STATENS GEOTEKNISKA INSTITUT

SWEDISH GEOTECHNICAL INSTITUTE

No. 29

SÄRTRYCK OCH PRELIMINÄRA RAPPORTER

REPRINTS AND PRELIMINARY REPORTS

Supplement to the "Proceedings" and "Meddelanden" of the Institute

Classification of Soils with Reference to Compaction

by Bengt Broms & Lars Forssblad

STOCKHOLM 1968

STATENS GEOTEKNISKA INSTITUT

SWEDISH GEOTECHNICAL INSTITUTE

No. 29

SÄRTRYCK OCH PRELIMINÄRA RAPPORTER

REPRINTS AND PRELIMINARY REPORTS

Supplement to the ''Proceedings'' and ''Meddelanden'' of the Institute

Classification of Soils with Reference to Compaction

by Bengt Broms & Lars Forssblad

STOCKHOLM 1968

CLASSIFICATION OF SOILS WITH REFERENCE TO COMPACTION

Bengt Broms, Swedish Geotechnical Institute, Stockholm
Lars Forssblad, AB Vibro-Verken, Solna

Introduction

The technique of soil compaction has been discussed in numerous articles. However, only very general recommendations regarding the choice of the most efficient and economical compaction equipment for different soil conditions are usually given in these articles. It is therefore often difficult to decide which type of compaction equipment should be used for different soils on the bases of routine soil investigations and from presently available soil classification systems. The usual classification systems for fine grained soils which are based on the liquid and plastic limits can frequently not be directly related to the compaction properties. Due to these difficulties an attempt has been made to develop a soil classification system with respect to the compaction properties of different types of soils. Such a classification system is proposed and discussed in this article.

Proposed classification system

The proposed classification system consists of the following four principal groups:

I. Rock fill and granular soils with large stones and boulders[a)]
(Less than 5 to 10 % of material smaller than 0.06 mm[b), c)])

II. Sand and gravel
(Less than 5 to 10 % of material smaller than 0.06 mm[b), c)])

A. Well graded sand and gravel
(Coefficient of uniformity larger than 4)

B. Uniformly graded sand and gravel
(Coefficient of uniformity less than 4)

---

a) Largest dimension exceeding 200 mm (8 in).

b) Percentage of fines determined on the fraction with a maximum grain size of 19 mm (3/4 in).

c) The size 0.06 mm represents in most classification systems the boundary between sand and silt. The size 0.074 mm (sieve No. 200) is, however, often used in practice instead of 0.06 mm.

d) Clays can generally be separated from silts by shaking tests and plasticity tests.

III. Silt, silty soils, clayey sand and clayey gravel
(More than 5 to 10 % of material ~~larger~~ smaller than 0.06 mm[b), c)])

A. Silty sand and silty gravel

B. Silt and sandy silt, clayey sand and clayey gravel.

IV. Clay[d), 1)]

A. Clay with low or medium strength
(Unconfined compressive strength less than 20 t/m^2 (2.0 tons/sq ft) or undrained shear strength less than 10 t/m^2 (1.0 tons/sq ft)).

B. Clay with high strength
(Unconfined compressive strength larger than 20 t/m^2 (2.0 tons/sq ft) or undrained shear strength larger than 10 t/m^2 (1.0 tons/sq ft)).

<u>Comments and discussion</u>

The classification of soils according to the proposed system should be relatively simple. It is necessary to determine the grain size distribution curves of the soils belonging to Groups I, II and III. For soils in Group IV the unconfined compressive strength or undrained shear strength has to be estimated or measured. The strength should be determined at the water content which will be used during the compaction by unconfined compression, vane, penetrometer or fall-cone tests.

Groups I and II are non-cohesive soils with high permeability. Thus excess water can be forced out of these soils during the compaction, and the surface of the compacted fill will not be soft, even if the soil is compacted at high water content. Soils belonging to Groups I and II have a high bearing capacity when compacted and they are not susceptible to frost action.

---

1) Peck, R. B., Hanson, W. E. and Thornburn, T. H., "Foundation Engineering", John Wiley & Sons, New York, 1952, p. 12.

The best compaction is obtained when the materials are saturated or watered. The Proctor curve is often relatively flat, and in such a case a satisfactory compaction can be obtained also at water contents lower than the optimum. Good compaction can in many cases be obtained when the soils are completely dry.

A small amount of fines (silt and clay size materials) can be accepted in the soils belonging to Group I and II. Experience from the Scandinavian countries indicates that up to 10 % of fines smaller than 0.06 mm generally can be accepted. The maximum percentage of fines varies, however, depending on the particle size and other properties of the material smaller than 0.06 mm, and a maximum percentage of fines of 5 to 10 % is therefore indicated in the proposed classification system[2)].

Groups III and IV are generally well graded soils with a high content of fines. The degree of compaction which can be reached for these soils is dependent of the water content. If a high degree of compaction is required, the water content should not differ considerably from the optimum water content. The water content is also of great importance with respect to the strength and compaction properties of the soils.

Sand and gravel and other coarse grained soils can as a rule be efficiently compacted by vibration. To compact fine grained, cohesive soils compaction machines with high contact pressures are required to overcome the shear resistance of the soil. The pressures may be applied statically or dynamically. The contact pressure must be at least five to six times the undrained shear strength of the compacted soil. Rubber-tired rollers give a maximum surface pressure of about 6 - 8 kp/cm^2 (90 - 120 psi). At this contact pressure it is possible to compact cohesive soils with a maximum undrained shear strength of about 10 - 15 t/m^2 (1.0 - 1.5 tons/sq ft). This shear strength corresponds to an unconfined compressive strength of about 20 - 30 t/m^2 (2.0 - 3.0 tons/sq ft), and it is possible to indent a soil with this shear strength with the thumb.

---

2) See also "Earth Manual", Bureau of Reclamation, Denver, Colorado, 1963, p. 208.

When the unconfined compressive strength exceeds 20 t/m^2 (2.0 tons/sq ft) sheepsfoot rollers or other compaction machines with higher contact pressure than rubber-tired rollers usually will be required.

The proposed classification system does not include organic soils which are usually not used in compacted fills.

Group I. Rock fill and granular soils with large stones and boulders

Rock fill and other materials containing large stones must be compacted in thick layers. The maximum diameter of the stones should be less than 1/2 or 2/3 of the layer thickness. Heavy vibrating rollers with 10 to 15 tons weight give a sufficient compaction effect to compact efficiently rock fill in layers with a thickness up to 1 - 2 m (40 - 80 in).

The placement and compaction of rock fill and other coarse material in 0.5 - 2 m (20 - 80 in) layers with a bulldozer generally results in a fill with a comparatively high relative density. Settlements in a rock fill or a coarse granular fill which is placed and compacted in suitable lifts by a crawler tractor are generally small, especially in the case when the fill is sluiced or saturated.

Group II. Sand and gravel

Vibrating rollers and vibrating plate compactors are effective and economical in soils belonging to Group II. Layers with a thickness up to 0.5 - 1.5 m (20 - 60 in) can be efficiently compacted by vibrating rollers and vibrating plate compactors of medium and heavy size. Light vibrating rollers and vibrating plate compactors can also be used if the layer thickness is small.

Type II soils can also be efficiently compacted when saturated with vibrators which are inserted into the soil.

Also static smooth-wheel rollers, rubber-tired rollers, pad-type rollers, grid rollers and crawler tractors are used to compact sand and gravel, but the layer thickness should be smaller than for medium and heavy size vibratory compactors.

Very often self-propelled rollers do not have sufficient traction on uniformly graded sand and gravel. This must be considered when suitable compaction equipment is selected.

Group III. Silt, silty soils, clayey sand and clayey gravel

Group III soils are as a rule compacted efficiently by heavy rubber-tired rollers. Also heavy rubber-tired tractors can be used. Vibrating smooth-wheel rollers are also effective, especially on soils of type silty sand and silty gravel (Group III A). Moraines often belong to Group III A. However, the layer thickness must be lower than for the soils of groups I and II. Static and vibrating pad-type rollers and grid-rollers are other alternatives.

The types of machines which are suitable for soils in group III can as a rule also be used to compact soils stabilized with cement, lime and bituminous products.

Group IV. Clay

The results of the compaction of clay are to a very high degree dependent of the shear strength of the soil and thus of the water content. Clay of low or medium strength can usually be compacted efficiently by rubber-tired rollers or by static smooth-wheel, grid- or pad-type rollers. Also sheepsfoot rollers are used since it is possible with this type of equipment to dry the surface layer of the soil.

Since the strength of the soil varies considerably with the water content, the weight of the rollers is of great importance. Thus the ballast and tyre pressure of rubber-tired rollers have to be adjusted to fit the water content and strength of the soil.

At a high water content and very low strength the bearing capacity will be too small for most types of compaction machines. In such cases crawler tractors are often used for compaction. With a high water content, however, the density of the fill will be low, why such materials are used in fills only in special cases.

When clay and clayey soils with a high strength - unconfined compressive strength larger than 20 t/m^2 (2.0 tons/sq ft) - are compacted it is necessary to use sheepsfoot rollers or other compaction machines with high contact pressures. Heavy pad-type rollers or heavy vibrating rollers can also be used.

To compact weathered rock, heavy static or vibrating sheepsfoot rollers are efficient.

Small compactors

Vibrating plate compactors, vibrating tampers and rammers are used for small jobs and as a complement to large compaction machines. Vibrating plate compactors are most suitable in soils in Group II and III. Vibrating tampers and rammers produce higher contact pressures and are efficient on soils belonging to Groups II, III and IV.

Summary and Conclusions

A system for classification of soils with reference to compaction is proposed in this article. The proposed system consists of four principle soil groups. The principle groups are divided in subgroups. Within each soil group it is expected that the degree of compaction which can be reached for a given compaction machine will be approximately the same.

The types of compaction equipment which are suitable for the compaction of soils belonging to the proposed soil groups as proposed in this article are summarized in Table 1.

The proposed classification system is tentative and it is expected that changes will be required as further experience is gained with the system. It is possible that additional groups will be required but it is desirable to keep the number of principle groups as low as possible in order to make the classification system simple and easy to use.

ole type of compaction equipment for different groups of soils

ction equipment	I. Rock fill	II. Sand and gravel		III. Silt, silty soils, clayey sand and clayey gravel		IV.
		A. Well-graded	B. Uni-formly graded a)	A. Silty sand, silty gravel	B. Silt, sandy silt, clayey sand, clayey gravel	A. Low or mediu[m] strengt[h] b)
vheel rollers[1], 3-15 tons	-	x	x	x	x	x
h-wheel rollers[2], 3-5 tons	x	x̲	x̲	x	x	x
h-wheel rollers[2], 10-15 tons	x̲	x̲	x̲	x̲	x	-
compactors, 0.1-0.5 tons	-	x̲	x̲	x	x	-
rs, rammers, 0.05-0.1 tons	-	x	x	x	x	x
llers[2], 10-50 tons	-	x	x	x̲	x̲	x̲
rs[2) 3)], 5-30 tons	-	-	-	-	x	x
s[2) 3)], 5-30 tons	-	x	x	x̲	x̲	x̲
rs[2], 5-15 tons	x	x	x	x	x	x
s, 10-30 tons	x	x	x	x[c)]	x[c)]	x[c)]

d

vn or self-propelled

ating

often be used

ommended

a) Self-propelled rollers often do not have sufficient traction on uniformly graded sand and gravel.

b) Crawler tractors are often used at high water contents and ve low strength.

c) Compacted at higher water content than the optimum water co determined by Proctor compaction tests.

STATENS GEOTEKNISKA INSTITUT
Swedish Geotechnical Institute

SÄRTRYCK OCH PRELIMINÄRA RAPPORTER
Reprints and preliminary reports

No.			Pris kr. (Sw. crs.)
1.	Views on the Stability of Clay Slopes. *J. Osterman*	1960	Out of print
2.	Aspects on Some Problems of Geotechnical Chemistry. *R. Söderblom*	1960	»
3.	Contributions to the Fifth International Conference on Soil Mechanics and Foundation Engineering, Paris 1961. Part I.	1961	»
	1. Research on the Texture of Granular Masses. *T. Kallstenius & W. Bergau*		
	2. Relationship between Apparent Angle of Friction — with Effective Stresses as Parameters — in Drained and in Consolidated-Undrained Triaxial Tests on Saturated Clay. Normally-Consolidated Clay. *S. Odenstad*		
	3. Development of two Modern Continuous Sounding Methods. *T. Kallstenius*		
	4. In Situ Determination of Horizontal Ground Movements. *T. Kallstenius & W. Bergau*		
4.	Contributions to the Fifth International Conference on Soil Mechanics and Foundation Engineering, Paris 1961. Part II.	1961	5:—
	Suggested Improvements in the Liquid Limit Test, with Reference to Flow Properties of Remoulded Clays. *R. Karlsson*		
5.	On Cohesive Soils and Their Flow Properties. *R. Karlsson*	1963	10:—
6.	Erosion Problems from Different Aspects.	1964	10:—
	1. Unorthodox Thoughts about Filter Criteria. *W. Kjellman*		
	2. Filters as Protection against Erosion. *P. A. Hedar*		
	3. Stability of Armour Layer of Uniform Stones in Running Water. *S. Andersson*		
	4. Some Laboratory Experiments on the Dispersion and Erosion of Clay Materials. *R. Söderblom*		
7.	Settlement Studies of Clay.	1964	10:—
	1. Influence of Lateral Movement in Clay Upon Settlements in Some Test Areas. *J. Osterman & G. Lindskog*		
	2. Consolidation Tests on Clay Subjected to Freezing and Thawing. *J. G. Stuart*		
8.	Studies on the Properties and Formation of Quick Clays. *J. Osterman*	1965	5:—
9.	Beräkning av pålar vid olika belastningsförhållanden. *B. Broms*	1965	30:—
	1. Beräkningsmetoder för sidobelastade pålar.		
	2. Brottlast för snett belastade pålar.		
	3. Beräkning av vertikala pålars bärförmåga.		
10.	Triaxial Tests on Thin-Walled Tubular Samples.	1965	5:—
	1. Effects of Rotation of the Principal Stress Axes and of the Intermediate Principal Stress on the Shear Strength. *B. Broms & A. O. Casbarian*		
	2. Analysis of the Triaxial Test—Cohesionless Soils. *B. Broms & A. K. Jamal*		
11.	Något om svensk geoteknisk forskning. *B. Broms*	1966	5:—
12.	Bärförmåga hos pålar slagna mot släntberg. *B. Broms*	1966	15:—
13.	Förankring av ledningar i jord. *B. Broms & O. Orrje*	1966	5:—
14.	Ultrasonic Dispersion of Clay Suspensions. *R. Pusch*	1966	5:—
15.	Investigation of Clay Microstructure by Using Ultra-Thin Sections. *R. Pusch*	1966	10:—
16.	Stability of Clay at Vertical Openings. *B. Broms & H. Bennermark*	1967	10:—

No.			Pris kr. (Sw. crs.)
17.	Om pålslagning och pålbärighet.	1967	5:—
	1. Dragsprickor i armerade betongpålar. *S. Sahlin*		
	2. Sprickbildning och utmattning vid slagning av armerade modellpålar av betong. *B-G. Hellers*		
	3. Bärighet hos släntberg vid statisk belastning av bergspets. Resultat av modellförsök. *S-E. Rehnman*		
	4. Negativ mantelfriktion. *B. H. Fellenius*		
	5. Grundläggning på korta pålar. Redogörelse för en försöksserie på NABO-pålar. *G. Fjelkner*		
	6. Krokiga pålars bärförmåga. *B. Broms*		
18.	Pålgruppers bärförmåga. *B. Broms*	1967	10:—
19.	Om stoppslagning av stödpålar. *L. Hellman*	1967	5:—
20.	Contributions to the First Congress of the International Society of Rock Mechanics, Lisbon 1966.	1967	5:—
	1. A Note on Strength Properties of Rock. *B. Broms*		
	2. Tensile Strength of Rock Materials. *B. Broms*		
21.	Recent Quick-Clay Studies.	1967	10:—
	1. Recent Quick-Clay Studies, an Introduction. *R. Pusch*		
	2. Chemical Aspects of Quick-Clay Formation. *R. Söderblom*		
	3. Quick-Clay Microstructure. *R. Pusch*		
22.	Jordtryck vid friktionsmaterial.	1967	30:—
	1. Resultat från mätning av jordtryck mot brolandfäste. *B. Broms & I. Ingelson*		
	2. Jordtryck mot oeftergivliga konstruktioner. *B. Broms*		
	3. Metod för beräkning av sambandet mellan jordtryck och deformation hos främst stödmurar och förankringsplattor i friktionsmaterial. *B. Broms*		
	4. Beräkning av stolpfundament. *B. Broms*		
23.	Contributions to the Geotechnical Conference on Shear Strength Properties of Natural Soils and Rocks, Oslo 1967.	1968	10:—
	1. Effective Angle of Friction for a Normally Consolidated Clay. *R. Brink*		
	2. Shear Strength Parameters and Microstructure Characteristics of a Quick Clay of Extremely High Water Content. *R. Karlsson & R. Pusch*		
	3. Ratio c/p' in Relation to Liquid Limit and Plasticity Index, with Special Reference to Swedish Clays. *R. Karlsson & L. Viberg*		
24.	A Technique for Investigation of Clay Microstructure. *R. Pusch*	1968	22:—
25.	A New Settlement Gauge, Pile Driving Effects and Pile Resistance Measurements.	1968	10:—
	1. New Method of Measuring in-situ Settlements *U. Bergdahl & B. Broms*		
	2. Effects of Pile Driving on Soil Properties. *O. Orrje & B. Broms*		
	3. End Bearing and Skin Friction Resistance of Piles. *B. Broms & L. Hellman*		
26.	Sättningar vid vägbyggnad	1968	20:—
	Föredrag vid Nordiska Vägtekniska Förbundets konferens i Voksenåsen, Oslo 25—26 mars 1968		
	1. Geotekniska undersökningar vid bedömning av sättningar. *B. Broms*		
	2. Teknisk-ekonomisk översikt över anläggningsmetoder för reducering av sättningar i vägar. *A. Ekström*		
	3. Sättning av verkstadsbyggnad i Stenungsund uppförd på normalkonsoliderad lera. *B. Broms & O. Orrje*		
27.	Bärförmåga hos släntberg vid statisk belastning av bergspets. Resultat från modellförsök. *S-E. Rehnman*	1968	15:—

No.			Pris kr. (Sw. crs.)
28.	Bidrag till Nordiska Geoteknikermötet i Göteborg den 5—7 september 1968. 1. Nordiskt geotekniskt samarbete och nordiska geoteknikermöten. *N. Flodin* 2. Några resultat av belastningsförsök på lerterräng speciellt med avseende på sekundär konsolidering. *G. Lindskog* 3. Sättningar vid grundläggning med plattor på moränlera i Lund. *S. Hansbo, H. Bennermark & U. Kihlblom* 4. Stabilitetsförbättrande spontkonstruktion för bankfyllningar. *O. Wager* 5. Grundvattenproblem i Stockholms city. *G. Lindskog & U. Bergdahl* 6. Aktuell svensk geoteknisk forskning. *B. Broms*	1968	15:—
29.	Classification of Soils with Reference to Compaction. *B. Broms & L. Forssblad*	1968	5:—