NUMERO: **2460A** ANNO: 2020

A P P U N T I

STUDENTE: Chiforeanu Loredana

MATERIA: Construction of roads,railways and airports - Part 2 - exams delays - Prof. Santagata, Riviera

POLITECNICO DI TORINO

MASTER COURSE IN CIVIL ENGINEERING

Construction of Roads, Railways and Airports

Report on the study of the construction of a road section: from the embankment to the pavement

Student
LOREDANA MIHAELA CHIFOREANU

Professors
EZIO SANTAGATA
PIER PAOLO RIVIERA

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PART 1

DESIGN OF AN EMBANKMENT

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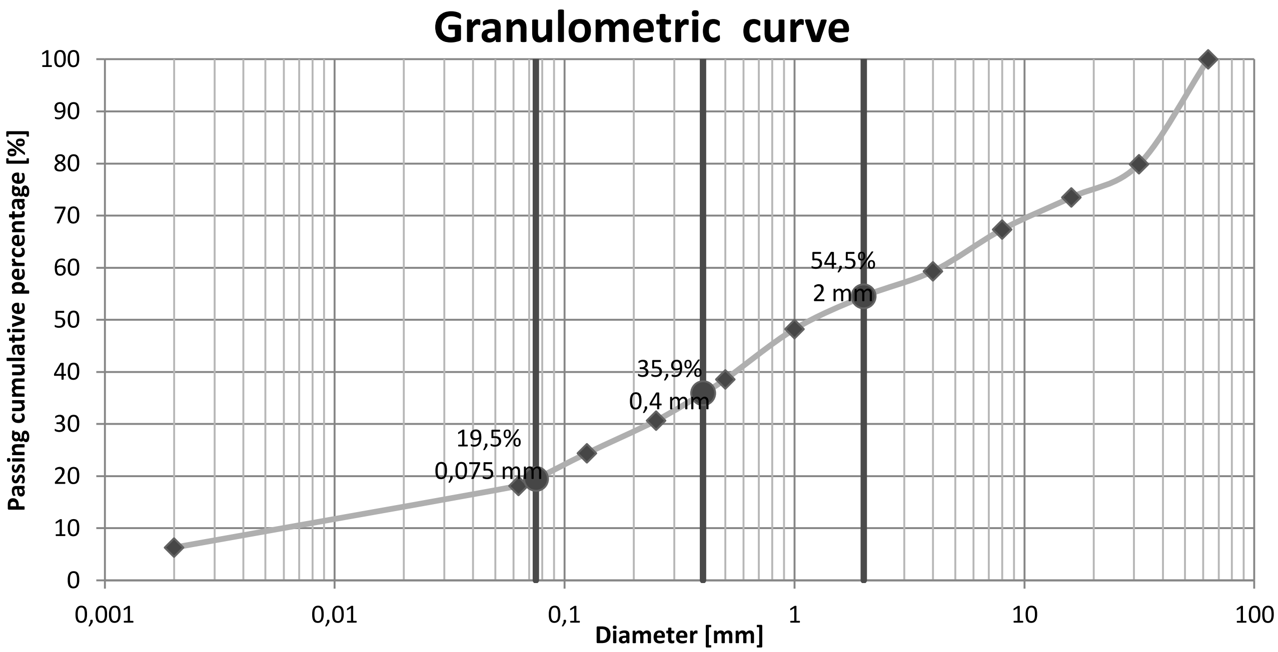
Diameter [mm]	Retained [g]	Retained cumulative [g]	Retained cumulative percentage [%]	Passing cumulative percentage [%]
63	0	0	0	100
31,5	4022,8	4022,8	20,1	79,9
16	1272,5	5295,3	26,5	73,5
8	1231,5	6526,8	32,7	67,3
4	1600,9	8127,7	40,7	59,3
2	964,7	9092,4	45,5	54,5
1	1252	10344,4	51,8	48,2
0,5	1929,3	12273,7	61,4	38,6
0,4	533,6	12807,3	64,1	35,9
0,25	1046,8	13854,1	69,3	30,7
0,125	1252,1	15106,2	75,6	24,4
0,075	985,1	16091,3	80,5	19,5
0,063	266,8	16358,1	81,9	18,1
0,002	2364,6	18722,7	93,7	6,3
0,0000001	1258,7	**19981,4**	100,0	0
Total	**19981,4**			



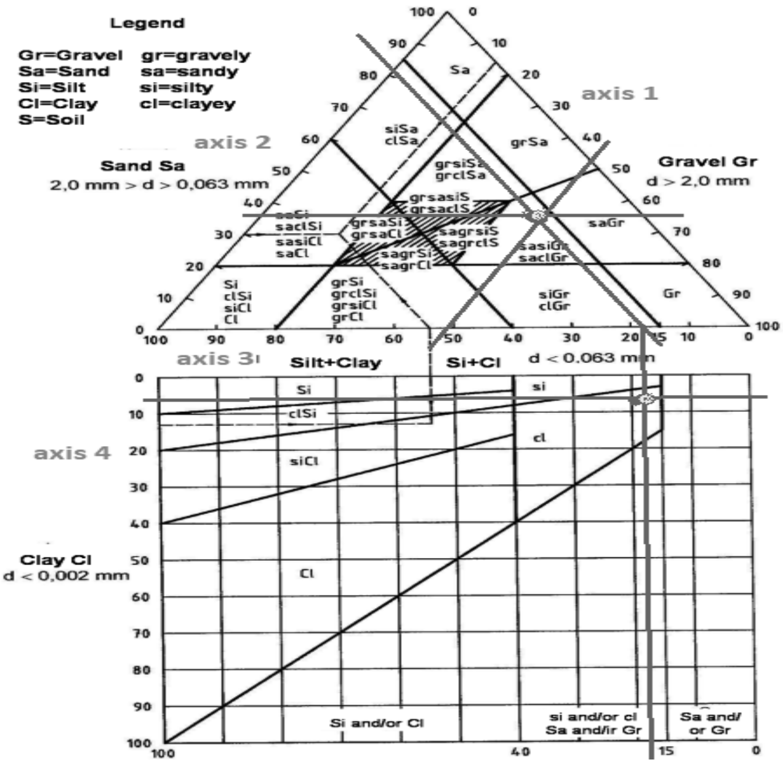
2) Find PI=plastic index and GI=group index

WL [%]	WP [%]
41,2	32,2
PI [%]	=WL-WP
9	

GI			=0,2*a + 0,005*a*c +00,01*b*d
0			
a [0-40]	-15,5	0	= $P_{0,075}$ - 35
b [0-40]	4,5	ok	= $P_{0,075}$ - 15
c [0-20]	1,2	ok	= WL - 40
d [0-20]	-11	0	= PI -20

According to the EN classification, the soil is a gravel with low presence of sand, silt and clay, which is in agreement with the previous test.

- How to use the EN diagram:
    a) Find the 4 passing percentages of the previous table.
    b) Starting from the value 45,5% on the axis 1,draw a line parallel to axis 2 (inclined);
    c) Starting from the value 36,4% on the axis 2,draw a line parallel to axis 3 (horizontal);
    d) Starting from the value 18,1% on the axis 3,draw a line parallel to axis 1 (inclined);
    e) The point found is in an area which describes our soil;
    f) Starting from the value 18,1% on the axis 3,draw a line parallel to axis 4 (vertical);
    g) Starting from the value 6,3% on the axis 4,draw a line parallel to axis 3 (horizontal);
    h) The point found is in an area which describes the finest part of our soil.



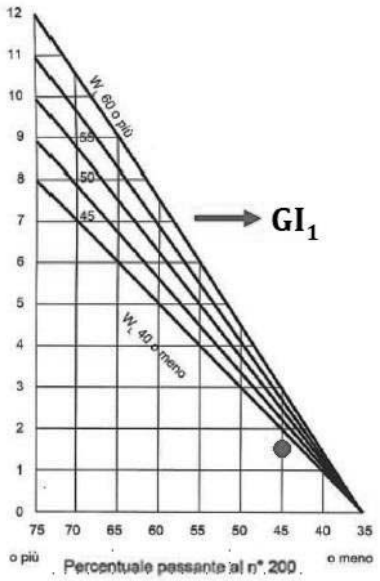
Soil fractions	Sub-fractions	Symbols	Particle sizes mm
Very coarse soil	Large boulder	LBo	> 630
	Boulder	Bo	> 200 to 630
	Cobble	Co	> 63 to 200
Coarse soil	Gravel	Gr	> 2,0 to 63
	Coarse gravel	CGr	> 20 to 63
	Medium gravel	MGr	> 6,3 to 20
	Fine gravel	FGr	> 2,0 to 6,3
	Sand	Sa	> 0,063 to 2,0
	Coarse sand	CSa	> 0,63 to 2,0
	Medium sand	MSa	> 0,2 to 0,63
	Fine sand	FSa	> 0,063 to 0,2
Fine soil	Silt	Si	> 0,002 to 0,063
	Coarse silt	CSi	> 0,02 to 0,063
	Medium silt	MSi	> 0,006 3 to 0,02
	Fine silt	FSi	> 0,002 to 0,006 3
	Clay	Cl	⩽ 0,002

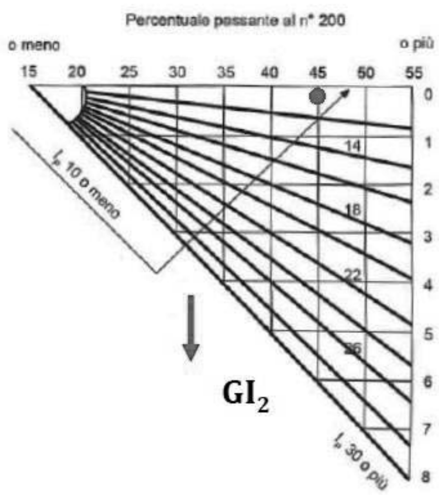
2) Find PI=plastic index and GI=group index

WL [%]	**WP [%]**
42,2	34,9
PI [%]	=WL-WP
7,3	

GI			=0,2*a + 0,005*a*c +00,01*b*d
2			
a [0-40]	9,9	ok	= $P_{0,075}$ - 35
b [0-40]	29,9	ok	= $P_{0,075}$ - 15
c [0-20]	2,2	ok	= WL - 40
d [0-20]	-12,7	0	= PI -20

By the graphical approach we get:





$$GI = GI_1 + GI_2$$

GI = 1,... + 0,... = 2

3) Classify the soil using HRB

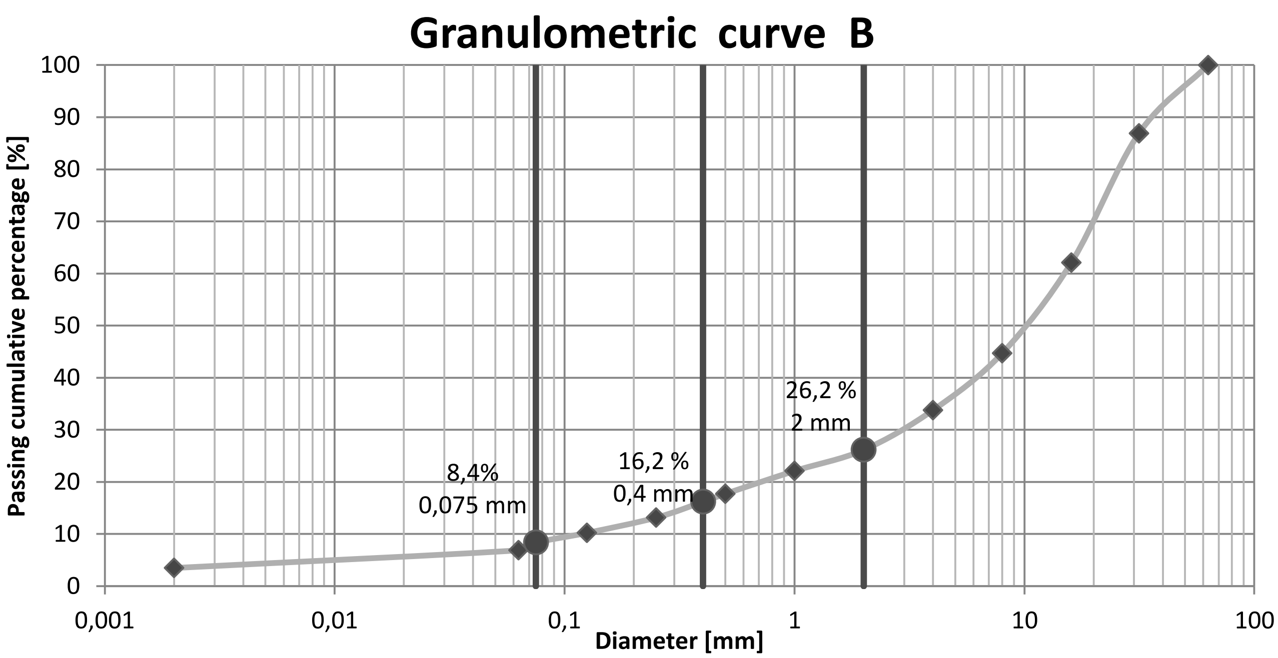
P_2	85,4%
$P_{0,4}$	63,6%
$P_{0,075}$	44,9%
WL	42,2%
PI	9%
HRB	**A-5**

General Classification	General Materials (35% or less passing 0.075 mm) no							Silt-clay materials (more than 35% passing 0.075 mm) ok			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis % passing 2.00 mm (No10) 0.425 mm (No40) 0.075mm (No200)	50max 30max 15max	50max 25max	51min 10max	35max	35max	35max	35max	ok 36min	ok 36min	ok 36min	ok 36min
Characteristics of fraction passing Liquid limit Plastic Index	6max		N.P	40max 10max	41min 10max	40max 11min	41min 11min	no 40max 10max	ok 41min 10max	no 40max 11min	ok 40min 11min
Usual types of significant Constituent material	Stone fragment Gravel and sand		Fine Sand	Silty or clayey Gravel and sand				ok ok Silty soils		no no Clayey soils	
General rating	Excellent to Good							Fair to poor			

- **Soil B**

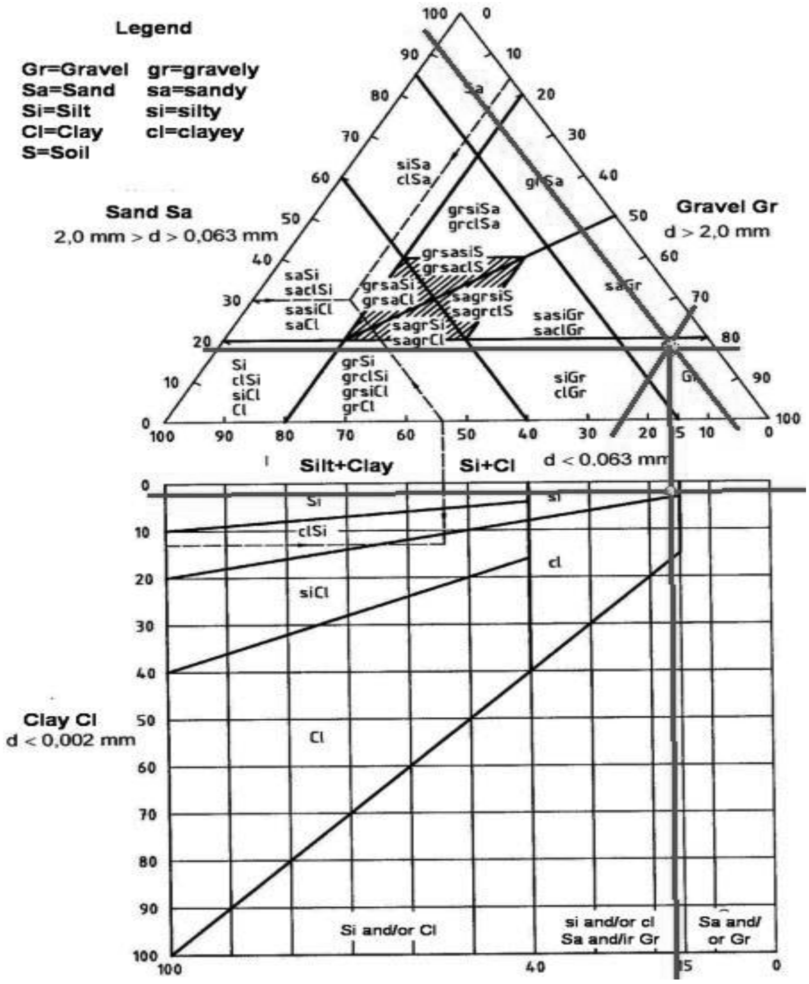
1) Find the cumulative passing retained material after the sieve analysis

Diameter [mm]	Retained [g]	Retained cumulative [g]	Retained cumulative percentage [%]	Passing cumulative percentage [%]
63	0	0	0	100
31,5	3567,1	3567,1	13,1	86,9
16	6752,9	10320	37,9	62,1
8	4736,8	15056,8	55,3	44,7
4	2973,8	18030,6	66,2	33,8
2	2073,4	20104	73,8	26,2
1	1101,4	21205,4	77,9	22,1
0,5	1195,7	22401,1	82,3	17,7
0,4	412,1	22813,2	83,8	16,2
0,25	832,1	23645,3	86,8	13,2
0,125	796,8	24442,1	89,8	10,2
0,075	503,1	24945,2	91,6	8,4
0,063	404,3	25349,5	93,1	6,9
0,002	925,8	26275,3	96,5	3,5
0,0000001	955,4	**27230,7**	100,0	0,0
Total	**27230,7**			



4) Classify the soil using EN 14688-2

axis	%
1 [63-2]	73,8
2 [2-0,063]	19,3
3 [< 0,063]	6,9
4 [< 0,002]	3,5
EN	**Gr & Si** **↓** **GRAVEL**



According to the EN classification, soil B is a gravel with low presence of silt, which is in agreement with the previous test.

2) Find PI=plastic index and GI=group index

WL [%]	WP [%]
/	/
PI [%]	=WL-WP
/	

GI			=0,2*a + 0,005*a*c +00,01*b*d
/			
a [0-40]	-25,9	0	= $P_{0,075}$ - 35
b [0-40]	-5,9	0	= $P_{0,075}$ - 15
c [0-20]	/	/	= WL - 40
d [0-20]	/	/	= PI -20

3) Classify the soil using HRB

P_2	81,7%
$P_{0,4}$	60,3%
$P_{0,075}$	9,1%
WL	/
PI	/
HRB	**A-3**

General Classification	General Materials (35% or less passing 0.075 mm) ok							Silt-clay materials (more than 35% passing 0.075 mm) no			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis % passing 2.00 mm (No10) 0.425 mm (No40) 0,075 mm (No200)	no 50max 30max 15max	no 50max 25max	ok 51min ok 10max	ok 35max	ok 35max	ok 35max	ok 35max	36min	36min	36min	36min
Characteristics of fraction passing Liquid limit Plastic Index	6max		ok N.P	40max 10max	41min 10max	40max 11min	41min 11min	40max 10max	41min 10max	40max 11min	40min 11min
Usual types of significant Constituent material	Stone fragment Gravel and sand		Fine Sand	Silty or clayey Gravel and sand				Silty soils		Clayey soils	
General rating	Excellent to Good							Fair to poor			

According to the HRB classification, soil C is A-3, which is a fine sand.

4) Classify the soil using EN 14688-2

axis	%
1 [63-2]	18,3
2 [2-0,063]	77,4
3 [< 0,063]	4,3
4 [< 0,002]	1,4
EN	**Sa & Si** **↓** **SAND**

According to the EN classification, soil C is a sand with presence of silt, which is in agreement with the previous test.

Exercise 1 b

Settlement prediction

3. An embankment with the geometry shown in Figure 1 has been built on a natural cohesive soil (soil A of the previous exercise) characterized by the following properties:

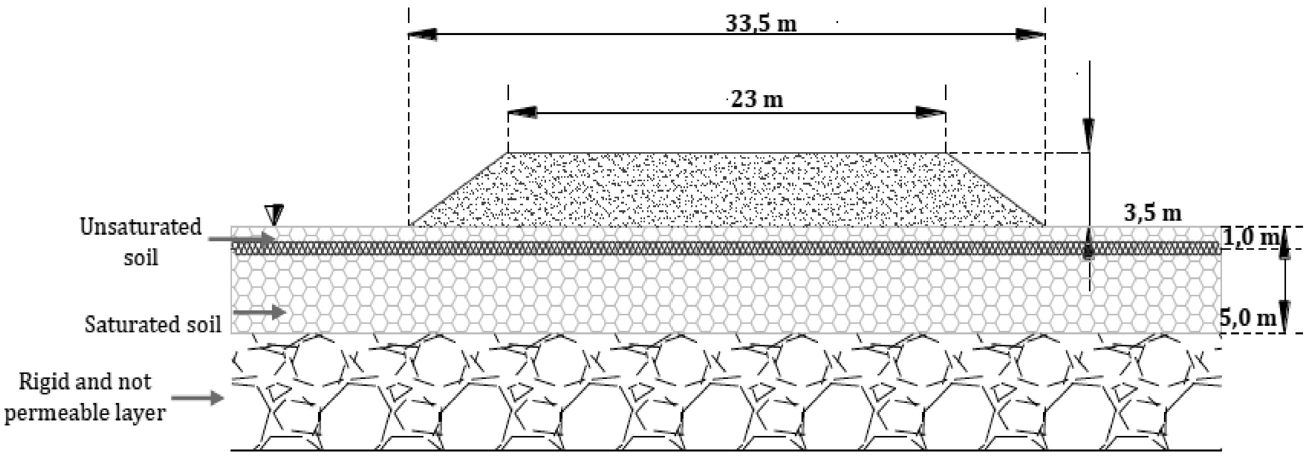
- Void index: 1,3;
- Unsaturated soil density: 14,5 kN/m^3;
- Saturated soil densitiy: 18 kN/m^3;
- Undrained shear resistance $\mathbf{c_u}$: 34 kN/m^2;
- Consolidation degree: NC;
- Primary consolidation coefficient c_v: 3,2 x 10^{-6} m^2/s;
- Construction time: 80 days.

On the soil used for the construction of the embankment, a Proctor study was carried out. In Table 1 obtained results are listed:

	Sample				
	1	**2**	**3**	**4**	**5**
Wet mass + mould [g]	14345,7	14472,5	14602,4	14622,5	14640,2
Water content [%]	3,4	4,7	5,8	7,1	8,4
Mould weight [g]	10188,2				
Mould volume [cm^3]	2120,6				

Table 1: Proctor test results

Assuming a density of the embankment equal to 95% of the maximum dry density derived by the Proctor study, evaluate the total settlement and its residual value at the end of the construction of the embankment.



1.1 Evaluate the dry density Υ_{dry} in order to find the design density Υ

In the design phase we don't know the real dry density but we can calculate the maximum ideal dry density that can be obtained after a Proctor study.

$$\gamma_{dry} = \frac{m_{solid}}{V_{solid}}$$

We do step by step for the first sample:

1) Find the wet mass:

$$m_{wet} = m_{wet+mould} - m_{mould} = 14345.7 - 10188.2 = 4157.7 \text{ g}$$

2) Find the solid mass:

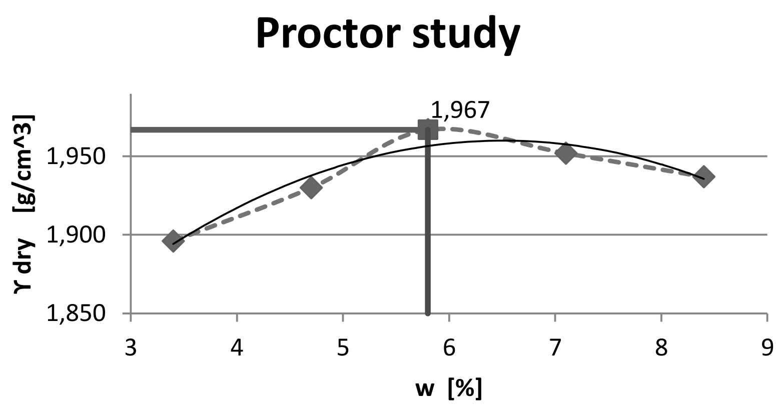
$$m_{solid} = \frac{m_{wet}}{1+w} = \frac{4157.7}{1+\frac{3.4}{100}} = 4020.8 \text{ g}$$

3) Find the dry density:

$$\gamma_{dry} = \frac{m_{solid}}{V_{solid}} = 1.896 \ {}^{g}/_{cm^3}$$

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
γ_{dry} $[{}^{g}/_{cm^3}]$	1.896	1.930	1.967	1.952	1.937
w [%]	3.4	4.7	5.8	7.1	8.4

4) Draw a diagram with these points (w, Υ_d):



As we can see, the data are not intersected perfectly by a parabola, so the maximum that we take is the one obtained from the experiments: $\mathbf{\Upsilon_{d,max} = max(\Upsilon_{d,i}) = 1.967\ g/cm^3}$ **for** $\mathbf{w_{opt} = 5.8\%}$.

For design and practical purpose the value that we use for our calculations is:

$$\Upsilon_{d,design} = 95\% * \Upsilon_{d,max} = 95\% * 1.967 = 1.869 \text{ g/cm}^3$$

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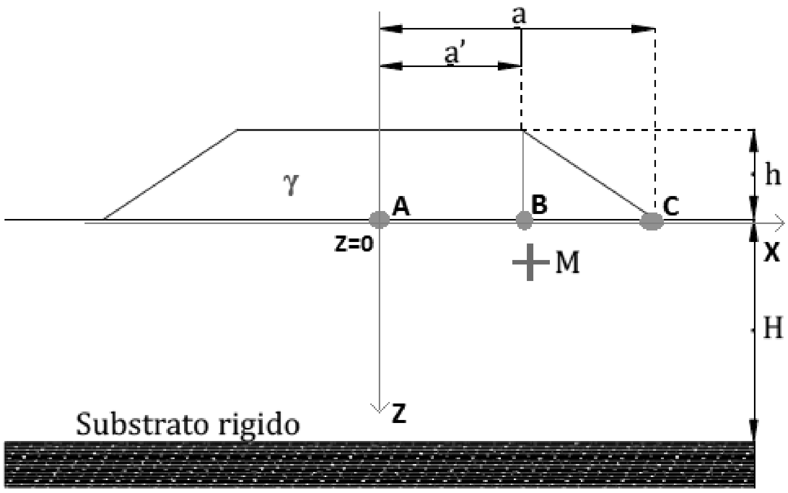
1.3 Evaluate the parameters a, a', r_H, r'_H

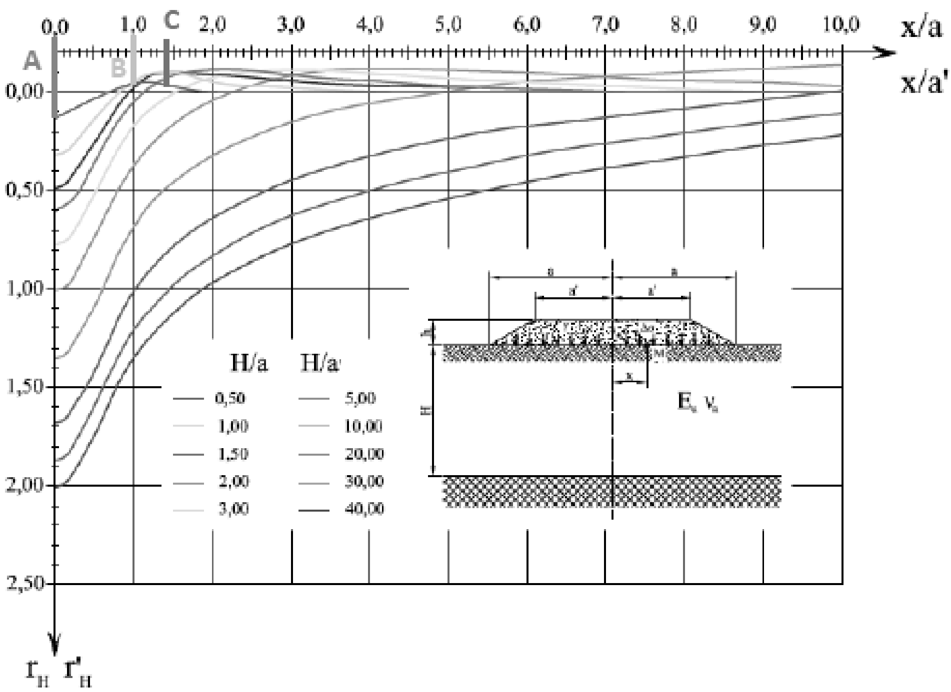
$$a = \frac{33.5}{2} = 16.75\ \text{m}$$

$$a' = \frac{23}{2} = 11.5\ \text{m}$$



We want to evaluate the settlement in 3 points, A,B,C, for which we have to find the quantities X/a, H/a, r_H and X/a', H/a', r'_H.
The Giroud approach is used at the base of the load at Z = 0.

	X [m]	X/a	X/a'	H/a	H/a'	r_H	r'_H
A	0	0	0	0.3 → 0.5	0.43 → 0.5	0.123	0.123
B	11.5	0.69	1	0.5	0.5	0	-0.044
C	16.75	1	1.45	0.5	0.5	-0.044	-0.018



2. Consolidation settlement $S_c(t)$

To calculate the consolidation settlement we use **Terzaghi's formula for a normal consolidated soil**:

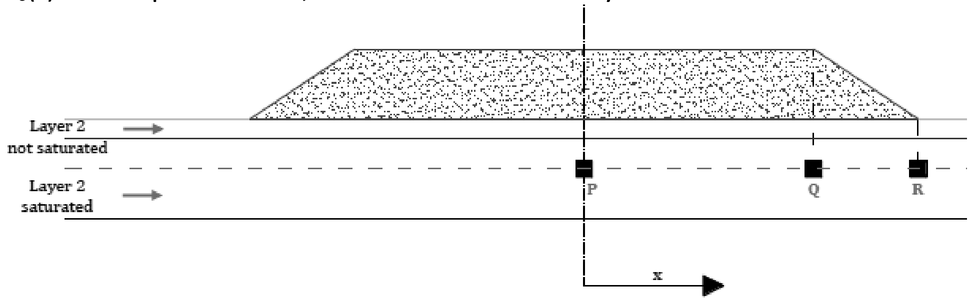
$$S_{consolid}(t) = \frac{H \cdot c_c}{1 + e_0} \log\left(\frac{\sigma'_{V0} + \Delta\sigma'_{V0}}{\sigma'_{V0}}\right)$$
$$c_c = 0.009 \cdot (w_L - 10)$$

H = thickness of the compressible layer
e_0 = void index
c_c = consolidation coefficient from Terzagni & *Peck formula*
σ'_{V0} = stress due to the terrain load $(\Upsilon' * Z)$
$\Delta\sigma'_{V0}$ = increase of stress due to applied load

! Remember that if there is no load there is no settlement:

$$S_{consolid}(t) = \frac{H\, c_c}{1 + e_0} \log\left(\frac{\sigma'_{V0} + 0}{\sigma'_{V0}}\right) = \cdots \log(1) = 0$$

We calculate $S_c(t)$ at a depth of 2.5m, in the middle of the layer of thickness H=5m.



2.1 Evaluate the parameters c_c, e_0, H

The needed parameters have been given and, using Terzaghi & Peck's formula, we get:

wL = 42.2% e0 = 1.3 H = 5 m

$$c_c = 0.009\,(w_L - 10) = 0.009\,(42.2 - 10) = 0.29$$

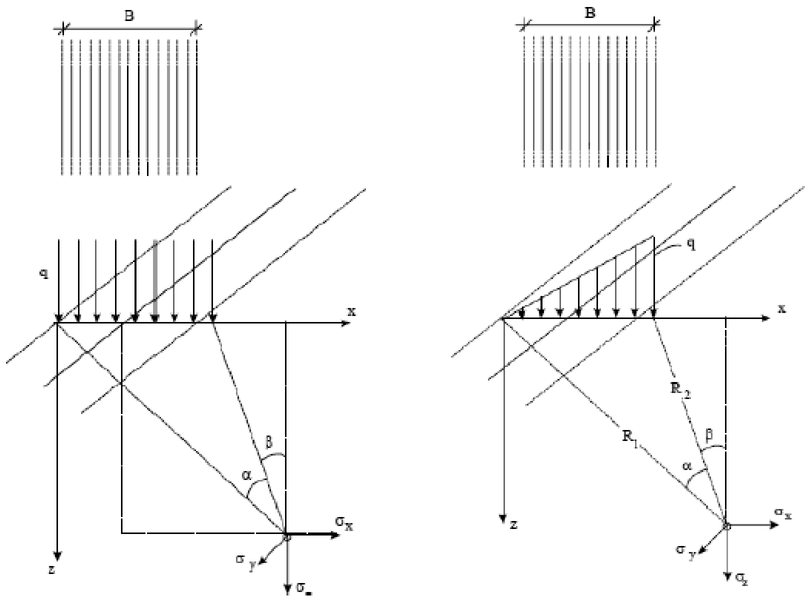
2.2 Evaluate geotechnical stress σ'_{V0} at Z = 2.5 m

In this case all the points have the same depth Z=2.5m so we can calculate once the **effective vertical initial stress** at the depth of 2.5 m:

$$\sigma'_{V0}(2.5\text{m}) = Z_1\, \gamma_{not\ saturated} + Z_2(\gamma_{saturated} - \gamma_{water}) = 14.5 * 1 + 1.5 * (1.8 - 1.0) = 26.5\ \text{kN}/\text{m}^2$$

!!! $\gamma_{not\ saturated} \neq \gamma_{dry}$, because the dry density comes from heating the material (no water at all) and the not saturated density indicates a soil containing water but not close to 100%.

β is the angle between the line, connecting point Q and the point of the load havin the biggest distance from the reference system (in x direction), and the line between Q and it's vertical axis.



e) Compute the values of the distances and of the angles [rad];

f) Calculate:

$$q = h \cdot \gamma_{wet,design} = 3.5\,m \cdot 1.976 \cdot 10^3 \frac{kg}{m^3} \cdot 9.81 \frac{m}{s} = 67.85 \frac{kN}{m} = q_{AB} = q_{BC}$$

Where:
- q = load of the piece of soil [kN/m^2]
- h = height of the embankment (this formula is valid for both rectangles and triangles);

g) For all points, calculate $\Delta\sigma'_{V0,j}$, where j = number of pieces of the load:

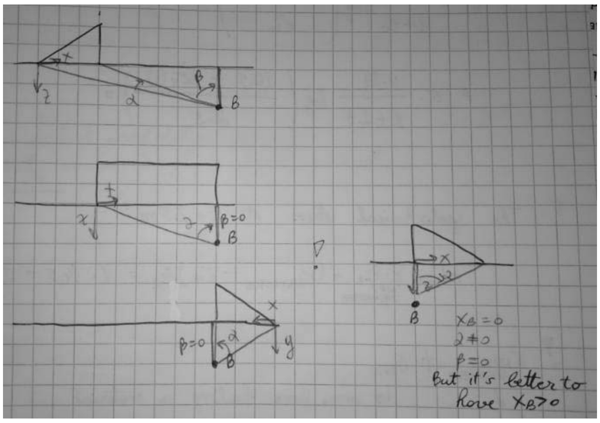
- $\Delta\sigma'_{V0,A,j} = \frac{q}{\pi}[\alpha + \sin(\alpha) \cdot \cos(\alpha + 2\beta)]$ uniform vertical rectangular load
- $\Delta\sigma'_{V0,A,j} = \frac{q}{\pi}\left[\frac{X}{B}\alpha - \frac{1}{2}\sin(2\beta)\right]$ vertical triangular load

h) Find the total settlement in A by summing all the contributions:

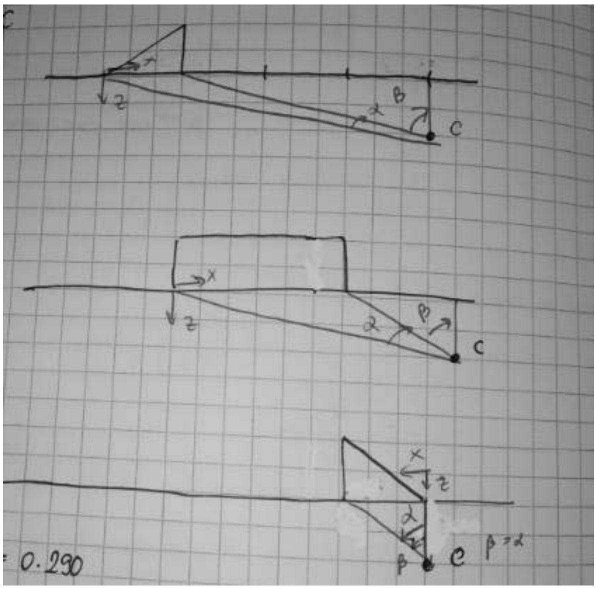
$$\Delta\sigma'_{V0,A,tot} = \sum_{j=1}^{tot\ pieces} \Delta\sigma'_{V0,A,j}$$

i) Calculate the consolidation settlement using Terzaghi's formula of Sc(t);

- Point B



- Point C

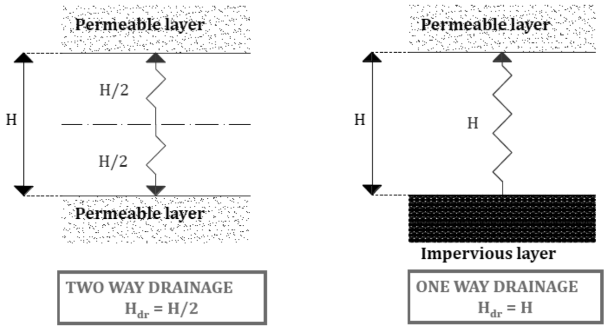


$|\alpha| = |\beta| = 1.1264\ rad$
$\alpha > 0$
$\beta < 0$
Xc = 0m

The stresses found are collected in the table:

[kN/m²]	A	B	C
Δσ′ Æ	0.070	0.014	0.002
¿′¸ Æ	67.575	33.911	1.208
¿′¸ Æ	0.070	24.321	8.300
¿′¸ Æ	**67.577**	**58.246**	**9.600**
: ; >	**34.70**	**31.80**	**8.50**
Æ : ;	**25 cm**		

!!! Evaluation of H_{drain}:

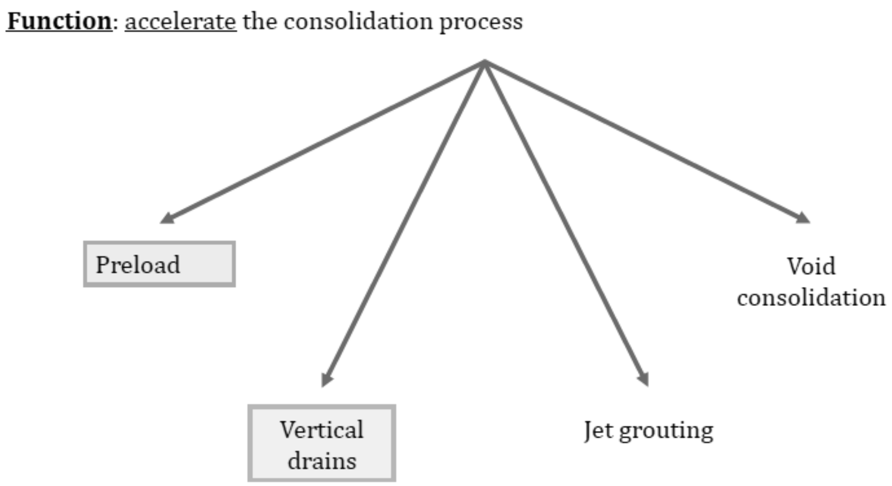


3.2 Find the residual settlement

We check the requirements of the art. 1.4.2.1 of the CIRS specifications.

$$\begin{cases} S_{residual}(t) = 25.4 - 0.4 - 0.908 * 25 = 2.30 \text{ cm} \\ S_{residual}(t) < 10\% \ S_{TOT}(t) = 2.54 \text{ cm} \\ S_{residual}(t) < 5 \text{ cm} \end{cases}$$

These two conditions guarantee that any other future settlement won't affect the infrastructure's surface. In our case both are satisfied, so we don't need any improvement of the soil, such as:



!!! If the construction is finished before 80 days, problems may occur because we should use another time t to compute the residual settlement.

WORK STAGE

1. Preparation of the laying surface.

   A. Removal of the organic soil (thickness 50 cm): width 1 m more than the bottom surface of the embankment for each side;
   B. Clearing and compaction of the trench;
   C. Field control (according to the Technical Specifications): 1 day long.

2. Construction of the embankment.

   A. Transport of the soil required for the formation of each sub-layer of the embankment;
   B. Formation of the sub-layer;
   C. Compaction of the sub-layer;
   D. Field control (according to the Technical Specifications): 1 day long.

   Suppose to have 7 layers of 50 cm of thickness.

3. Escarpments.

   A. Grassing of escarpments by means of organic soil.

MACHINE

Available equipment:

- Activity 1A : n. 1 DOZER type D7R Series 2 (blade 7SU)
- Activity 1B : n. 1 STEEL ROLLER type CS54B
- Activity 2A : n. 1 WHEEL LOADER type 988K (bucket: General Purpose Bucket 347-4980) and n. *"X"* TRUCKS type 725C (*"X"* number of trucks to be evaluated)
- Activity 2B : n. 1 GRADER type 140M
- Activity 2C : see 1B
- Activity 3A : n. 1 DOZER type D7R Series 2 (blade 7SU) and n. 1 n. 1 GRADER type 140M

Additional data:

Work stage n.1:

- Max delay for the activity 1A: 2 days;
- Activity 1B can be run simultaneously with 1A, it can't start or finish before 1A, max delay 1 day;
- Activity 1C can start at the end of 1B.

Work stage n.2:

- Activity 2A can start at the end of 1C, max delay: 2 days;
- Activity 2B can be run simultaneously with 2A, it can't start or finish before 2A, max delay 1 day;
- Activity 2C can be run simultaneously with 2B, it can't start or finish before 2B, max delay 1 day;

WHEEL LOADER type 988K (General Purpouse Bucket 347-4980)
- Specifications: pp. 23-192 (consider "Static tipping load – full turn 43°" and "Dump Clearance")

TRUCK/DUMPER type 725C)
- Specifications: pp. 1-2 (gross load = GMW, net load = target Payload)
- Rimpull-Speed-Gradeability (for the evaluation of the speed): pag. 1-9
- Filling factor: 0.9
- Assume a width of 3 m

GRADER type 140M
- Specifications: pp. 11-13
- For the embankment: consider 2 passes for spreading (working speed 6 km/h) and 2 passes for finishing (working speed 2 km/h)
- For escarpments: consider 2 passes (working speed 1 km/h)
- Efficiency: 0.75

Solution 1 c

There exist two types of problems:
- Number of construction days given → **find number of equipment necessary**
- Number of equipment needed to finish a certain work given → **find nr of total days**

In both cases we have to calculate the Hourly Production of each machine.
The operations to follow for the construction are already given by the exercise.

1. Preparation of the laying surface

1.A Removal of organic soil

This operation involves the removal of the organic soil, having a thickness of 50 cm and a transversal length of the embankment cross section bigger than its base: 1 m on both sides. The work is done using a dozer, shown in the figure, having the following characteristics:

1 DOZER type D7R Series 2 (blade type 7SU)

Blade width [m]
3.69

Blade capacities [m^3]
6.86

- **Evaluation of the cycle time t_C**

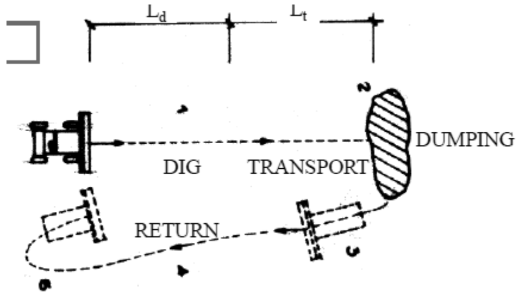
The needed time to complete a cycle is calculated using this relation:

$$t_C = \frac{L_D}{V_1} + \frac{L_T}{V_2} + \frac{L_D + L_T}{V_3} + T_0 + T_M + 2T_P$$

Where:

L_d = digging length (6-10 m, function of the type of dozer)
L_t = transport length
V_1 = digging working speed (1st forward gear)
V_2 = transport working speed (2nd forward gear)
V_3 = non-cutting return working speed (2nd reverse gear)
T_o = time to lower the blade (1-2 s)
T_m= time for speed variation (4-5 s)
T_p = time for change direction: at the end of the digging-transport section and before restart the cutting operations (1 s for each change)

The dozer has to do some operations: dig, transport, dump, return: these require a certain amount of time, which is calculated by dividing the corresponding lengths by the corresponding velocities (known from the handbook).

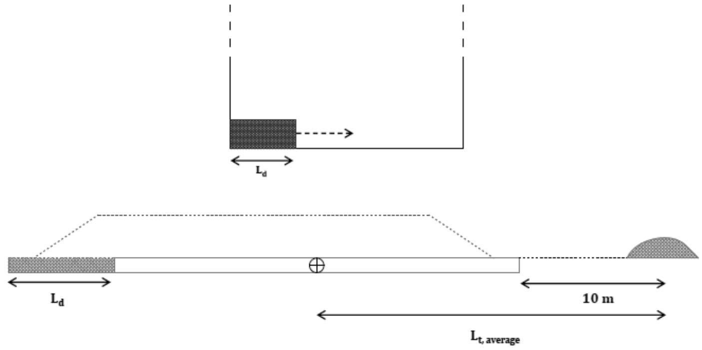


We can make another assumption: the length of excavation is taken as the double of the blade length:

$$L_D = 2 \cdot B = 2 \cdot 3.69 = 7.38 \text{ m}$$

The designer decides to store the material at 10m from the embankment, which implies that distances change continuously. We have also to consider a distance of 1m on both sides of the embankment in order to prevent soil contamination. For these reasons we take the transport length, L_T, as an average value to which we add 10m:

$$L_T = \frac{33.5 + 1 + 1 - 7.38}{2} + 10 = 24.06 \text{ m}$$



- **Evaluation of loose volume**

We have to evaluate the bank volume V_B to be removed (the height is the thickness of the organic soil) and transform it into loose volume V_L by applying a swelling coefficient $f_S = 22\%$.

$$V_B = l_{dig} \cdot h_{dig} \cdot L_{dig} = 35.5 * 0.5 * 1000 = 17750 \text{ m}^3$$
$$V_L = V_B(1 + f_S) = 17750 * (1 + 0.22) = 21655 \text{ m}^3$$

- **Evaluation of the total time for this activity, T_{1A}**

$$T_{1A} = \frac{V_L}{P_{H,dozer}} = \frac{21655}{321,3} = 67.4 \text{ h}$$

The working day has only 8 hours, so to find the number of days required, we divide the time by 8h:

$$\frac{T_{1A}}{8h} = \frac{67.4}{8} = 8.4 \ \approx 9 \text{ days}$$

1.B Clearing and compaction

For the leveling and the compaction of the soil on which the embankment will be constructed, we use a roller having the following characteristics:

MODEL	CS54B*	
Gross Power	98 kW	131 hp
Rated Engine RPM	2200	
No. Cylinders	4	
Displacement	4.4 L	268 in³
Engine Model	C4.4 ACERT	
Emission Standards	Tier 4 Final/Stage IV	
Speeds	2 forward/2 reverse	
Max. Speed (For./Rev.)	11.1 km/h	6.8 mph
Approximate Operating Weight	10 555 kg	23,265 lb
Drive	Drum/Rear Wheel	
Steering:		
Inside Radius	3680 mm	12'1"
Outside Radius	5810 mm	19'1"
Steering Angle	±34°	
Vibratory System:		
Ecc. Weight Drive	Hydraulic	
Frequency[3]	30.5 Hz	1830 vpm
Amplitude:	2	
High Amplitude	1.90 mm	0.075"
Low Amplitude	0.95 mm	0.037"
Centrifugal Force:		
Maximum	234 kN	52,600 lb
Minimum	133 kN	29,900 lb
General Dimensions:		
Overall Width with Blade	—	
Overall Width without Blade	2300 mm	7'7"
Drum Width	2134 mm	7'0"
Drum Diameter	1534 mm	5'0"
Tires	3.1 × 26 — 8 ply floatation	
Overall Height	3110 mm	10'3"
Wheel to Drum	2900 mm	9'7"
Overall Length	5850 mm	19'2"
Curb Clearance	543 mm	21.4"
Service Refill Capacities:		
Fuel Tank	242 L	64 U.S. gal
Diesel Exhaust Fluid Refill Capacity	15 L	4 U.S. gal
Crankcase	8.8 L	2.3 U.S. gal
Hydraulic Fluid	50 L	13.2 U.S. gal

t: 1 STEEL ROLLER type CS54B

Drum width [mm]
2130

Working speed [km/h]
11.1

- V is the working speed (50% of the max speed)
- Suppose a compaction thickness of 30 cm

- 1 WHEEL LOADER type 988K with 347-4980 bucket (General Purpose Bucket)
- n ARTICULATED TRUCKS type 725C

2.A.1 Loading

The hourly production is evaluated as the division of the effective capacity by the mean cycle time per the efficiency:

$$P_{H,loader} = \frac{Q_e}{\overline{t_C}} \eta$$

Where:

- $P_{H,\dots}$ = hourly production $[\frac{m^3}{h}]$
- Q_e = effective capacity (declared by the constructor) $[m^3]$
- $\overline{t_C}$ = cycle time of the equipment [h]
- η = efficiency

				88K HL Tires: 5/65 R33 XLDD1 PN: 339-8790 SLR: 978 mm				
				Standard Lift				
Bucket Type			General Purpose		Rock			Heavy Duty Rock
Ground Engaging Tools			Adapters or BOCE	Adapters or BOCE	K130	K131	K132	K133
Cutting Edge Type			Straight	Straight	Spade	Spade	Spade	Spade
Bucket Part Number			347-4990	347-4980	347-4960	347-4950	347-4970	339-1370
Struck capacity		m^3	6.0	5.5	6.5	5.5	5.0	5.0
		yd^3	7.8	7.2	8.5	7.2	6.5	6.5
Heaped capacity — rated		m^3	7.6	6.9	7.6	6.9	6.4	6.4
		yd^3	10.0	9.0	10.0	9.0	8.3	8.3
Bucket width		mm	3897	3897	4020	4020	4020	4080
		ft	12.8	12.8	13.2	13.2	13.2	13.4
Dump clearance at full lift and 45° discharge	Bare	mm	3810	3894	3595	3807	3726	3714
		ft	12.5	12.8	11.8	12.5	12.2	12.2
	With teeth	mm	3810	3894	3402	3445	3535	3509
		ft	12.5	12.8	11.2	11.3	11.6	11.5
Reach at lift and 45° discharge	Bare	mm	1730	1653	1944	1778	1811	1824
		ft	5.7	5.4	6.4	5.8	5.9	6.0
	With teeth	mm	1730	1653	2127	2074	1994	1998
		ft	5.7	5.4	7.0	6.8	6.5	6.6
Reach with lift arms horizontal and bucket level — tooth		mm	3668	3554	4237	4144	4049	4071
		ft	12.0	11.7	13.9	13.6	13.3	13.4
Digging depth — segment		mm	203	198	204	204	204	204
		in	8.0	8.0	8.0	8.0	8.0	8.0
Overall length bucket level ground		mm	11 716	11 598	12 286	12 204	12 098	12 119
		ft	38.4	38.1	40.3	40.0	39.7	39.8
Overall height with bucket at full raise		mm	7583	7479	7549	7447	7373	7376
		ft	24.9	24.5	24.8	24.4	24.2	24.2
Loader clearance turning circle — SAE carry with teeth		mm	17 240	17 173	17 400	17 338	17 295	17 317
		ft	56.6	56.3	57.1	56.9	56.7	56.8
Full dump angle		degrees	51	51	51	51	51	51
Static tipping load — straight*		kg	34 768	35 148	33 811	34 249	34 390	33 331
		lb	76,650	77,488	74,541	75,506	75,817	73,483
Static tipping load — full turn (articulated 35°)*		kg	31 139	31 508	30 196	30 625	30 760	29 703
		lb	68,649	69,462	66,571	67,517	67,815	65,484
Static tipping load — full turn (articulated 43°)*		kg	29 377	29 740	28 441	28 866	28 998	27 941
		lb	64,765	65,566	62,701	63,638	63,930	61,600
Breakout force		kN	437	468	371	392	410	402
		lbf	98,316	105,297	83,330	88,207	92,170	90,383
Operating weight		kg	50 306	50 065	50 873	50 530	50 502	51 481
		lb	110,905	110,375	112,155	111,399	111,337	113,496
Weight distribution at SAE carry — unloaded	Front	kg	27 450	27 034	28 538	27 979	27 880	29 476
		lb	60,516	59,600	62,916	61,683	61,465	64,982
	Rear	kg	22 856	23 031	22 335	22 551	22 622	22 005
		lb	50,388	50,775	49,239	49,716	49,873	48,514
Weight distribution at SAE carry — loaded	Front	kg	45 653	45 177	46 776	46 164	46 028	47 629
		lb	100,649	99,599	103,123	101,773	101,474	105,003
	Rear	kg	15 992	16 228	15 437	15 706	15 814	15 192
		lb	35,257	35,777	34,032	34,627	34,864	33,493

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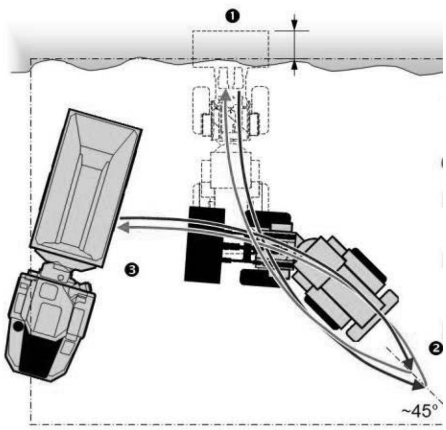
Materials	
Mixed	+0,02 min
Up to 3 mm	+0,02 min
3 mm to 20 mm	-0,02 min
20 mm to 150 mm	±0,00 min
150 mm and over	+0,03 and up min
Bank or broken	+0,04 and up min

Pile	
Conveyor or Dozer piled 3 m and up	±0,00 min
Conveyor or Dozer piled 3 m or less	+0,01 min
Dumped by truck	+0,02 min
Miscellaneous	
Common ownership of trucks and loaders	up to -0,04 min
Independently owned trucks	up to +0,04 min
Constant operations	up to -0,04 min
Inconsistent operation	up to +0,04 min
Small target	up to +0,04 min
Fragile target	up to +0,05 min

We have considered a "double V cycle":



$$\overline{t_C} = 0.5\ \text{min} + (0.02 - 0.04 - 0.04)\ \text{min} + 0.00\ \text{min} = 0.44\ \text{min} = 26.4\ \text{s}$$

- **Evaluation of the efficiency η**

Also the efficiency is given by a formula:

D L D_L fiD_aj fiD_a L wr/xr rzw L ryr z

Where:

- D_aj fiD_a L — E — :L ; L zw¤
- D_L L — L wr L zu¤

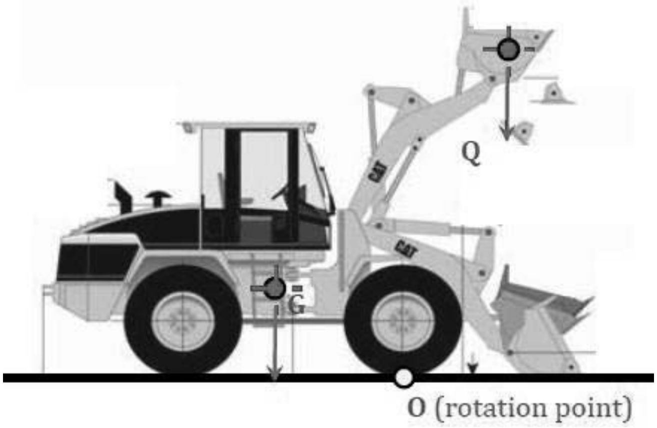
- **Evaluation of the hourly production P_H**

L∄ m _b c p ... D L xts/txv ryr ∡L rsx y 7 W L w{ {w 7 W

To evaluate the total time for loading we need to calculate the necessary amount of soil for the construction of the i-th layer.

- **Tipping check**

  The ultimate static load that a loader can carry without tipping has been reported in the *Caterpillar Handbook:* in the most critical configuration as shown in the figure, the weigth of tipping is $P_{TIPPING}$ = 29740 kg (static tipping load).



The ultimate working load is evaluated as the product between the effective capacity and the loose density of the soil:

P L 3 fi - L 3 fi fi » sE B L x { fir { fi s yv r sE rss L { yu zvGC

So the effective capacity is calculated as the nominal capacity in heaped configuration (6.9 m^3) per the fill factor equal to 90%; while the loose density is calculated from the constant bank density equal to 1740 kg/m^3.
We can see that the **safety requirement** is satisfied:

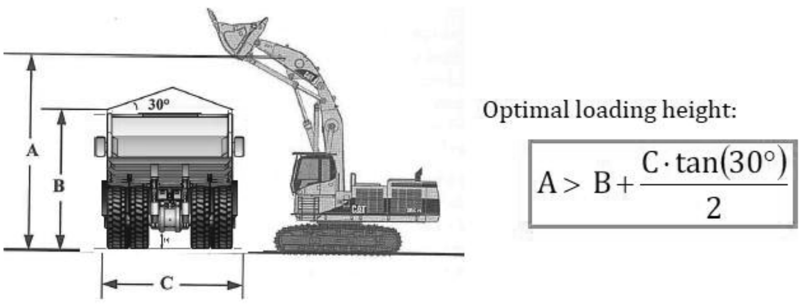
2 XMTT MR L { yu zv t {y v r L ruu O rw

! If these requirements weren't satisfied, we should:
- Change the construction material (not good choice)
- Change type of loader

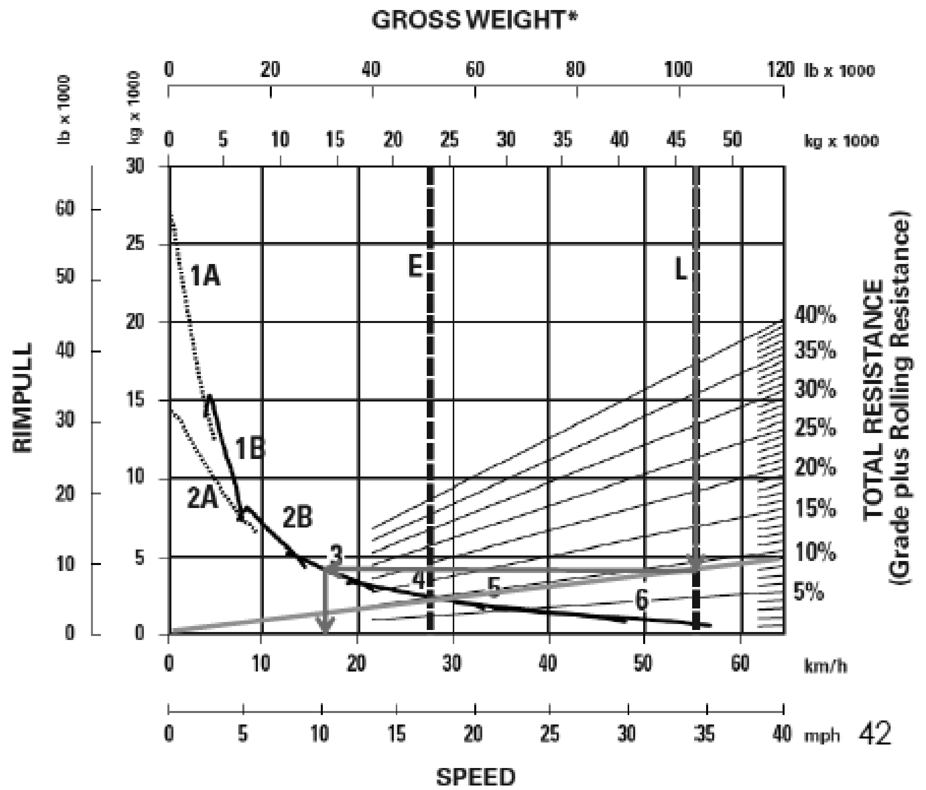
2.A.2 Transport

- **Verification of the choice of the truck**

a) First of all we need to verify if the choice of the truck is good or not to work i combination with the loader.
   We check if the height of the loader's arm is bigger than the truck's height:



b) For the calculation of $t_{VARIABLE}$ we consider the machine's performance and the quality of the road on which it travels.
Its velocity depends on how much load it carries (full load – forth; empty – back) and on the resistance of the road (RR% + i%).
We estimate the velocity using the nomogram:



$$t_{variable} = \sum \frac{\text{lenght of ith path}}{\text{average speed of dumper on ith}}$$

The results are resumed in the following tables.

	Line	L [km]	i [%]	RR [%]	R_{tot} [%]	V [km/h]	$t_{VARIABLE}$ [s]
FORWARD FULL LOAD	**A**	0.30	+4	5	9	17.5	61.7
	B	0.45	0	3	3	40.0	40.5
	C	0.35	-1	3	2	53.0	23.7
	D	0.40	-1	6	5	30.0	48.0
	E	0.50	0	6	6	24.0	75.6

	Line	L [km]	i [%]	RR [%]	R_{tot} [%]	V [km/h]	$t_{VARIABLE}$ [s]
BACKWARD NO LOAD	**E**	0.50	0	6	6	38.3	46.4
	D	0.40	+1	6	7	33.0	43.5
	C	0.35	+1	3	4	46.0	27.2
	B	0.45	0	3	3	55.0	29.3
	A	0.30	-4	5	1	56.0	19.3

Where:

- D is the length of the embankment = 1000 m
- η is the efficiency
- V is the spread velocity
- n is the number of passes evaluated as: 33.5 / 3.658 = 9.2 → 10 continuous passings: 2 for spreading and 2 for finishing

! But with this formula we calculate the passes that cover a width equal to the blade width, while in our case there is overlapping. The correct formula is then:

$$t_{2B_{ith\text{-}layer}} = \frac{D}{\eta} \cdot \left(\frac{n_{spreading}}{V_{spreading}} + \frac{n_{finishing}}{V_{finishing}} \right)$$

So we get:

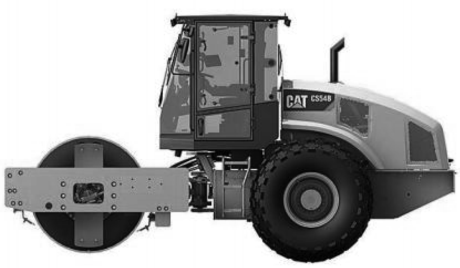
Layer	Passes	Days
1	10	3
2	9	2
3	9	2
4	8	2
5	8	2
6	8	2
7	7	2
	T_{2B}	**15 days**

2.C Sub-layer compaction

The roller used for this operation is the same as in step 1.B:

MODEL	CS54B*	
Gross Power	96 kW	131 hp
Rated Engine RPM	2200	
No. Cylinders	4	
Displacement	4.4 L	268 in³
Engine Model	C4.4 ACERT	
Emission Standards	Tier 4 Final/Stage IV	
Speeds	2 forward/2 reverse	
Max. Speed (For./Rev.)	11.1 km/h	6.8 mph
Approximate Operating Weight	10 555 kg	23,265 lb
Drive	Drum/Rear Wheel	
Steering:		
Inside Radius	3680 mm	12'1"
Outside Radius	5810 mm	19'1"
Steering Angle	±34°	
Vibratory System:		
Ecc. Weight Drive	Hydraulic	
Frequency[1]	30.5 Hz	1830 vpm
Amplitude:	2	
High Amplitude	1.90 mm	0.075"
Low Amplitude	0.95 mm	0.037"
Centrifugal Force:		
Maximum	234 kN	52,600 lb
Minimum	133 kN	29,900 lb
General Dimensions:		
Overall Width with Blade	—	
Overall Width without Blade	2300 mm	7'7"
Drum Width	2134 mm	7'0"
Drum Diameter	1534 mm	5'0"
Tires	3.1 × 26 — 8 ply floatation	
Overall Height	3110 mm	10'3"
Wheel to Drum	2900 mm	9'7"
Overall Length	5850 mm	19'2"
Curb Clearance	543 mm	21.4"
Service Refill Capacities:		
Fuel Tank	242 L	64 U.S. gal
Diesel Exhaust Fluid Refill Capacity	15 L	4 U.S. gal
Crankcase	8.8 L	2.3 U.S. gal
Hydraulic Fluid	50 L	13.2 U.S. gal

t: 1 STEEL ROLLER type CS54B



Drum width [mm]
2130

Working speed [km/h]
11.1

- V is the working speed (50% of the max speed)
- Suppose a compaction thickness of 30 cm

3. Shaping of the escarpments

The equipments for this operation are:


Available machine: 1 DOZER type D7R Series 2 (blade type 7SU)
1 GRADER type140M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MODEL	D7E 7S LGP		D7R/D7R XR 7SU		D7R/D7R XR 7A		D7R LGP 7S	
Type	Straight		Semi-Universal		Angling		Straight	
Blade Capacities*	6.1 m²	7.9 yd³	6.86 m³	8.98 yd³	3.89 m³	5.07 yd³	5.89 m³	7.7 yd³
Weight, Shipping** (Dozer)	3855 kg	8498 lb	3593 kg	7904 lb	3523 kg	7751 lb	3732 kg	8229 lb
Tractor and Dozer Dimensions:								
A Length (Blade Straight)	6.28 m	20'7"	6.03 m	19'9"	4218 mm	13'10"	5.81 m	19'1"
Length (Blade Angled)	—		—		5098 mm	16'9"	—	
Width (Blade Angled)	—		—		4114 mm	13'6"	—	
Width (with C-Frame only)	—		—		3073 mm	10'1"	—	
Blade Dimensions:								
B Width (including std. end bits)	4.59 m	15'1"	3.69 m	12'1"	4503 mm	14'9"	4.50 m	14'9"
C Height	1351 mm	4'5"	1524 mm	5'0"	1111 mm	3'8"	1343 mm	4'4.9"
D Max. Digging Depth	631 mm	2'1"	527 mm	1'8.7"	647 mm	2'1"	688 mm	2'2.3"
E Ground Clearance @ Full Lift	1292 mm	4'3"	1145 mm	3'9.1"	1340 mm	4'5"	1153 mm	3'9.4"
G Max. Pitch Adjustment	54° to 60°		+3.1° to 3.9°		—		+3.0° to 3.9°	
Blade Angle (either side)	778 mm	2'7"	—		25°			
H Max. Hydraulic Tilt	468 mm	1'7"	799 mm	2'7.4"	466 mm	1'6"	686 mm	2'3"
J Hydraulic Tilt (Manual Brace Centered)	3.35 m	11'0"	474 mm	18.6"	627 mm	2'1"	426 mm	16.8"
K Push Arm Trunnion Width (to Ball Centers)	—		2.87 m	9'5"	2795 mm	9'2"	3.37 m	11'1"

With the dozer we move the organic soil previously removed (loading and transport), with the grader we shape the edges of the embankment.

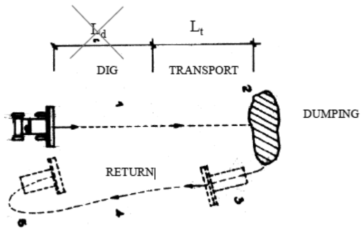
3.A Transport

We need to calculate the hourly production of the machine of this operation:

$$P_{H,dozer} = \frac{Q_e}{t_C}\eta$$

Where:

- $P_{H,\dots}$ = hourly production $[\frac{m^3}{h}]$
- Q_e = effective blade capacity (declared by the constructor) $[m^3]$
- t_C = cycle time of the equipment $[h]$
- η = efficiency



$$\bar{t}_c = \frac{L_d}{V_1} + \frac{L_t}{V_2} + \frac{L_d + L_t}{V_3} + T_o + T_m + 2T_p$$

- **Evaluation of the efficiency η**

Also the efficiency is given by a formula:

$$\eta = \eta_H \cdot \eta_{cl} \cdot \eta_c = \frac{50 \text{ min}}{60 \text{ min}} * 0.85 = 0.708$$

Where:

- $\eta_{cl} \cdot \eta_c$ = climate efficiency + efficiency of the working site (general organization) = 85%
- η_H = hourly efficiency = 50 min each workinh hour = 83%

- **Evaluation of the hourly production P_H**

$$P_{H,dozer} = \frac{Q_e}{t_C}\eta = \frac{6.517}{20.3} 0.708 = 818.3 \ {m^3}/{h}$$

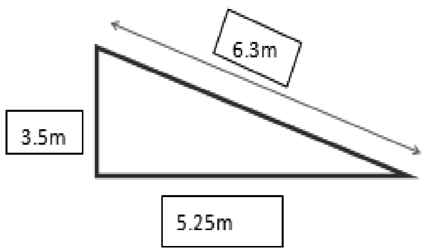
To evaluate the total number of hours for this operation, we have to divide the total soil volume transported by P_H.

- **Evaluation of loose volume**

We have to evaluate the total bank volume V_B of both escarpments (the height is the thickness of the organic soil) and transform it into loose volume V_L by applying a swelling coefficient $f_S = 22\%$.

$$V_B = l_{escarp} \cdot h_{escarp} \cdot L_{escarp} = 2 * (6.3 * 0.3 * 1000) = 3780 \text{ m}^3$$

$$V_L = V_B \cdot (1 + f_S) = 3780 * (1 + 0.22) = 4611.6 \text{ m}^3$$



! $\mathbf{V_{loose}} < \left(\mathbf{V_{bank}} \leq \textbf{or} \geq \mathbf{V_{compacted}}\right)$

4. Chronoprogram

We have since now estimated the days needed for the construction of the embankment. Now we want to represent all the activities and their times together, in order to understand how long will last the site.
We can do 2 types of Chronograms:

- With **NO** delays, which means a very organized site, where the activities start exactly as calculated;
- With delays, where we consider the worst situation in which there are a lot of delays between activities.

In the following table we resume the general amount of days, but some activities can work simultaneously, as said in the exercise text.

Activity		Equipment	Days
1	A	Dozer	9
	B	Roller	2
	C	Field test	1
2	A.1	Loader	28
	A.2	Truck	
	B	Grader	15
	C	Roller	26
	D	Field test	7
3	A	Dozer	1
	B	Grader	2

Usually GANTT Software is used, but here are reported the chronoprograms using Excel, in both cases.

Considering a general period of time (no festivities):

- With NO delays, there are 58 consecutive days, but during Saturday and Sunday the site is closed, so we have to add some days to recover them:
  58 days + 16 days = 74 days, about 11 weeks
- With delays, there are 89 consecutive days, but during Saturday and Sunday the site is closed, so we have to add some days to recover them:
  89 days + 24 days = 113 days, about 17 weeks

Exercise 2 a

Bituminous Binders

Example #1 Viscosity test (Rotational viscometer)

Data reported in Table 1 was obtained by performing rotational viscosity test on 50/70 penetration grade bitumen at four different temperatures and three shear rates.

Temperature (°C)	Shear Rate (s^{-1})	Shear Stress (Pa)	Temperature (°C)	Shear Rate (s^{-1})	Shear Stress (Pa)
135	6.8	3.06	165	18.6	2.32
	18.6	8.37		46.5	5.76
	46.5	20.64		93	11.43
150	18.6	4.18	175	46.5	4.09
	46.5	10.41		93	8.09
	93	20.64		139.5	11.99

1.1. Calculate the dynamic viscosity (η), in mPa·s, expressed to 3 significant figures

As we know the viscosity can be expressed in terms of the shear stress and rate of shear deformation as following equation:

$$\eta = \frac{\tau}{\dot{\gamma}}$$

Where:

- Dynamic viscosity [mPa.s]
- Shear stress [Pa]
- Shear rate [1/s]

So using the formula and Excel we obtained:

Temperature T	Shear rate	Shear stress	Viscosity	Viscosity
[°C]	**[1/s]**	**[Pa]**	**[Pa*s]**	**[mPa*s]**
135	6,80	3,06	0,450	450
	18,60	8,37	0,450	450
	46,50	20,64	0,444	444
150	18,60	4,18	0,225	225
	46,50	10,41	0,224	224
	93,00	20,64	0,222	222
165	18,60	2,32	0,125	125
	46,50	5,76	0,124	124
	93,00	11,43	0,123	123
175	46,50	4,09	0,088	88
	93,00	8,09	0,087	87
	139,50	11,99	0,086	86

$$T = \frac{7416,5}{\ln(\eta) - \ln(6 \cdot 10^{-06})}$$

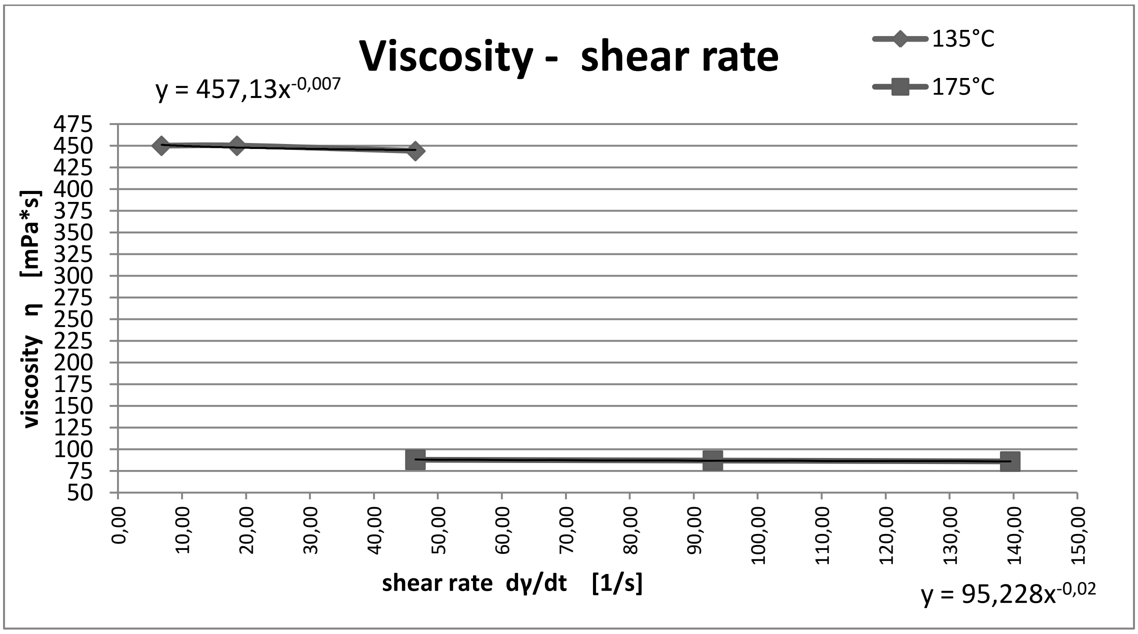
Using this was found the T(ºC) for a $\eta = 200\ mPa.s$:

η [mPa*s]	T [K]	T [°C]
200	428.15	155

1.3. Viscosity versus shear rate – power law

For constant temperature respectively equal to 135 °C and 175 °C, plot viscosity versus shear rate (˙) and apply power-law model to fit experimental data. Provide specific comments on obtained results, highlighting the different behavior exhibited by the binder in such conditions.

Temperature T	Shear rate ‰6	Shear stress ‘	Viscosity `
[°C]	[1/s]	[Pa]	[mPa*s]
135	6,80	3,06	450
	18,60	8,37	450
	46,50	20,64	444
175	46,50	4,09	88
	93,00	8,09	87
	139,50	11,99	86



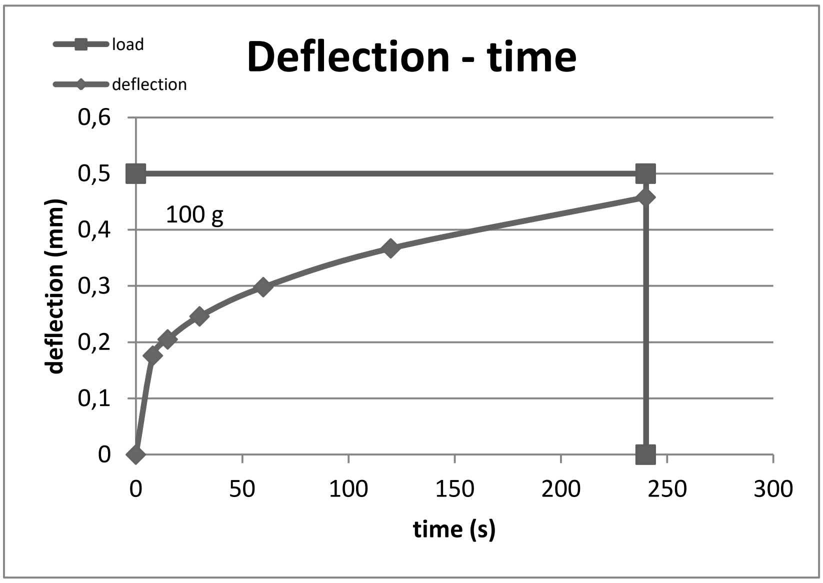
It can be observed that the binder heated to a 175°C presents much less Dynamic Viscosity than the binder heated to 135°C. That means that while higher is the temperature, the binders present a lower dynamic viscosity. That corresponds with the expected behavior of the visco-elastic materials, in which the viscosity presents an inverse behavior respect to the temperature.

Example #2 Creep test (BBR)

A 70/100 penetration grade bitumen, aged with PAV apparatus, was tested using the BBR. Following information is available:

- Constant temperature of -18 °C
- Constant load (P) of 100 g
- Beam dimensions (b x h x l) 12.70 mm x 6.35 mm x 127.00 mm
- Span length (L) 102 mm
- Deflection data monitored versus time:

Time T (s)	Deflection δ (mm)
8	0,176
15	0,205
30	0,246
60	0,298
120	0,367
240	0,458



2.1. Flexural creep stiffness S(t)

Using the elementary bending theory, calculate the time-dependent flexural creep stiffness ($S(t)$), in MPa, expressed with three significant figures

In order to calculate the creep stiffness it is used the following equation:

$$S(t) = \frac{2\ \text{fi}.^{7}}{\text{v fi> fiD}^{7}\ \text{fi}\ :P;}$$

Where:

- 5 :P; I time dependent flexural creep stiffness [MPa]
- 2 I Constant load [N]
- . I span length [mm]
- > I beam base [mm]
- D I beam height [mm]
- :P; I time dependent flexural maximum deformation [mm]

So, the following results are obtained:

2.3. Estimation of m-value

Estimate m-value (m) by the first derivative of the polynomial function using the fitting polynomial equation and deriving it:

$$y = a + bx + cx^2$$
$$\dot{y} = m = b + 2cx$$

Substituting the real variables:

$$Log\,(S(t)) = A + B \cdot Log(t) + C \cdot Log(t)^2$$
$$m = B + 2C \cdot Log(t)$$

$$m = -0{,}176 - 2 \cdot 0{,}032 \cdot Log(t)$$

Using the previous equation the following values are obtained:

Time t	Stiffness S(t)	m
[s]	[Mpa]	[-]
8	454	0,2338
15	390	0,2513
30	325	0,2705
60	268	0,2898
120	218	0,3091
240	175	0,3283

2.4. Verify if it is PGXX-28

Verify if this bitumen can be graded as PGXX-28.

It cannot be classified as a PGXX - 28, because, although the maximum creep stiffness S_{60}=S(t=60s), is verified, (268 MPa < 300 MPa; 60s) the minimum m (creep grade) is not verified (0,2898 < 0,30).

Then, transforming these values in maximum amplitude of shear stress and shear deformation respectively:

$$\tau o = \frac{2Mo}{\pi R^3} = \frac{2 \cdot 12100}{\pi \cdot 8^3} = 120{,}36\ mPa$$

$$\gamma o = \frac{\Upsilon R}{h} = \frac{4 \cdot 8}{2} = 16\ mRad$$

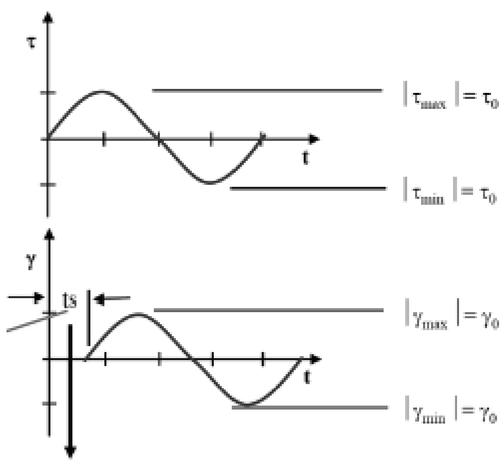
Calculate the complex modulus G^*:

$$G^* = \frac{\tau o}{\gamma o} = \frac{120{,}36}{16} = 7.52\ Pa$$

3.3. Phase angle of G*

Estimate the phase angle of the complex shear modulus (δ) in degrees. Using the following equation:

$$\delta = \omega \cdot ts$$



Where ts is the out of phase time measured in the chart:

$$ts = 7.625 - 7.52 = 0{,}1\ s\ \ (values\ taken\ from\ the\ given\ graph)$$

$$\delta = 10{,}053 \cdot 0{,}11 = 1{,}22\ rad \rightarrow\ 69{,}7°$$

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PP08	20	3,16	1,12E+06	69,77	3,16
PP08	20	1	4,49E+05	74,53	1
PP08	20	0,316	1,74E+05	77,82	0,316
PP08	20	0,1	6,68E+04	80,2	0,1
PP25	40	100	2,99E+05	77,61	0,630957
PP25	40	31,6	1,08E+05	80,28	0,199383
PP25	40	10	3,81E+04	82,53	0,063096
PP25	40	3,16	1,31E+04	84,5	0,019938
PP25	40	1	4,37E+03	86,18	0,00631
PP25	40	0,316	1,43E+03	87,48	0,001994
PP25	40	0,1	4,69E+02	88,34	0,000631
PP25	60	100	1,46E+04	85,13	0,022387
PP25	60	31,6	4,85E+03	86,96	0,007074
PP25	60	10	1,58E+03	88,03	0,002239
PP25	60	3,16	5,07E+02	88,98	0,000707
PP25	60	1	1,61E+02	89,61	0,000224
PP25	60	0,316	5,06E+01	89,97	7,07E-05
PP25	60	0,1	1,58E+01	90	2,24E-05
PP25	80	100	1190	88,49	0,001585
PP25	80	31,6	3,80E+02	89,27	0,000501
PP25	80	10	1,19E+02	90	0,000158
PP25	80	3,16	3,81E+01	90	5,01E-05
PP25	80	1	1,21E+01	90	1,58E-05
PP25	80	0,316	3,82E+00	90	5,01E-06
PP25	80	0,1	1,23E+00	90	1,58E-06

4.2. Semi-log plot of $a(T)$

Make a semi-log plot of the obtained shift factors ($a(T)$) versus temperature and apply William-Landel-Ferry (WLF) equation. The parameters of the curve C1 and C2 can be obtained by minimizing the sum of the squares differences between experimental shift factors and shift factors estimated with the WLF equation.

At this point is necessary to calculate the coefficients present in the equation of William-Landel-Ferry (W-L-F) in order to model the shift factor variation. For doing this, we put random initial values and program the square difference between the estimated value (by manual shifting) and those calculated with W-L-F, and finally using the Solver tool of excel, are calculated the real quantities considering the less differences as possible in the square amounts.

These results are shown in the following Tables and Chart.

$T_{ref} = T_0$	20
C1	14,4
C2	117,9

4.4. Christensen-Anderson model

Fit the master curve with the Christensen-Anderson model (CA). Fitting parameters G_g, ω_0 and R can be obtained by minimizing the sum of the squares difference between measured and estimated complex shear modulus.

It is done the same procedure that was developed in point 2. Here the coefficients to find correspond to those from the Christensen – Anderson analytical model, which is used to graph the master curve G* vs ω_r. The equation is the following:

$$G^*(\omega) = G_g\left[1+\left(\frac{\omega_0}{\omega}\right)^{\frac{\log 2}{R}}\right]^{-\frac{R}{\log 2}}$$

It is necessary to remark that in this part the parameters to suppose are: $R, Log(Gg), Log(\omega o)$.

Measuring System	Frequency (rad/s)	Complex Modulus (Pa)	Phase Angle (°)	T (°C)	Red Freq (HZ)	G* (CA) [Pa]	Square of the difference
PP08	100	1,78E+08	23,96	0	6,31E+04	1,52E+08	2,14
PP08	31,6	1,29E+08	27,95	0	1,99E+04	1,17E+08	0,92
PP08	10	8,84E+07	32,37	0	6,31E+03	8,35E+07	0,31
PP08	3,16	5,71E+07	37,25	0	1,99E+03	5,52E+07	0,11
PP08	1	3,46E+07	42,59	0	6,31E+02	3,35E+07	0,11
PP08	0,316	1,96E+07	48,32	0	1,99E+02	1,85E+07	0,30
PP08	0,1	1,04E+07	54,21	0	6,31E+01	9,39E+06	0,95
PP08	100	1,24E+07	54,37	20	1,00E+02	1,25E+07	0,00
PP08	31,6	5,95E+06	59,99	20	3,16E+01	5,99E+06	0,00
PP08	10	2,67E+06	65,23	20	1,00E+01	2,66E+06	0,00
PP08	3,16	1,12E+06	69,77	20	3,16E+00	1,10E+06	0,04
PP08	1	4,49E+05	74,53	20	1,00E+00	4,29E+05	0,21
PP08	0,316	1,74E+05	77,82	20	3,16E-01	1,59E+05	0,74
PP08	0,1	6,68E+04	80,2	20	1,00E-01	5,68E+04	2,24
PP25	100	2,99E+05	77,61	40	6,31E-01	2,90E+05	0,09
PP25	31,6	1,08E+05	80,28	40	1,99E-01	1,06E+05	0,04
PP25	10	3,81E+04	82,53	40	6,31E-02	3,73E+04	0,05
PP25	3,16	1,31E+04	84,5	40	1,99E-02	1,28E+04	0,06
PP25	1	4,37E+03	86,18	40	6,31E-03	4,30E+03	0,03
PP25	0,316	1,43E+03	87,48	40	1,99E-03	1,42E+03	0,01
PP25	0,1	4,69E+02	88,34	40	6,31E-04	4,64E+02	0,01
PP25	100	1,46E+04	85,13	60	2,24E-02	1,42E+04	0,06
PP25	31,6	4,85E+03	86,96	60	7,07E-03	4,79E+03	0,01
PP25	10	1,58E+03	88,03	60	2,24E-03	1,59E+03	0,00
PP25	3,16	5,07E+02	88,98	60	7,07E-04	5,19E+02	0,05
PP25	1	1,61E+02	89,61	60	2,24E-04	1,68E+02	0,21
PP25	0,316	5,06E+01	89,97	60	7,07E-05	5,42E+01	0,50
PP25	0,1	1,58E+01	90	60	2,24E-05	1,74E+01	0,99
PP25	100	1190	88,49	80	1,58E-03	1,14E+03	0,20
PP25	31,6	3,80E+02	89,27	80	5,01E-04	3,70E+02	0,06
PP25	10	1,19E+02	90	80	1,58E-04	1,20E+02	0,01
PP25	3,16	3,81E+01	90	80	5,01E-05	3,85E+01	0,01

Performance Grade	PG 46			PG 52							PG 58					PG 64					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day max pavement design temp, °C[a]	<46			<52							<58					<64					
Min pavement design temperature, °C[a]	>-34	>-40	>-46	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	> 22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40
Original Binder																					
Flash point temp, T 48, min °C	230																				
Viscosity, T 316:[b] max 3 Pa•s, test temp, °C	135																				
Dynamic shear, T 315:[c] G*/sinδ,[d] min 1.00 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Rolling Thin-Film Oven Residue (T 240)																					
Mass change,[e] max, percent	1.00																				
Dynamic shear, T 315: G*/sinδ,[d] min 2.20 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Pressurized Aging Vessel Residue (R 28)																					
PAV aging temperature, °C[f]	90			90							100					100					
Dynamic shear, T 315: G* sinδ,[d] max 5000 kPa test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Creep stiffness, T 313:[g] S, max 300 MPa m-value, min 0.300 test temp @ 60 s, °C	−24	−30	−36	0	−6	−12	−18	−24	−30	−36	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	−30
Direct tension, T 314:[g] Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	−24	−30	−36	0	−6	−12	−18	−24	−30	−36	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	−30

- DSR: Original binder

  G*/sin(δ) min 1kPa @ 10 rad/s

T (ºC)	G*	δ (º)	G*/sin(δ)	Satisfy?
52	2,53	85,1	2,54	yes
58	1,15	86,6	1,15	yes
64	0,549	87,9	0,55	no

Automatically discarded PG64

- DSR: RTFOT

  G*/sin(δ) min 2,2 kPa @ 10 rad/s

T (ºC)	G*	δ (º)	G*/sin(δ)	Satisfy?
58	3,26	83,1	3,28	yes
64	1,49	85,1	1,50	no

- DSR: PAV

  G*.sin(δ) max 5000 kPa @ 10 rad/s

T (ºC)	G*	δ (º)	G*.sin(δ)	Satisfy?
19	5100	46,6	3706	yes
16	8020	43,6	5531	no

- BBR: PAV

  S max 300 MPa; m min 0,3 @ 60 s

T (ºC)	S	m	Satisfy?
-18	117	0,346	yes
-24	291	0,281	no

Concluding it is possible to say, that the bitumen can be classified as a **PG 58-24.**

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Exercise 2 b

Bituminous mixtures: Mix-design Marshall

By applying the Marshall method, perform the mix design of a bituminous mixture to be employed as a wearing course. Bitumen type is selected on the basis of environmental conditions and traffic by employing the SUPERPAVE methodology. Maximum and minimum daily air temperature data are available from 2007 to 2016 in "Temperature_Data.xlsx". The site location in which the mixture will be employed is characterized by latitude of 45.22° and the selected reliability is 98 %. The laboratory mix design study requires volumetric and mechanical tests on different mixtures with the same aggregate skeleton but different binder content. Starting from a first trial bitumen content by weight of aggregates (%B'), defined by specific-surface method (Duriez), other four different binder contents were considered (%B' ± 0.5 % and %B' ± 1 %).
Input data:

- Layer thickness: 5 cm;
- Aggregates: 4 different grades of gravel (G1, G2, G3, G4), 2 sand grades (S1, S2), filler (F). For each grade is available the granular size distribution (see Table 1);
- Aggregate blend: to be defined in such a way that the final gradation is within the specification limits given by CIRS (Table 4.6 pag.4/6 Technical specifications);
- MMVT and MV are available in Table 2 for each of the 5 mixtures with different binder content (2 samples of loose mixture and 4 Marshall specimens);

Mechanical properties were determined by means of Marshall Stability and flow test. For each mixture, 4 Marshall Specimens were tested. Obtained results are reported in Table 3 (Marshall stability (S), flow (s), and average thickness (h));
Specification limits: Table 4.8 pag.4/7 of CIRS technical specifications.

1. Binder type selection

1.1. Maximum and Minimum design temperature

- **Maximum air temperature**

It was calculated as the maximum value of 7 days moving average of each of the year:

$$\boldsymbol{Tmax_{a,i} = Tmax_{d,i}(Mov.Avg(7d))}$$

Then was taken the mean value of all the years in the data
The results are shown in the following table:

Tmax a,i (°C)	Year										Tmax mean (°C)
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	
	30,7	29,4	30,6	28,3	30,6	32,9	29,1	27,9	30,4	29,5	29,9

LAT	45,22
H (mm)	20
z for (98%)	2,054
σ max	1,443548
σ min	2,856649
Tmax	29,9
Tmin	-8,84

So, the results are:

Tmin,p	-13,3918
Tmax,p	54,1176

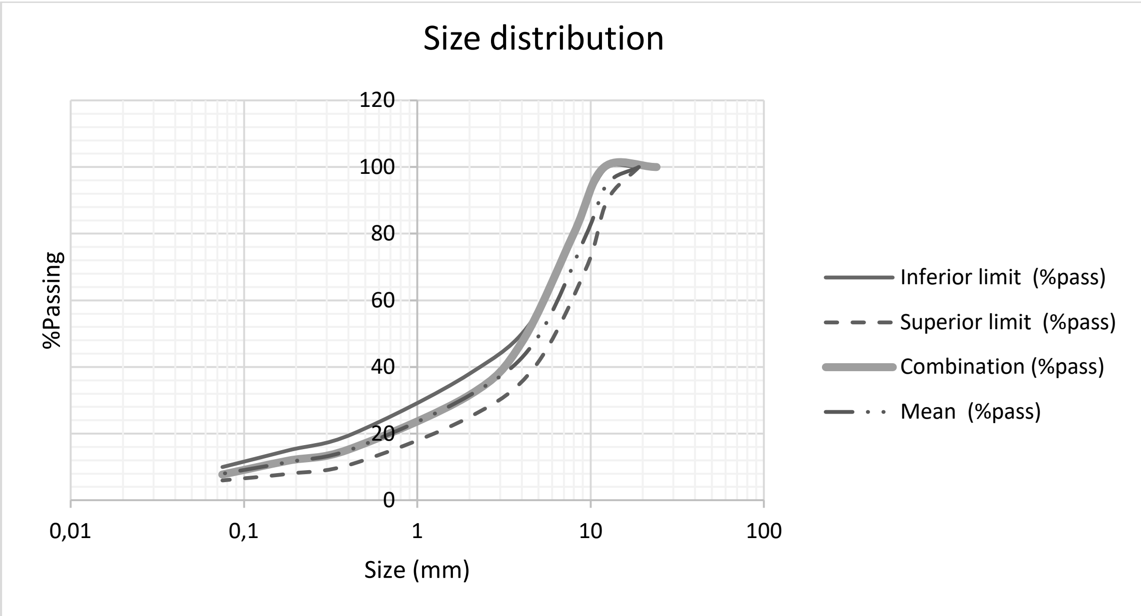
1.2. Binder type selection

According to the table of the PG classification:

Performance Grade	PG 46			PG 52							PG 58					PG 64					
	34	40	46	10	16	22	28	34	40	46	16	22	28	34	40	10	16	22	28	34	40
Average 7-day max pavement design temp, °C[a]	<46			<52							<58					<64					
Min pavement design temperature, °C[a]	>-34	>-40	>-46	>-10	>-16	>-22	>-28	>-34	>-40	>-46	>-16	> 22	>-28	>-34	>-40	>-10	>-16	>-22	>-28	>-34	>-40
Original Binder																					
Flash point temp, T 48, min °C	230																				
Viscosity, T 316:[b] max 3 Pa•s, test temp, °C	135																				
Dynamic shear, T 315:[c] G*/sinδ,[d] min 1.00 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Rolling Thin-Film Oven Residue (T 240)																					
Mass change,[e] max, percent	1.00																				
Dynamic shear, T 315: G*/sinδ,[d] min 2.20 kPa test temp @ 10 rad/s, °C	46			52							58					64					
Pressurized Aging Vessel Residue (R 28)																					
PAV aging temperature, °C[f]	90			90							100					100					
Dynamic shear, T 315: G* sinδ,[d] max 5000 kPa test temp @ 10 rad/s, °C	10	7	4	25	22	19	16	13	10	7	25	22	19	16	13	31	28	25	22	19	16
Creep stiffness, T 313:[g] S, max 300 MPa m-value, min 0.300 test temp @ 60 s, °C	−24	−30	−36	0	−6	−12	−18	−24	−30	−36	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	−30
Direct tension, T 314:[g] Failure strain, min 1.0% test temp @ 1.0 mm/min, °C	−24	−30	−36	0	−6	−12	−18	−24	−30	−36	−6	−12	−18	−24	−30	0	−6	−12	−18	−24	−30

Was selected the binder:

PG 58-16



3. Estimation of first trial binder content

It was estimated the specific surface, using **Duriez's equation**:

$$\Sigma = \frac{1}{100}(0{,}17G + 0{,}33g + 2{,}30A + 12a + 135f)\ [m^2/kg]$$

Where:

- G = % gradation > 10 mm
- g = % gradation 5 mm < size < 10 mm
- A = % gradation 0,3 mm < size < 5 mm
- a = % gradation 0,075 mm < size < 0.3 mm
- f = % gradation < 0,075 mm

The result is shown is the following table:

G (%)	0,00
g (%)	19,91
A (%)	64,83
a (%)	7,49
f (%)	7,77
∑	12,9466651

Then, applying the following equation in order to calculate the trial binder content

$$\%B = K \cdot \Sigma^{1/5}$$

Where:

- K = Richness modulus, which in this case is 3,5

Then, is obtained:

K	3,5
%B	5,84

6. Determination of mechanical properties

There are some remarks that had needed to considerate:

- If the specimen's thickness (h) differs from 63.5 mm, it is needed to make an adjustment to the measured stability, S.

$$c = 5{,}2 \cdot e^{-0{,}02598 \cdot h}$$

Scorrected = S * c

- If the thickness is not comprised in the interval from 60.5 to 66.5 mm, the specimen is rejected.
- Test results are considered reliable if S and s differs less than 15 % and 20 % respectively from the average value of the four replications. If these conditions are not satisfied, the specimen is rejected, and a new average is performed on the three remaining samples. Then the verification procedure is repeated. The variation is calculated in a generic way as:
-

$$Variation\% = \frac{value - mean}{mean}$$ sr r

- For the Marshall Quotient is used the equation:

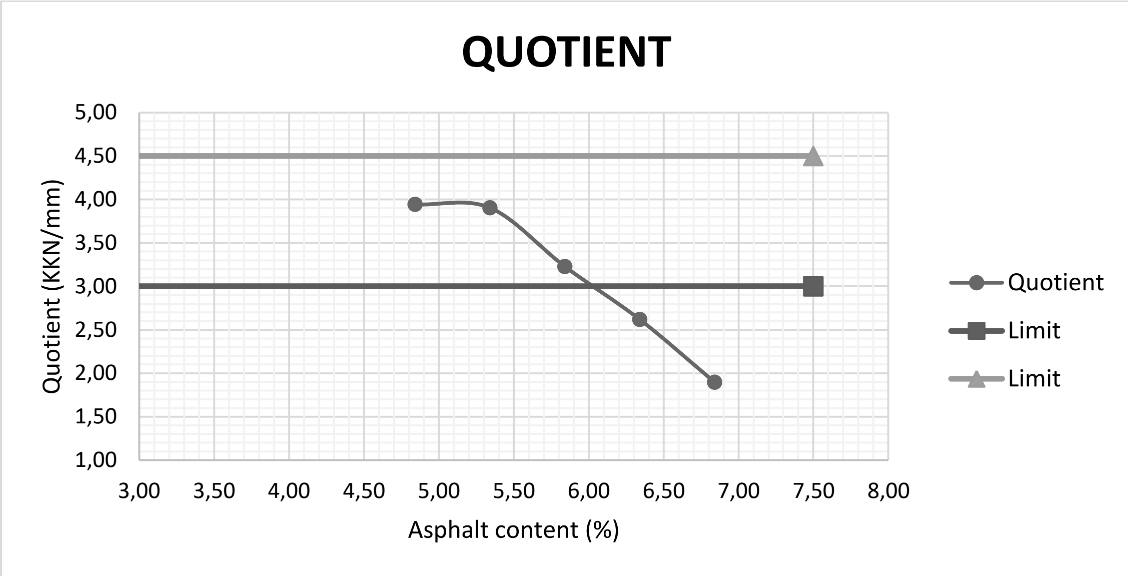
Q = S/s [kN/mm]

- For the final analysis is necessary to obtain the different means for each parameter and for each specimen according to the binder content.

And the different results for the calculations are in the following table:

	h (mm)	S (KN)	c	S adjust (KN)	s (mm)	S adjust mean (KN)	s mean (mm)	S Variation (%)	s Variation (%)	Aceptance	S mean (KN)	s mean (mm)	Q (KN/mm)	Qmean (KN/mm)
%B - 1%	63,58	10,68	0,997	10,65	2,55	10,33	2,50	3,08	2,000	YES	10,67	2,71	4,18	3,94
	65,08	10,22	0,959	9,80	2,65			-5,13	6,000	YES			3,70	
	63,5	9,32	0,999	9,31	1,88			-9,86	-24,800	NO			-	
	63,33	11,52	1,003	11,56	2,92			11,91	16,800	YES			3,96	
%B - 0.5%	65,23	15,3	0,955	14,61	3,50	12,83	3,28	13,85	6,707	YES	12,83	3,28	4,17	3,90
	63,88	13,2	0,989	13,06	3,31			1,73	0,915	YES			3,94	
	63,25	11,21	1,005	11,27	3,10			-12,18	5,488	YES			3,64	
	64,83	12,85	0,965	12,40	3,21			-3,39	2,134	YES			3,86	
%B	65,1	12,92	0,958	12,38	3,85	12,77	3,96	-3,08	2,839	YES	12,77	3,96	3,22	3,23
	65	14,25	0,961	13,69	4,30			7,18	8,517	YES			3,18	
	66,13	13,3	0,933	12,41	3,65			-2,86	7,886	YES			3,40	
	63,9	12,76	0,989	12,61	4,05			-1,24	2,208	YES			3,11	
%B + 0.5%	66,28	12,1	0,929	11,24	4,10	11,50	4,45	-2,19	7,865	YES	11,50	4,40	2,74	2,62
	67,43	12,4	0,902	11,18	4,60			-2,72	3,371	NO			-	
	64,93	12,25	0,962	11,79	4,43			2,56	0,449	YES			2,66	
	65,98	12,23	0,937	11,45	4,67			-0,37	4,944	YES			2,45	
%B +1%	61,35	7,02	1,056	7,42	4,98	9,29	5,02	-20,14	0,797	NO	9,50	5,03	-	1,90
	61,3	9,15	1,058	9,68	4,80			4,23	4,382	YES			2,02	
	62,45	10,44	1,027	10,72	5,05			15,42	0,598	NO			-	
	64,35	9,55	0,977	9,33	5,25			0,50	4,582	YES			1,78	

The rejected samples are highlight in green.

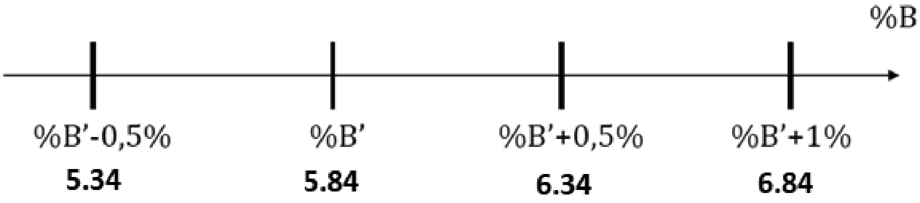


	Binder content (%)	S mean (KN)	s mean (mm)	Qmean (KN/mm)	v mean(%)
%B - 1%	4,84	10,67	2,71	3,94	5,95
%B -0.5%	5,34	12,83	3,28	3,90	4,31
%B	5,84	12,77	3,96	3,23	3,62
%B+0.5%	6,34	11,50	4,40	2,62	3,00
%B+ 1%	6,84	9,50	5,03	1,90	2,73

In this case are obtained two values of binder contents that satisfy all the specifications so due to engineering criteria is selected the binder content equal to **%B -0.5%** because we are using the economic criteria for the selection.

4. Preparation of trial HMA blends at different binder content (4)

In this case are considerate 4 configurations of binder content, and are the following



5. Preparation of gyratory specimens (2) at N_{max} and determination of volumetric properties and workability

First can be defined some important remarks to determine the volumetric properties and workability.

- the geometrical density of the sample can be calculated with the following equation:

$$MV(geo) = D(geo) = \frac{Wm}{Vmx}$$

Where W_m is the weight of the specimen and V_{mx} is the volume of the cylindrical mould that can be found as

$$Vmx = 17.6515 * hx = Vmould$$

And hx is the height of the sample.

- Due to surface irregularities, the real volume of the specimen is smaller than the geometric one and for that reason, is necessary to correct D(geo) through the correction factor C defined as:

$$c = \frac{MV(measured) for\ Nmax}{MV(geo) for\ Nmax}$$

And the densities corrected can be defined as:

$$MVcorrected = Dcorrected = c * MV(geo)$$

- The degree of compaction or the percentage of the theoretical maximum density present can be obtained as (TMD=MMVT):

$$\%TMD = \frac{MVcorrected}{MMVT} * 100$$

- For the calculation of the voids content is used the equation:

$$\%voids = 100 - \%TMD$$

For the solution has been given the following data:

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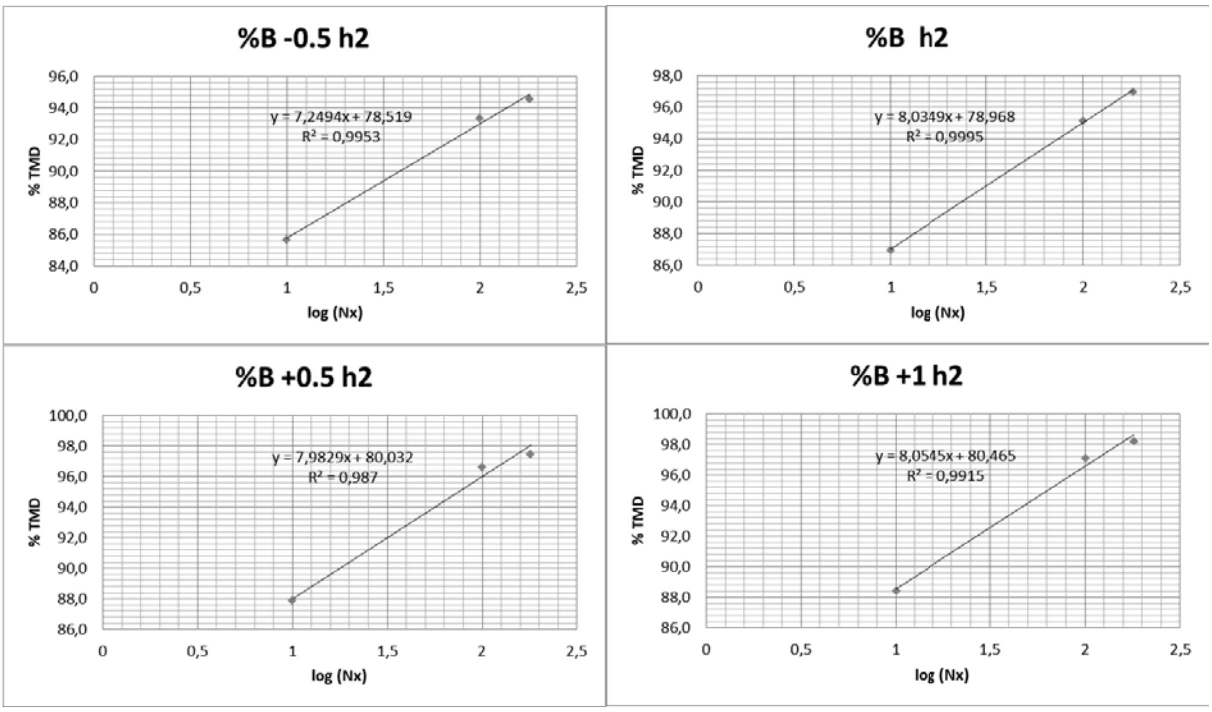


6. Evaluation of volumetric properties at N_{design} (N_{ini} e N_{max})

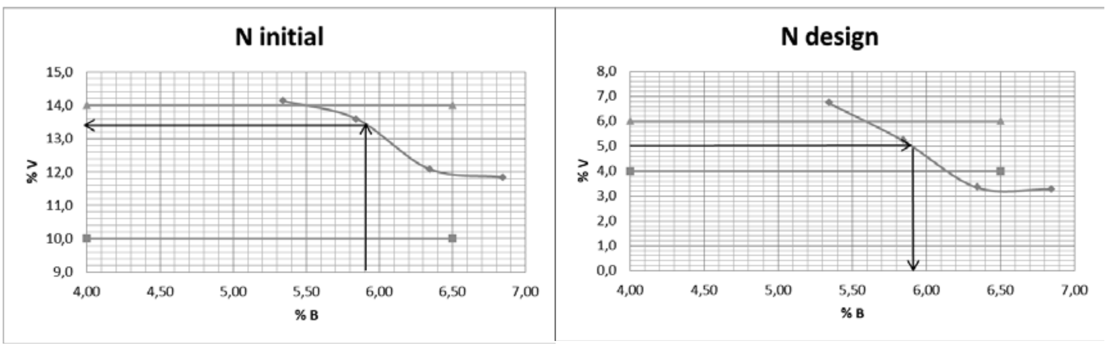
Here are calculated the average of different voids content found in the previous numeral and the results are in the following table:

	Voids mean (%)			
Nini	14,1	13,6	12,1	11,9
Ndes	6,7	5,2	3,3	3,3
Nmax	5,6	3,4	2,4	2,2
B%	**5,34**	**5,84**	**6,34**	**6,84**

7. Determination of the optimum binder content

To check the optimum binder content is plotted the curves to check the conditions of voids at certain number of revolutions.

[Ni = 10; Nd = 100; Nmax = 180 gyrations].



Checking the acceptance of the voids content again considering the average between both H:

	Voids mean (%)	Aceptance
Nini	12,2	yes
Ndes	4,9	yes
Nmax	3,2	yes

Also it was important to check the resistance of the indirect tensile strength and indirect tensile strength ratio. This was done with the following equations:

ITS (Indirect tensile strength):

$$ITS = \frac{2P}{\pi DH}$$

Where:

- P = peak load in KN
- D = diameter of the sample (mm)
- H = height of the sample (mm)

ITSR (indirect tensile strength ratio):

$$ITSR = (ITSw/ITSd) \cdot 100$$

- ITSRw = indirect tensile strength of the specimens with 15 days in water.
- ITSRd = indirect tensile strength of the specimens with 15 days in air.

Then, the results are shown in the following table:

Specimen	1	2	3	4	5	6
Conditions	15 days in water			15 days in air (control)		
Height, H (mm)	99,5	99,3	99,4	99,3	99,2	99,3
Peak load, P (KN)	16,72	16,484	17,441	20,803	20,065	20,354
Diameter (mm)	150					
ITS (MPa)	0,713	0,705	0,745	0,889	0,858	0,870
ITS w,d (Mpa)	0,721			0,873		
ITSR (%)	82,613					

LOSS IN ITS = 100 – ITSR = 100 – 82.613 = 17.387% < 25% → verified!

The limits on the curves came from the table:

Tabella 4.7

METODO VOLUMETRICO		Strato pavimentazione		
Condizioni di prova	*Unità di misura*	Base	Binder	Usura
Angolo di rotazione		1.25° ± 0.02		
Velocità di rotazione	Rotazioni/min	30		
Pressione verticale	Kpa	600		
Diametro del provino	mm	150		
Risultati richiesti				
Vuoti a 10 rotazioni	%	10 – 14	10 – 14	10 – 14
Vuoti a 100 rotazioni (*)	%	3 – 5	3 – 5	4 – 6
Vuoti a 180 rotazioni	%	> 2	> 2	> 2
Resistenza a trazione indiretta a 25°C (**)	N/mm^2			> 0,6
Coefficiente di trazione indiretta[2] a 25 °C (**)	N/mm^2			>50
Perdita di resistenza a trazione indiretta a 25°C dopo 15 giorni di immersione in acqua	%	≤ 25	≤ 25	≤ 25

(*) La densità ottenuta con 100 rotazioni della pressa giratoria viene indicata nel seguito con D_G
(**) Su provini confezionati con 100 rotazioni della pressa giratoria

According to the curves it is possible to see that only for **%B = 5, 91** are verified the test conditions for voids in 10, 100 and 180 rotations. Also the limits for tensile strength parameters were checked and verified.

ORAL EXAM QUESTIONS

1. What is the complex modulus G*? What is its physical meaning? How it can be obtained?
2. What's the creep stiffness S(t)? What's the physical meaning and how's obtained?
3. What's the thermal cracking? In which conditions it happens? What parameters represent it? [S(t) and m]. What are these parameters? Why do we calculate them in a long term aged configuration? From which test do we calculate them? How is made the test, at which temperature and why? [Tmin+10° for 60 seconds otherwise the test would last 2 hours but we don't want such a long time because the purpose of the superpave classification is to do quick tests and reliable].
4. What type of settlements exist? How and why are they evaluated?
5. What is the hourly production? Parameters and differences between the machines (times, efficiency, effective volume).
6. Performance grade classification of bitumens.
7. IRI parameter and pavement texture? How is done the calculation? What is a quarter car? Validity of IRI with respect to the wavelength.
8. How is classified a soil? Granulometric distribution? Parameters that we need.
9. Rheological tests. How parameters change in time and with temperature?
10. Master curves.
11. Tests on bitumens.
12. Tests on soils.
13. Tests on mixtures.
14. Resilient modulus: what does it represent? How is it calculated?
15. What is viscosity? What is a visco-elastic material?
16. Meaning of the range of temperature for binders. How is temperature calculated?
17. What are the steps and parameters to be calculated for Marshall mix design?
18. What are the steps and parameters to be calculated for Volumetric mix design?
19. In the superpave classification what is the tests done for original, short term and long term bitumen?
20. Layers of the pavement, characteristics and properties?

TIPS!

Obviously the questions can be about all the treated arguments and posed in a different way.

It is important to understand the relationship between the tests and the physical meaning of each parameter and concept. Also is good to know the basis of classification method and the differences.

In the written exam precision of results (drawings, decimal numbers,...) is very important to achieve a higher mark.

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OSC	E_u/c_u		
	PI < 30	30 < PI < 50	PI > 50
< 3	600	300	125
3 - 5	400	200	75
> 5	150	75	50

Tabella 1

FORMULARIO

$$S_i = \frac{\gamma \cdot h}{E_u} \cdot \frac{a^2}{a - a'} \cdot \left\{ r_H - \left(\frac{a'}{a} \right)^2 \cdot r'_H \right\}$$

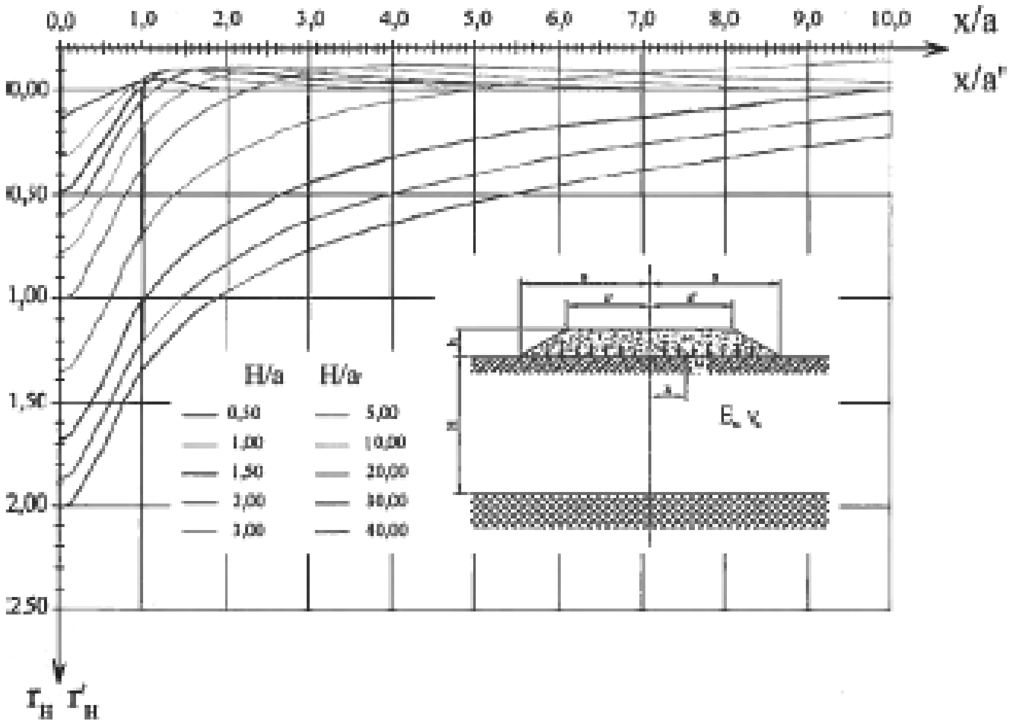
$$S_c(t) = H \cdot \frac{C_c}{1 + e_0} \cdot \log \frac{\sigma'_{v0} + \Delta\sigma'_v}{\sigma'_{v0}}$$

$$C_c = 0{,}009 \cdot (w_L - 10)$$

$$\sigma_z = \frac{q}{\pi} \cdot [\alpha + \sin(\alpha) \cdot \cos(\alpha + 2\beta)]$$

$$\sigma_z = \frac{q}{\pi} \cdot \left[\frac{x}{B} \cdot \alpha - \frac{1}{2} \cdot \sin(2\beta) \right]$$

$$U_m = \frac{\left(4 \cdot \frac{T_v}{\pi} \right)^{\frac{1}{2}}}{\left[1 + \left(4 \cdot \frac{T_v}{\pi} \right)^{2,8} \right]^{0,179}}$$



#5

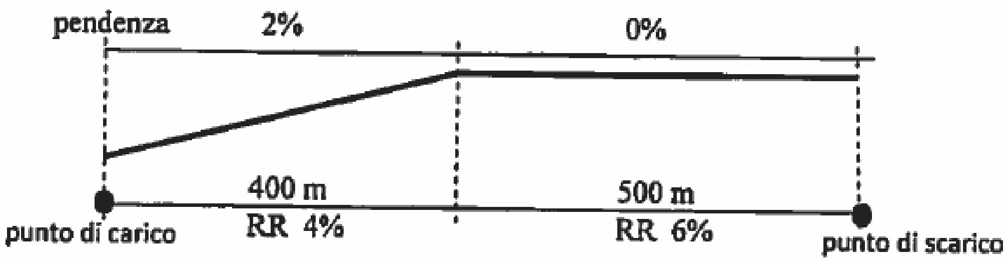
Si chiede di determinare il numero di dumper necessari per effettuare il trasporto dalla zona di stoccaggio al cantiere del materiale necessario alla formazione dello strato di fondazione in misto granulare. Verificare l'idoneità dei mezzi utilizzati sia dal punto di vista statico che geometrico.
Siano noti i seguenti dati:

PALA CARICATRICE GOMMATA	**DUMPER**
Capacità della benna: 5.6 m^3	Capacità del cassone: 16,4 m^3
Carico statico di ribaltamento: 25 000 kg	Massimo carico netto trasportabile: 36 000 kg
Massima altezza di scarico : 4 100 mm	Altezza di carico: 3 m
	Larghezza cassone: 3 m
Tempo ciclo: 0,5 minuti	Tempi fissi di manovra (zona di carico e scarico): 1,5 min
	Tempo per il trasporto: (utilizzare nomogramma di pag.4)

Informazioni generali:
Densità del materiale in banco: 1 800 kg/m^3
Fattore di rigonfiamento: 8%
Fattore di riempimento: 97% (PALA e DUMPER)

Efficienza oraria: 50 minuti su 60
Efficienza di cantiere: 80% (climatico + specifico di cantiere)

Andamento altimetrico del percorso



#6

ESERCIZIO #2
Determinare la percentuale di bitume di progetto di una miscela in conglomerato bituminoso per strato di binder secondo le prescrizioni previste nella tabella 4.7 del Capitolato CIRS – metodo volumetrico.
Sono noti i risultati volumetrici delle 4 miscele contenenti percentuali diverse di bitume (vedi Tabella 1).
Per ogni miscela sono stati prodotti 2 campioni di diametro 150 mm e per ciascuno di essi si è determinato l'altezza del campione a 100 e 180 rotazioni (h), la massa volumica reale a 180 giri (MV), il peso del materiale impiegato (W) e la massima massa volumica teorica (MMVT). Sviluppare l'esercizio utilizzando lo schema di calcolo riportato in Tabella 1.
Didascalia Tabella 1:
MV(geo) : massa volumica geometrica
MV(cor) : massa volumica corretta
%C : percentuale di compattazione
C : fattore di correzione
%v@100: percentuale dei vuoti a 100 rotazioni
%B: percentuale di bitume

#7

Un terreno su cui dovrà essere realizzato un rilevato stradale ha la stratigrafia riportata in Figura 1.

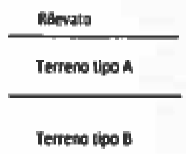


Figura 1

Siano noti i risultati delle analisi granulometriche effettuate su tali terreni e su quello costituente il corpo del rilevato:

Diametro [mm]	Trattenuto [g]			Passante [%]		
	A	B	Rilevato	A	B	Rilevato
63	0.0	0.0	0.0			
31,5	0.0	265.8	668.9			
16	0.0	582.3	785.6			
8	10.4	469.2	556.0			
4	44.9	364.8	700.0			
2	56.9	658.2	789.6			
1	42.3	1568.9	556.0			
0,5	33.0	856.1	759.0			
0,063	219.1	862.1	768.9			
0,002	1269.8	223.6	358.9			
< 0,002	2369.1	122.3	258.7			

Si richiede di classificare il terreno secondo la normativa EN 14688-2 e di rappresentare graficamente la distribuzione granulometrica dei terreni indagati.
Siano noti, inoltre, i seguenti dati:

- Cedimento totale: 36.2 cm
- Cedimento immediato: 2% del cedimento di consolidazione
- Coefficiente di consolidazione primaria c_v: 3,2 x 10^{-6} m^2/s
- Tempo di costruzione del rilevato: 70 giorni
- Spessore dello strato A: 10 m

Si richiede di calcolare il cedimento residuo al termine della costruzione del rilevato e di confrontarlo con le richieste delle norme tecniche CIRS.