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DESIGN OF CSG PILES

1 BACKGROUND

Continuously shaft grouted impact driven, so called CSG piles, Fig. 1, have:

- steel core diameter 60,3…139,7 mm
- steel core made of RR pile (steel pipe pile)
- shaft made of grout or mortar
- shaft grouted continuously and simultaneously during embedding
- grouting to the void made by the collar which is located quite close to the pile tip
- embedding methods impact driving or jacking.

CSG piles have been used for foundations of new structures and underpinning of existing structures. Potential applications could be tension piles, soil nailing and other applications there micropile techniques are appropriate.

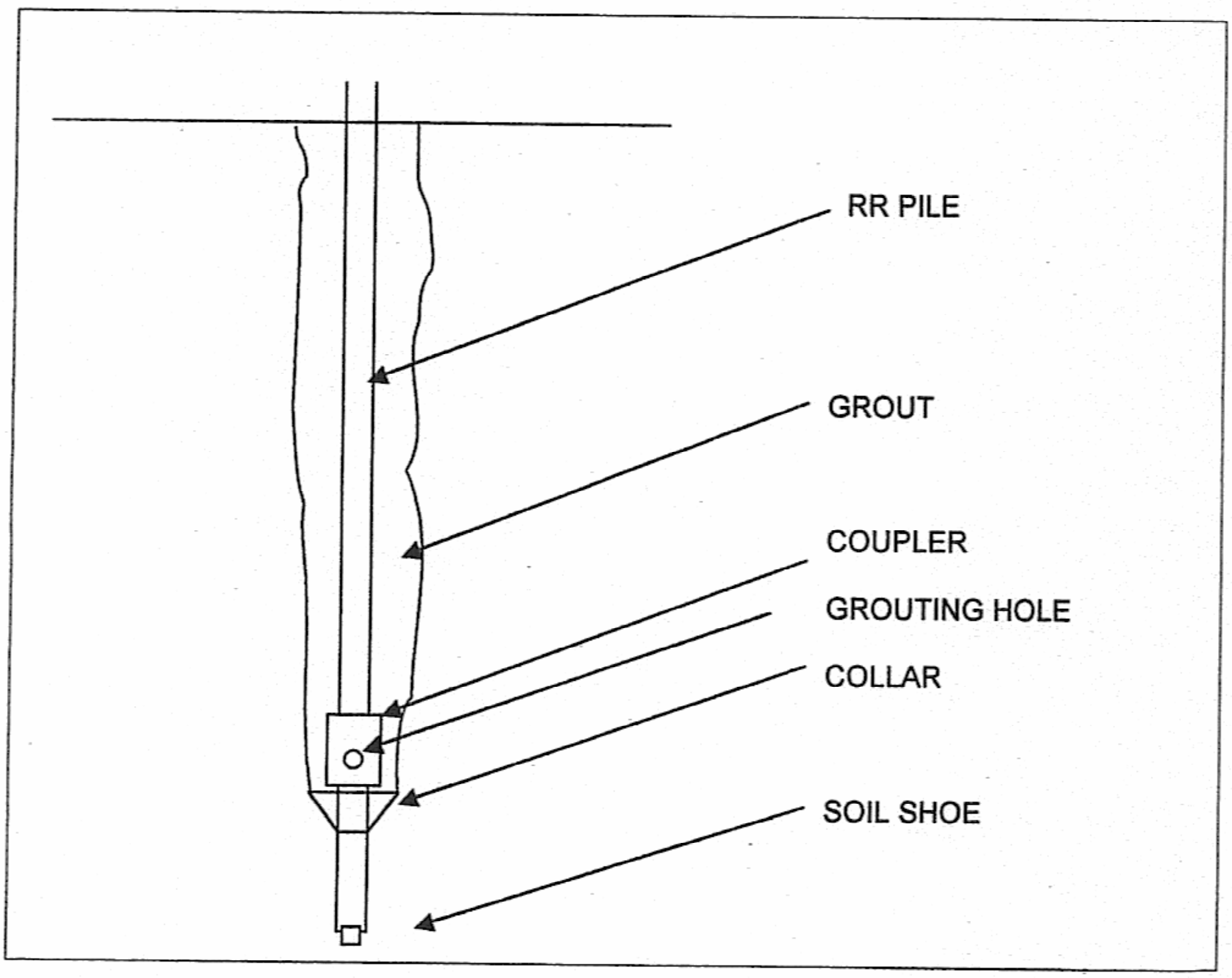

Figure 1. Structure of a CSG pile.

2 LOAD BEARING CAPACITY OF CSG PILES

Bearing capacity of CSG piles can be predicted according to Formula (1)

$$R = R_s + R_b \tag{1}$$

where R is total resistance of a pile
R_s shaft resistance
R_b base resistance

2.1 Prediction of shaft resistance

Shaft resistance of CSG piles can be predicted using values of soil parameters or results of in-situ tests.

2.2 Working diameter of CSG piles

Working diameter of CSG piles for predictions of shaft resistance may be increased due to pressure grouting during embedding, Formula (2):

$$D = a\, D_0 \tag{2}$$

where D is effective diameter
a correction factor
D_0 diameter of the collar of the CSG pile.

A proposal for the effective diameter of CSG piles is shown in Table 1.

Table 1. A proposal for correction factor *a* in Formula (2).

Soil type	a
Moraine	1,3...1,5
Gravel	1,3...1,5
Sand	1,1...1,3
Silt	1,1...1,2
Clay	1,0

2.3 Friction angle

Shaft resistance of CSG piles in non-cohesive soils can be calculated using Formula (3):

$$R_s = q_s\ A_s = K \tan\varphi\, \sigma'_v\, A_s = \beta\, \sigma'_v\, A_s \tag{3}$$

where R_s is shaft resistance
q_s unit shaft resistance (kN/m^2)
A_s shaft area (m^2)
K earth pressure coefficient
φ friction angle after installation
σ'_v vertical effective stress
β proportionality coefficient.

The proportionality coefficient β can be obtained using chart of Fig. 2. Dimensioning value for friction angle can be improved 3° to 5° compared with initial angle before lateral compaction due to installation of the pile.

Unit shaft resistance q_s should be limited up to value 250 kN/m². Bigger values can be used only based on full scale load tests on site.

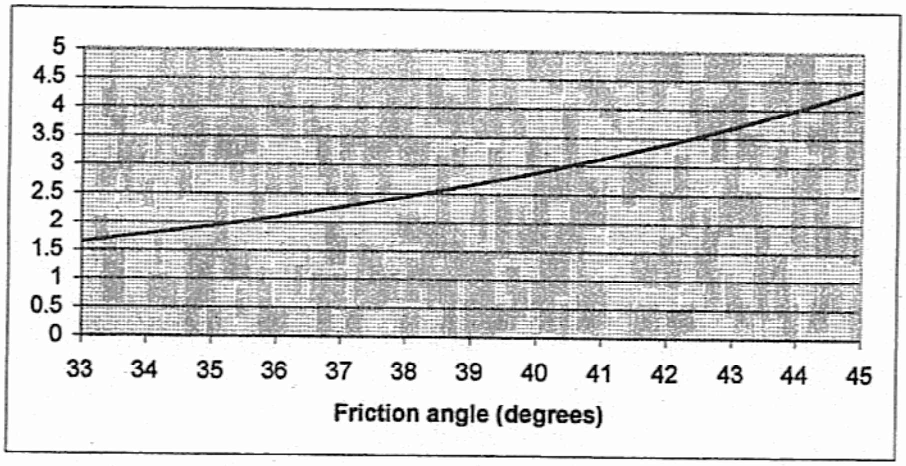

Figure 2. The proportionality coefficient β in Formula 3.

2.4 Prediction on in-situ tests

Prediction of unit shaft resistance q_s (kN/m²) can be made using Table 2.

Table 2. Prediction of unit shaft resistance of CSG piles based on in-situ tests.

Relative density	Friction angle (°)	Dynamic probing N_{20} (blows/ 0,2 m)	Standard penetration test SPT N_{30} (blows/ 0,3 m)	Cone penetration test CPT (MPa)	Pressure-meter test p_l (MPa)	Weight sounding N_{HT} (half turns/ 0,2 m)	Unit shaft resistance (kN/m²)
Loose	33	5	5	2	0,3	10	20
	34	10	10	4	0,5	30	40
Medium dense	35	12	20	8	1	40	80
	36	15	25	10	1,3	45	100
Dense	37	20	30	12	1,5	50	120
	39	30	45	18	2,2	80	180
Very dense	41	35	50	20	2,5	90	200
	43	50	80	25	3	110	250

2.5 Prediction of base resistance

Base resistance of CSG piles can be predicted using formula (4)

$$R_b = q_b A_b \tag{4}$$

where q_b is unit base resistance (kN/m2)
A_b base area (m2) including area of collar.

Prediction of unit base resistance q_b can be made using Table 3.

Table 3. Prediction of unit base resistance of CSG piles based on in-situ tests.

Relative density	Friction angle (°)	Dynamic probing N_{20} (blows/ 0,2 m)	Standard penetration test SPT N_{30} (blows/ 0,3 m)	Cone penetration test CPT (MPa)	Pressure-meter test p_l (MPa)	Weight sounding N_{HT} (half turns/ 0,2 m)	Unit base resistance (kN/m^2)
Loose	33	5	5	2	0,3	10	2000
	34	10	10	4	0.5	30	3000
Medium dense	35	12	20	8	1	40	4000
	36	15	25	10	1,3	45	5000
Dense	37	20	30	12	1,5	50	6000
	39	30	45	18	2,2	80	8000
Very dense	41	35	50	20	2,5	90	10000
	43	50	80	25	3	110	12000

2.6 Structural capacity

The axial plastic resistance to compression, N_{uc}, of a composite cross section can be written by formula

$$N_{uc} = A_c f_{cd} + A_s f_{yd} \tag{5}$$

where A_c, A_s cross-sectional areas of concrete and steel
f_{cd}, f_{yd} design strengths of materials.

For tension piles, corresponding formula for capacity is

$$N_{ut} = A_s f_{yd} \tag{6}$$

where influence of couplers to tension performance should be considered. Respectively the grout/steel interface should be considered. Typical design bond values for composite steel pipe piles have been $\leq$ 0,4 MPa. Concrete can not be considered outside of steel pipe when calculating structural capacity as a composite structure.