result

The result of the fall cone test have analysed to determinate undrained shear strength (cu) of soft clay ($\phi = 0$). It is obtained fall cone depth (h) and moisture content (w) for each load and penetration test with semi angle β variation as shown in Fig.3.

The undrained shear strength values can be determinate from Hansbo's theory:

$$cu = K\, Q/h^2 \qquad (2)$$

The coefficient of Hansbo(K) was obtained that is

$$K = 2{,}13/\pi\ Nc\ tg^2\alpha \qquad (3)$$

(Koumoto, 1989)

The angle of cone that used; $2\alpha = 60^o$, $\alpha = 30^o$ and Nc = 5,14

The weight of cone (Q) = 67,1gr

The calculation results of cu for each variation of β was described in Table.1

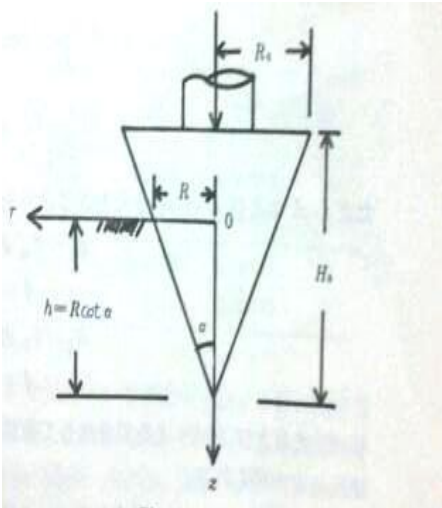

Fig.3. Cross Section Position of Cone TATSUYA KOUMOTO, Dinamic Analysis of the Fall Cone Test

Table 1. The result of undrained shear strength (cu) calculation

CASE	β(°)	h	water content	cu
		(mm)	(%)	(gr/ cm^3)
SMOOTH	15°	17,6	81,17	8,572
	30°	17,8	80,32	8,38
	45°	18,1	80,57	8,105
	60°	17,7	80,9	8,475
	90°	18,2	79,22	8,016
ROUGH	15°	17,8	82,2	8,38
	30°	17,7	80,8	8,475
	45°	17,9	80,03	8,287
	60°	18,2	81,41	8,016
	90°	18,4	80,98	7,842

The Load and Penetration Test Results

Result of model test

The result of cone model test using the load and penetration with modified CBR apparatus, have determined in relationship between penetration resistance (P) and penetration depth (D), in sands (c=0); loose sand, medium sand, dense sand and clays (ϕ=0). Using the general definition of ultimate bearing capacity by qu = P/A (Terzaghi, 1943), then the results of cone bearing capacity with semi angle β; variation 15°, 30°, 45°, 60°, 90° and different roughness; perfectly smooth and perfectly rough can be calculated for each depth of penetration.

Analysis of test result

The result of penetration test data for each unit weight of sand; γ = 1,35 gr/cm^3 for loose sand, γ = 1,45 gr/cm^3 for medium sand and γ = 1,55 gr/cm^3 for dense sand have analysed in model graphs as shown in Fig. 4,5,6, respectively. Similar, test result for cones in clays are expressed in Fig.7. The curves described that the value of penetration resistance (P) have increased with further increasing of penetration depth (D), for each various of semi angle β; 15°, 30°, 45°, 60°, 90° and different roughness; perfectly smooth and perfectly rough in sands (c=0) and clays (ϕ = 0). The curves indicated that the cone penetration resistance of semi angle β = 15°, with perfectly smooth surface in sands, have the smallest value to be compared with the values of the others semi angle β; where β > 15°. Otherwise, in the case of rough cone, the penetration resistance of semi angle β = 15° have the highest value, to be compared with the others of β where β > 15°. Similar, the penetration resistance values in clays for smooth cone, have decreased with decreasing semi angle β. However for β<30°, approximately, the values of penetration resistance increase again. Whereas, for rough cone, the values of penetration resistance increased continuously with decreasing of semi angle β.

Discussion

The theoretical results are presented as bearing capacity factors Ncr, Nqr, Nγr of cone bearing capacity for different angles of internal friction ϕ, various semi angle β, for both smooth and rough surfaces in homogeneous soils; sands (c = 0) and clays (ϕ = 0). The results were analysed according to the general bearing capacity equation to determined the values of cone bearing capacity by used the formula of Terzaghi, Meyerhoff, and Koumoto for shallow and deep foundations, as follows:

- Terzaghi's Formula :
  - $qu = 1{,}3\ c\ Nc + po\ Nq + 0{,}3\ \gamma\ B\ N\gamma$ (3.1a)
  - $qu = po\ Nq + 0{,}3\ \gamma\ B\ N\gamma$; for sand (c=0) (3.1b)
  - $qu = 1{,}3\ c\ Nc + 0{,}3\ \gamma\ B\ N\gamma$; for clay ($\phi$ = 0) (3.1c)
- Meyerhoff's Formula :
  - $qr = c\ Ncr + po\ Nqr + \gamma\ B/2\ N\ \gamma\ r$ (3.1a)
  - $qr = po\ Nqr + \gamma\ B/2\ N\ \gamma\ r$; for sand (c=0) (3.1b)
  - $qr = c\ Ncr + \gamma\ B/2\ N\ \gamma\ r$; for clay ($\phi$ = 0) (3.1c)
- Koumoto's Formula :
  - $qr = po\ Nqr$; for sands (c = 0) (3.1c)
  - $qr = cu\ Ncr$; for clays (ϕ = 0) (3.1c)

The theoretical values of cone bearing capacity are compared with the result of the experiment observations. The comparison results of theoretical and experimental value of cone bearing capacity, are presented in Tables. 2,3,4,5 and then the comparison curves of the theoretical and experimental values of cone bearing capacity in loose sand, medium sand and dense sands are presented in Fig. 8,9,10, respectively. Similar the results in clay as shown in Fig.11

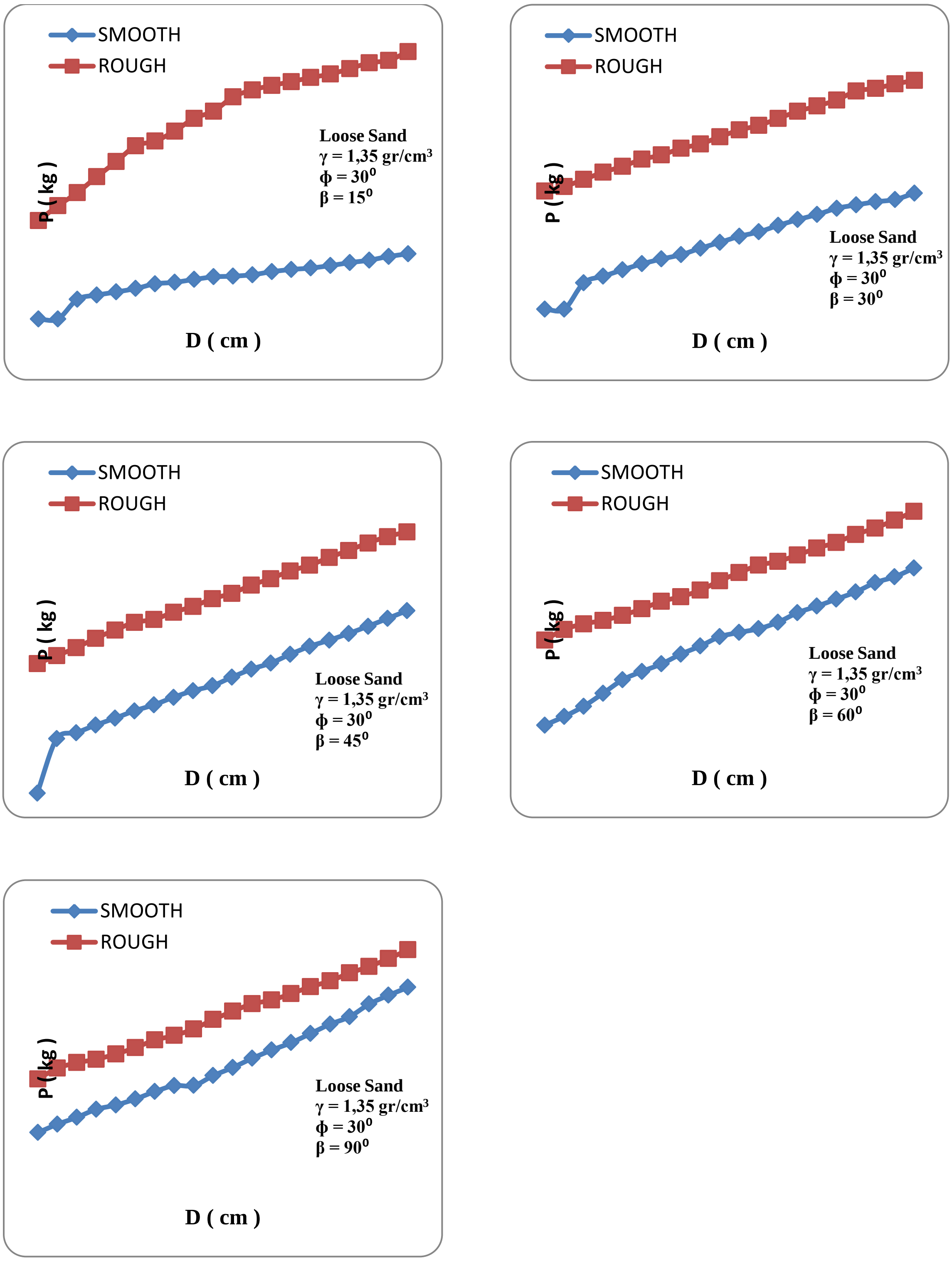

Fig. 4 Load and settlement curves of cone foundations in Loose Sand ($\gamma = 1{,}35$ gr/cm^3)

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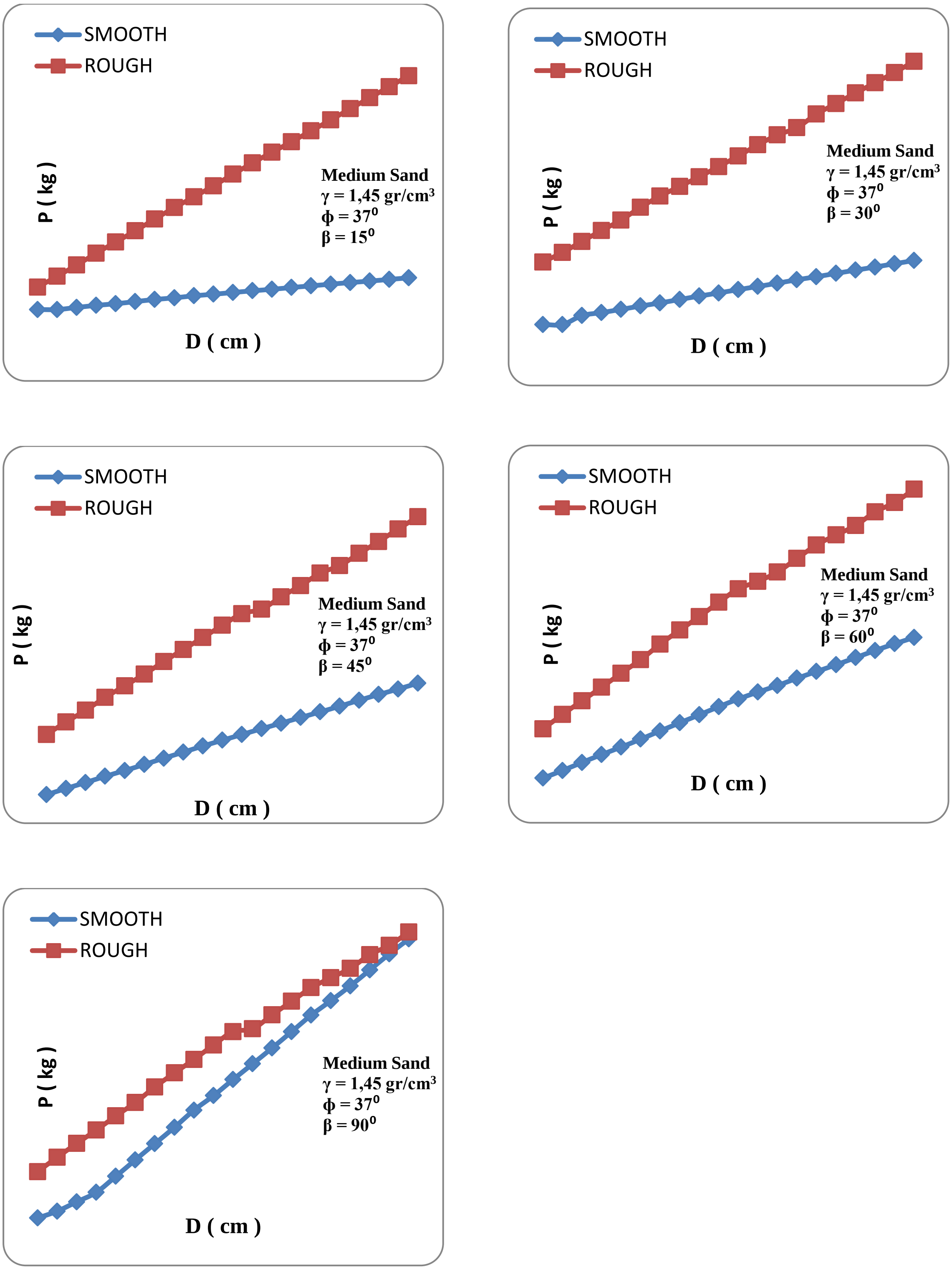

Fig. 5 Load and settlement curves of cone foundations in Medium Sand (γ = 1,45 gr/cm^3)

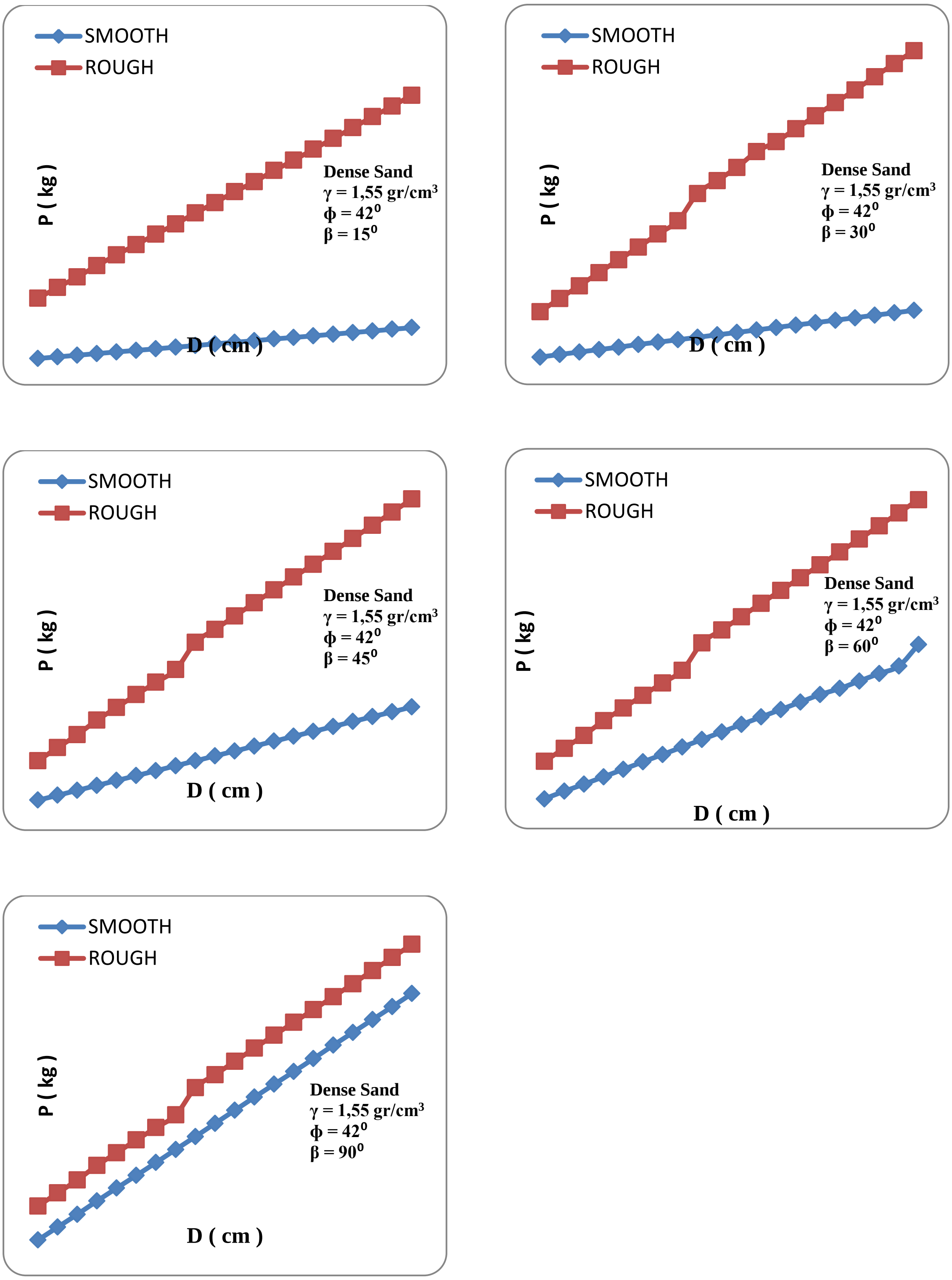

Fig. 6 Load and settlement curves of cone foundations in Dense Sand
(γ = 1,55 gr/cm^3)

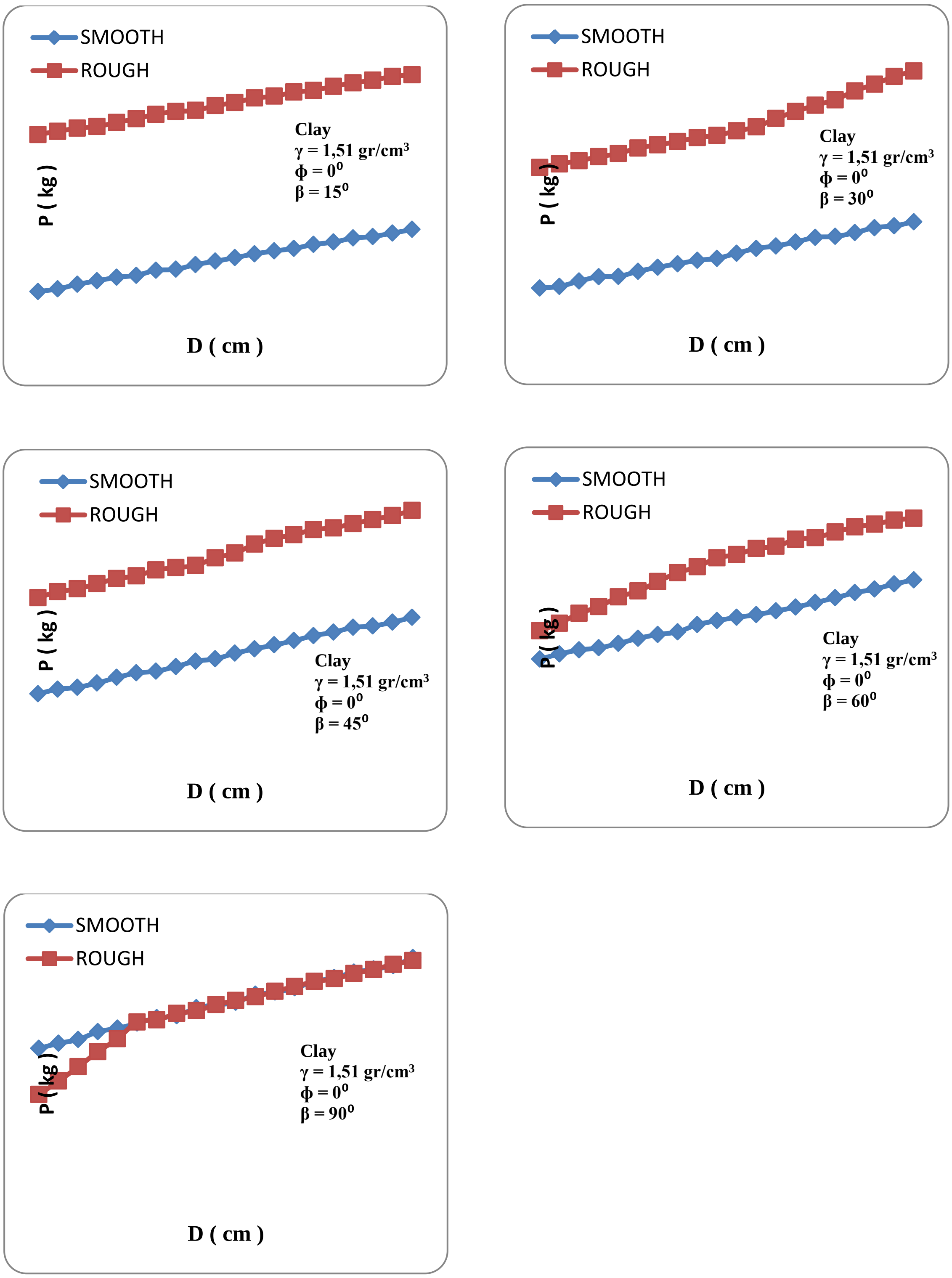

Fig. 7 Load and settlement curves of cone foundations in Clay
($\gamma = 1{,}51$ gr/cm^3)

TABLE.2 THE RESULTS OF CONE BEARING CAPACITY IN LOOSE SAND : qr (gr/ cm^2) ; γ = 1,35 gr/cm^3, ϕ = 30°

CASE	β(°)	THEORY						EXPERIMENT	
		TERZAGHI		MEYERHOF		KOUMOTO		q = P / A	
		D = 1,5 cm	D = 1,75 cm	D = 1,5 cm	D = 1,75 cm	D = 1,5 cm	D = 1,75 cm	D = 1,5 cm	D = 1,75 cm
SMOOTH	15°	-	-	-	-	24,705	28,8225	21,3743	24,6872
	30°	-	-	-	-	26,1225	30,4763	24,7582	27,3745
	45°	-	-	-	-	37,3951	43,6276	38,4315	41,2428
	60°	-	-	-	-	43,0313	50,2031	47,3584	50,2893
	90°	-	-	-	-	59,9400	69,9300	51,7572	54,6632
ROUGH	15°	-	-	217,35	225,45	125,955	146,9475	121,4752	124,7831
	30°	-	-	114,75	121,50	83,633	97,5713	81,7823	84,1143
	45°	-	-	100,2376	107,6626	82,3163	95,5159	79,7534	81,1473
	60°	-	-	95,5125	102,4313	81,00	94,500	71,7431	74,6789
	90°	28,35	31,1513	95,5125	102,4313	78,3675	91,4288	71,7431	74,6789

TABLE 3 RESULTS OF CONE BEARING CAPACITY IN MEDIUM SAND : qr (gr/ cm^2) ; γ = 1,45 gr/cm^3 , ϕ = 37°

CASE	β(°)	THEORY						EXPERIMENT	
		TERZAGHI		MEYERHOF		KOUMOTO		q = P / A	
		D = 1,75 cm	D = 2,25 cm	D = 1,75 cm	D = 2,25 cm	D = 1,75 cm	D = 2,25 cm	D = 1,75 cm	D = 2,25 cm
SMOOTH	15°	-	-	-	-	63,4375	81,5625	54,7831	74,7164
	30°	-	-	-	-	67,2438	86,4563	60,2715	79,3647
	45°	-	-	-	-	109,6200	140,9400	100,8622	131,1246
	60°	-	-	-	-	152,2500	195,7500	146,3813	181,7521
	90°	-	-	-	-	237,0025	304,7175	211,4774	284,1813
ROUGH	15°	-	-	552,8125	607,1875	509,7838	655,4363	491,8864	611,7754
	30°	-	-	365,4000	411,800	356,8740	458,8380	358,9763	412,8652
	45°	-	-	336,4000	382,800	351,4438	451,8563	340,7115	400,3473
	60°	-	-	325,5250	371,9250	346,0135	444,8745	334,7175	394,4131
	90°	242,7518	278,5523	325,5250	371,9250	335,1530	430,9110	334,7175	394,4131

TABLE 4 RESULTS OF CONE BEARING CAPACITY IN DENSE SAND : qr (gr/ cm^2) ; γ = 1,55 gr/cm^3 , ϕ = 42°

CASE	β(°)	THEORY						EXPERIMENT	
		TERZAGHI		MEYERHOF		KOUMOTO		q = P / A	
		D = 1,00 cm	D = 1,25 cm	D = 1,0 cm	D = 1,25 cm	D = 1,0 cm	D = 1,25 cm	D = 1,0 cm	D = 1,25 cm
SMOOTH	15°	-	-	-	-	65,5650	81,9563	60,4784	75,6743
	30°	-	-	-	-	74,6790	93,3488	69,4813	86,1873
	45°	-	-	-	-	145,8550	182,3188	138,7147	172,8183
	60°	-	-	-	-	217,000	271,2500	203,1764	254,7631
	90°	-	-	-	-	359,3520	449,1900	345,1843	434,7813
ROUGH	15°	-	-	1085,00	117,8750	863,660	1079,575	873,6187	974,1831
	30°	-	-	697,500	775,00	546,3440	682,930	603,8747	691,7862
	45°	-	-	689,750	767,250	543,1510	678,9388	591,7482	679,7184
	60°	-	-	689,750	767,250	539,958	674,9475	591,7482	679,7184
	90°	599,7880	645,5518	689,750	767,250	533,1572	666,9650	591,7482	679,7184

TABLE 5 RESULTS OF CONE BEARING CAPACITY IN CLAY : qr (gr/ cm^2) ; γ = 1,51 gr/cm^3 , ϕ = 0°

CASE	β(°)	Cu	THEORY						EXPERIMENT	
			TERZAGHI		MEYERHOF		KOUMOTO		q = P / A	
		(gr/ cm^2)	D = 1,5 cm	D = 2,0 cm	D = 1,5 cm	D = 2,0 cm	D = 1,5 cm	D = 2,00 cm	D = 1,5 cm	D = 2,00 cm
SMOOTH	15°	8,572	-	-	41,6962	42,4512	25,7523	26,5073	26,3435	28,1842
	30°	8,38	-	-	37,88	38,635	21,4887	27,6572	24,5277	26,5944
	45°	8,105	-	-	42,788	45,808	31,8468	32,6018	32,7133	34,2783
	60°	8,475	-	-	47,1825	47,9375	40,1483	40,9033	40,5224	42,1164
	90°	8,016	-	-	49,1586	49,1586	47,876	48,631	48,6441	50,2315
ROUGH	15°	8,38	-	-	77,685	77,685	80,199	80,954	74,6143	76,8177
	30°	8,475	-	-	60,3188	60,3188	60,5055	67,2605	58,7611	60,5232
	45°	8,287	-	-	53,23	53,23	58,6166	59,3716	56,5494	58,5534
	60°	8,016	-	-	51,5634	52,3184	53,4071	54,1621	52,1581	56,6871
	90°	7,842	55,9043	56,6593	50,4933	51,2483	49,7091	50,4641	48,9224	54,7371

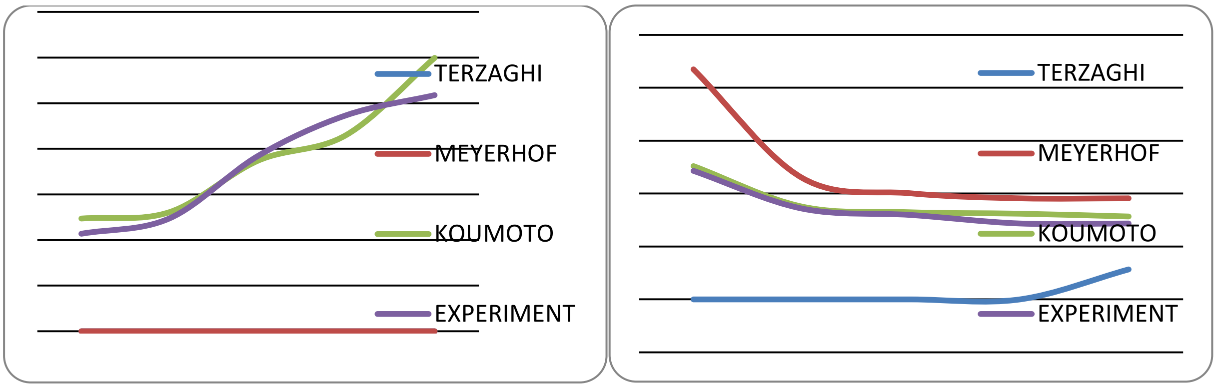

Fig.8 Comparison curve of theoretical and experimental values of cone bearing capacity in loose sands. (γ = 1,35 gr/cm^3, ϕ = 30^o)

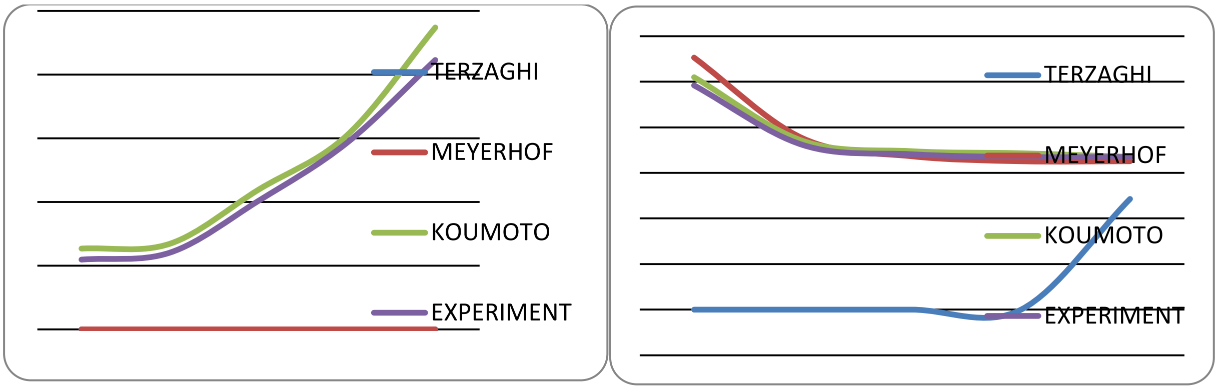

Fig.9 Comparison curve of theoretical and experimental values of cone bearing capacity in medium sands. (γ = 1,45 gr/cm^3 , ϕ = 37^o)

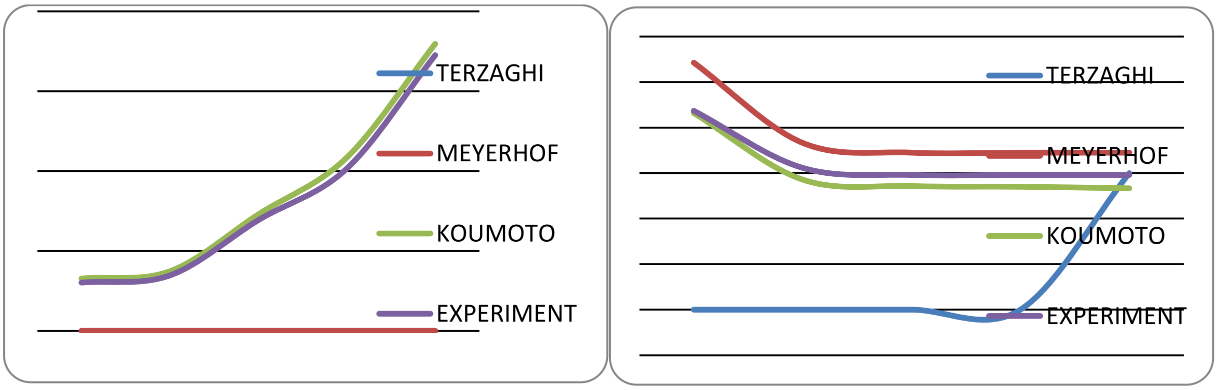

Fig.10 Comparison curve of theoretical and experimental values of cone bearing capacity in dense sands. (γ = 1,55 gr/cm^3 , ϕ = 42^o)

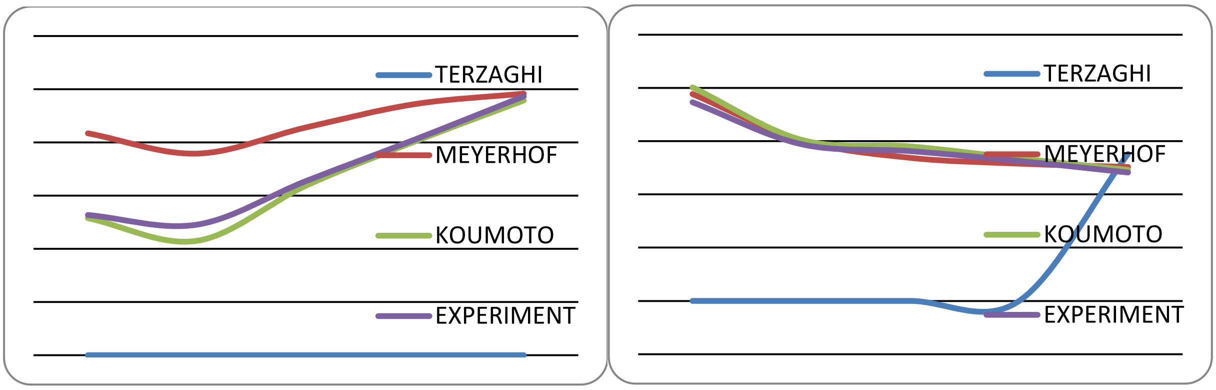

Fig.11 Comparison curve of theoretical and experimental values of cone bearing capacity in clay. (γ = 1,51 gr/cm^3 , ϕ = 0^o)

CONCLUSION

The analysis results of a theoretical and experimental study, on the problem of cone bearing capacity, which have been described in tables and curves, and after evaluated, the following conclusions are obtained:

1. The values of penetration results (P) or cone bearing capacity (qr) have increased with further increasing of each penetration depth (D), with various of semi angle β; 15°, 30°, 45°, 60°, 90° and different roughness; perfectly smooth and perfectly rough, in sands (c = 0) and clays (ϕ = 0).
2. The comparison of experimental cone bearing capacity test result with the theoretical calculation, have a good agreement.
3. The fall cone test result indicated that moisture content (w) of a soft clay have affected the values of undrained shear strength (cu).
4. The surface roughness and the semi angle β variation of cone foundations have affected the values of cone penetration resistance (P) or cone bearing capacity of foundation, as follows :
   - The cone bearing capacity have more higher values in rough case, to compared with smooth case, in sands (c = 0) and clays (ϕ = 0).
   - In sands; loose, medium, dense; for perfectly smooth surface, the smaller the angle of β, then the smaller too the values of cone bearing capacity. In this case, β = 15° has the smallest value, if it's compared with the others values of semi angle β; where β > 15°.
   - In sands, for perfectly rough surface, in the case of loose sand and medium sand; the greater the angle of β, the smaller the values of cone bearing capacity where 15° ≤ β ≤ 60°. The values of qr are sensibly unaffected by semi angle, where 60° < β ≤ 90°. In the case of dense sand; the greater the angle of β, the smaller the values of cone bearing capacity where 15° ≤ β ≤ 45°. The values of qr are sensibly unaffected by semi angle β, where 45° < β ≤ 90°.
   - In clays; for perfectly smooth surface; the values of cone bearing capacity decrease with decreasing semi angle β, where 30° ≤ β ≤ 90°. However for β < 30° approximately, the values of qr increase again, where 15° ≤ β < 30°.
   - In clays; for perfectly rough surface; the smaller the angle of β, then the greater the values of cone bearing capacity, in this case, β = 15° has the greatest value, if it's compared with the others values of semi angle β; where β > 15°.

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