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USE OF ARID SOILS AS FILL IN EMBANKMENT

1 Advantages of, and basis for dry compaction

In some dry and arid climates, adding water to achieve the moisture content qualifying the material as "dry" by GTR[1] for compaction purposes (q4 compaction[2]) may be relatively expensive (involving drilling, pumping, haulage, spreading, perhaps blending, site organisation) and in some cases consume large amounts of a rare resource. Experimental research conducted in the early eighties through controlled trials at CER Rouen and construction sites in Algeria and Niger led to recommendations for compacting soils with near-zero moisture content[3].

2 Definition of arid soils – application scope of the method

2-1 Nature of concerned soils

The soils which have been successfully experimented in this way are the following according to the GTR classification :

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[1] Technical Guidelines on Embankment and Capping Layers Construction (abbreviated to its French acronym GTR) issued September 1992 in France by LCPC and SETRA deals with the classification of soils according their natures and their states, and their use in embankments and capping layers. It does not plan placing the "very dry" (ts) soils with usual compaction machines, requiring wetting operation to obtain previously the "dry" state (s) before setting placing specifications

[2] The q_4 compaction level is the embankment compaction target for a constituent layer of fill with a dry unit weight averaged over the whole thickness of the compacted layer equal to or greater than 95% of the maximum dry unit weight from the normal Proctor test and a dry unit weight over the bottom 8 centimetres of the compacted layer equal to or greater than 92% of the maximum dry unit weight from the normal Proctor test.

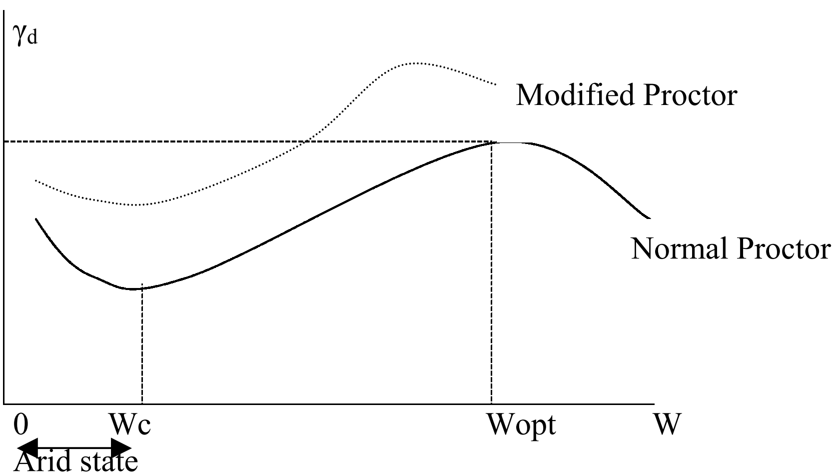
[3] ISTED (France) – Institut des Sciences et Techniques de l'Equipement de l'environnement pour le Développement "Compaction at low moisture content of soils and materials for earthworks and pavements" (June 1987)

Soils	GTR classification
Fine soils (more than 35% of grains passing 80 µm size ; no grain-size over 50 mm)	A1 (plasticity index less than 12), A2 (plasticity index between 12 and 25)
Fines – rich sand and gravel soils (between 12 and 35% of grains passing 80 µm size ; no grain-size over 50 mm)	B5 (plasticity index less than 12), B6 (plasticity index more than 12)
Soils	**GTR classification**
Fines – poor sand soils (less than 12% of grains passing 80 µm size ; no grain-size over 50 mm)	D1 (methyl blue absorption value of soil less than 0.1 ; more than 70% of soil passing 2 mm size), B1 (methyl blue absorption value of soil between 0.1 and 0.2 ; more than 70% of soil passing 2 mm size), B2 (methyl blue absorption value of soil more than 0.2 ; more than 70% of soil passing 2 mm size)
Fines –poor gravel soils (less than 12% of grains passing 80 µm size ; no grain-size over 50 mm)	D2 (methyl blue absorption value of soil less than 0.1 ; less than 70% of soil passing 2 mm size), B3 (methyl blue absorption value of soil between 0.1 and 0.2 ; less than 70% of soil passing 2 mm size), B4 (methyl blue absorption value of soil more than 0.2 ; less than 70% of soil passing 2 mm size)
Coarse soils (include grains exceeding 50 mm size ; 0/50 mm fraction is classed as above, >50 mm fraction is classified as C1 if less than 20 à 40% of the whole soil or if it is made of rounded (not angular) grains, otherwise it is classified C2 and characterizes then a more structured soil)	C1A1, C1A2, C1B5, C1B6, C1D1, C1B1, C1B2, C1D2, C1B3, C1B4 C2A1, C2A2, C2B5, C2B6, C2D1, C2B1, C2B2, C2D2, C2B3, C2B4

The proposed method applies only to the above soil classes.

2-2 Definition of moisture state «arid»

When a Proctor test is carried out on samples which have an initial moisture content close to zero, a minimum density appears at a moisture content W_c known as critical moisture content, as shown on the following figure.



Proctor curves obtained with a range of moisture contents close to zero.

The arid state is characterized by a moisture content between zero and Wc.

From this graph, we can conclude that the lower the moisture content in this range, the more the compaction is efficient. This is often true, but sometimes the soil becomes too dusty and its poor trafficability decreases compaction efficiency. The ranges of arid state defined below, take these facts into account.

2-3 "Arid" state classes of soils

Soil class	Range of moisture content corresponding to arid state
A1a	3[4] à 7
A2a	4[4] à 8
B1a	< 3
B2a	< 4
B3a	< 3 à 4
B4a	< 4
B5a	< 3 à 4
B6a	< 3 à 5
$(C1 – X_i)a$	Defined by the state of X_i
$(C2-Y_i)a$	< 3

2-4 Acceptable embankment height

Arid state soils which are dry-compacted according the following tables can be used in embankments the height of which must not exceed 3 metres. Necessary precautions must be taken to protect them from erosion, particularly by ravining. A more important height of embankment can be planned when out of soaking conditions by raining or flooding.

3 Compaction tables

The compaction conditions given in the following tables for smooth vibrating drum rollers (Vi[5]) normally produce a main body fill of q4 standard, subject to the followings :

- compliance with the stipulated maximum layer thickness,
- compliance on the job with the maximum value of Q/S ratio (Q is the compacted soil volume placed in a given time, while S is the area covered by the compaction machine in the same time on the placed soils). Q is calculated from the number of round trips by haulage plant of known capacity or estimated by a measure of the geometrical volume increased. Area S is obtained from the effective width of the compaction machine multiplied by the distance run by the machine and read from a tachograph fitted to the machine,
- compliance with the classification of the used roller.

These compliances are an *a priori* assurance of the quality of compaction.

[4] for moisture contents less than these values, it is first necessary to verify that trafficability for compacting machines are compatible with an efficient compaction.
[5] i index for classifying a vibrating drum roller depends on its weight by unit of width of vibrating drum and on the amplitude of the vibrating drum. GTR presents this classification.

Use of the tables is as following for instance for a B1 soil with a V2 vibrating roller :

Method	Class V2	
Q/S	0.080	Same value (in m) for all thickness
e V	0.40 2.0	Actual compacted thicknes e ≤ e (in m) V is max speed for vibratory plant in Kph
n	5	Number of load applications : rounded up from actual thickness e / (Q/S), given for a e table. If e = 0.30, then n = 4
Q/L	160	Rate per metre width Q/L = 1.000 x V x (Q/S) Practical rate of compacting operations with an efficiency ratio k (between 0,5 and 0,75) : Qpract = k x (Q/L x L) If k = 0,6 L = 2 m => Qpract = 192 m^3/h

It is however necessary to understand and allow for certain particularities of "dry compaction" when using this method. These are briefly described in the following paragraphs.

4 Particularities of dry compaction

- Risks of insufficient or zero compaction are very difficult to detect by eye during the work (plant trafficability is not closely dependent on compaction, the surface condition of the layer being compacted undergoes little change with the number of passes). Correct respect of compacting plan calls for vigilance on the part of the roller operator.

- "Standard" equipment for measuring unit weight from the surface (gammadensimeter, membrane densimeter or sand method) yields no information on compaction because the top of the layer is not (or very lightly) compacted, it is compacted when the subsequent layer is placed.

- Plate bearing test (EV2/EV1) or other means of determining the deformation modulus by applying load to the top of the layer are entirely inappropriate.
- <u>A strict application of the rules in the compaction tables is therefore the most important guarantee of the quality of construction</u>: continuous monitoring is essential. The following points demand special attention :
  - <u>The thickness</u> shown for the layer is the maximum permitted value (depending on plant used, the specifications may refer to the value in the table +0 to -x cm).
  - The forward speed shown is also the maximum value.
  - Vibratory rollers must be operated at maximum amplitude of vibration.

Post facto verification of compaction quality can be carried out with a double gamma probe or dynamic penetrometer (several layers are required).

5 "Dry compaction" trial embankments

To set conditions for use of soils not included in the tables (rock and materials displaying special behaviour), the above measuring systems must always be used in experimental on construction jobs or trials. Attention is drawn to the fact that "conventional" trials (compaction in a single layer) are not usually adequate for drawing conclusions. It is strongly recommended to compact at least two layers, one above the other, to assess the quality of the 15-18cm thickness on either side of the interface. If a penetrometer is used, the total investigates thickness is no less than around one metre.

6 Special site organisation for "dry compaction"

Generally speaking, preference should be given to rollers with good trafficability properties (self-propelled single drum, drive through vibrating drum and pneumatic tyred wheel shaft, large diameter vibrating drum) with enhanced attention to safety (for aspects relating to trafficability) as when compacting along the edges of face slopes for example.

Special operations to improve the densification and mechanical properties of the layer (during or towards the end of compaction) may be considered, for instance with a pneumatic tyred roller or non-vibratory steel tyred roller. At the top of the fill, it is good practice to wet the material as it is spread with up to 5-10 litres of water per square metre, and compact it with a pneumatic tyred roller or non-vibratory drum roller.

7 Specifications tables for compaction

SOILS	CLASS OF VIBRATORY ROLLER	Q/s	e	v	n	Q/l	REMARKS
B1 D1 C1B1$_{(*)}$ C1D1$_{(*)}$	v1	0.050	0.30	2.0	6	100	When using combinations of widely differing compaction plant classes, use the heavier items first - they are good for dry compaction in terms of final quality but involve trafficability problems
	v2	0.080	0.40	2.0	5	160	
	v3	0.130	0.55	2.5	4	340	
	v4	0.170	0.65	3.0	4	490	
	v5	0.215	0.75	3.5	4	650	

SOILS	CLASS OF VIBRATORY ROLLER	Q/s	e	v	n	Q/l	REMARKS
B3 D2 C1B3$_{(*)}$ C1D2$_{(*)}$	v1	0.045	0.25	2.0	6	80	
	v2	0.075	0.35	2.0	5	140	
	v3	0.110	0.45	2.5	4	280	
	v4	0.140	0.55	3.0	4	410	
	v5	0.180	0.65	3.5	4	560	

SOILS	CLASS OF VIBRATORY ROLLER	Q/s	e	v	n	Q/l	REMARKS
C2D1$_{(*)}$ C2D2$_{(*)}$ C2B1$_{(*)}$ C2B3$_{(*)}$	v1						Class v1 rollers can be used to improve the top of the layer
	v2	0.055	0.30	2.0	6	120	
	v3	0.085	0.40	2.5	5	200	
	v4	0.115	0.50	3.0	5	300	
	v5	0.140	0.55	3.0	4	410	

SOILS	CLASS OF VIBRATORY ROLLER	Q/s	e	v	n	Q/l	REMARKS
	v1						Class v1 rollers can be used to improve the top of the layer
B2	v2	0.030	0.25	2.0	8	60	
B4	v3	0.045	0.30	2.5	7	110	
C1B2(*)	v4	0.06	0.35	3.0	6	175	
C1B4(*)	v5	0.075	0.40	3.0	6	200	

SOILS	CLASS OF VIBRATORY ROLLER	Q/s	e	v	n	Q/l	REMARKS
	v1						Surface cohesion (for the top part of the fill in particular) can beneficially be improved by sprinkling (7-10 litres/m²) and compacting by pneumatic tyred roller CP2
	v2	0.020	0.20	2	10	40	
B5	v3	0.030	0.25	2	9	55	
C1B5(*)	v4	0.040	0.30	2.5	8	90	
	v5	0.055	0.35	2.5	7	125	

SOILS	CLASS OF VIBRATORY ROLLER	Q/s	e	v	n	Q/l	REMARKS
A1 C1A1(*)	v1						- as above -
B6 C1B6(*)	v2	0.015	0.15	2	10	30	
C2A1(*)	v3	0.025	0.20	2	8	50	
C2B2(*)	v4	0.038	0.30	2	8	75	
C2B4(* C2B5(*))	v5	0.048	0.35	2.5	8	110	

SOILS	CLASS OF VIBRATORY ROLLER	Q/s	e	v	n	Q/l	REMARKS
A2	v1						- as above -
C1A2(*)	v2						
C2A2(*)	v3	0.018	0.20	2.0	12	30	
C2B6(*)	v4	0.030	0.25	2.0	9	55	
	v5	0.040	0.30	2.0	8	75	

*Requires Dmax to be less than 2/3rds layer thickness

Roller not recommended (generally not efficient)

Q/S	(m)
e	(m)
V	(km/h)
N	-
Q/L	(m^3/h.m)