R3 28 05 01 Technical Directive

Calculations for underground pipes

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Issue : July 2000

Version : 2.0

For use at location IJmuiden

The latest version can be retrieved via Intranet at Tata Steel (ProjectNet) or internet https://www.tatasteeleurope.com/ts/nl/gezondheid-en-veiligheid/toegang-en-veiligheid-ijmuiden/voorschriften .

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1. GENERAL

CUR report no. 122 and the ATV guidelines referred to in the report can be drawn on for the dimensions of underground pipes.

In those cases not provided for by CUR and/or ATV, a highly automated computer input is present at TE-VKT-CIV for the ANSYS finite element method program. See Annex A.

The following can be used to gain a general impression of the strength and rigidity of underground pipes.

The calculation method described below applies for underground pipes without internal pressure. So, conduits, drainpipes, etc., loaded solely by soil and site load. It is assumed that pipes will have been laid in broad trenches or under embankments. The longitudinal and cross sections of pipes will be considered. The influence of the weight of the pipe itself will be negligible.

2. SYMBOLS

B = total external load per length unit
D = internal diameter
E = modulus of elasticity of pipe material
Eg = stiffness number of the soil
G = load as a result of earth fill per length unit
H = soil cover on the top of the pipe
I = moment of inertia of the pipe wall per length unit
M = moment per length unit
n = stiffness ratio of the pipe in relation to the soil
P = minimum test load in accordance with a ‘skull’compression test
Q = load as a result of site load per length unit
S = impact factor
W = section modulus of the pipe wall per length unit
c = bed coefficient, depending on how the pipe is supported in the site
e = wall thickness of the pipe
d = wall thickness of the pipe after any corrosion
g = soil pressure as a result of backfilling
k = test setup coefficient
q = soil pressure as a result of site load
v = safety coefficient
äv = vertical deformation
γ = unit weight of the soil
á = bed angle
ko = spring constant of the soil.

3. EXTERNAL LOAD

A distinction is made between load as a result of vertical soil pressure G and site load Q. The total external load on the pipe is:

$$B = G + Q.$$

3.1. Soil

The extent of the vertical soil pressure on the pipe will depend on the flexibility of the pipe in relation to the soil in which it has been laid.
The following criterion applies in this respect:

$$n = \frac{Eg \text{ x } (D + e)^3}{E \text{ x } e^3}$$

The stiffness number of the soil to be maintained for the Tata Steel site – based on backfilling and compacting – must be in accordance with Annex B.

$$Eg = 10 \text{ N/mm}^2$$

The time-dependent E must be entered for E for plastic pipes, among other types of pipe.

If n is smaller than 1, the pipe is “rigid”. If n is bigger than 1, the pipe is “flexible” in relation to the soil in which it has been laid.

The vertical soil pressure must now be calculated as follows:

“rigid” pipes (n smaller than or equal to 1)

$$G = (D + 2 e) \text{ x } g$$

g can be taken from Chart 1.

“flexible” pipes (n bigger than 1)

$$G = (D + 2 e) \text{ x } \gamma \text{ x } H$$

17 kN/ m^3 must be maintained for γ.

3.2. Site load

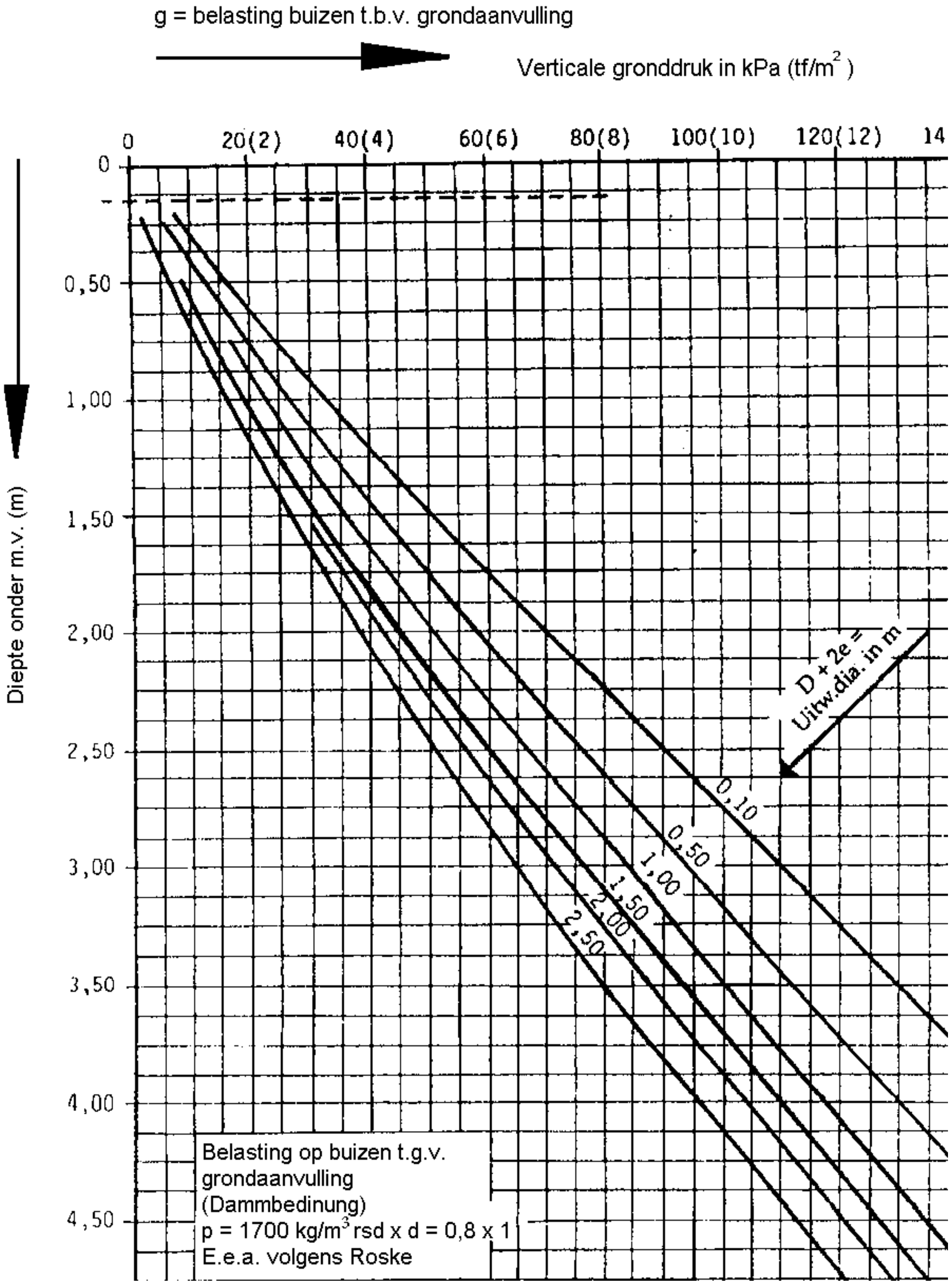
The vertical soil pressure on pipes as a result of site load must be calculated on the basis of the following formula for both “rigid” and “flexible” pipes:

$$Q = (D + 2\,e) \times q \times S$$

S must be determined in accordance with Annex C; D + e must be maintained for L.
q can be taken from Chart d1 for track vehicles and from Chart d2 in Annex D, page 21, for road vehicles.

A value of at least 20 kPa must be maintained for q x S.

Chart 1



1 kPa = 0.1 tf/m^2

4. STRENGTH

4.1. Cross section

Where pipes made from stone-like materials have been laid in a sand or concrete bed, it is customary to relate the strength of the pipe in the site to the test load in accordance with a so-called 'skull'compression test.
Based on test load

$$\nu = \frac{P \times c}{B \times k}\left(\frac{d}{e}\right)^2$$

The bed coefficient c follows from Chart 2. The test setup coefficient k follows from Table 1.

Table 1

Test setup	$\frac{2M}{P(D+e)}$	k
1. Line load - line support	0.318	0.90
2. As 1, with elastic intermediate layer	0.296	0.97
3. NEN 7025 and NEN 3261	0.291	0.99
4. DIN 4032	0.287	1.00
5. NEN 7025 with a bearing angle of 120º	0.277	1.04
6. N 370	0.271	1.06

Note:
The coefficients given will apply for the maximum moments applicable.

Based on permissible stress

$$\sigma = \frac{M}{W}$$

M follows from the table above.

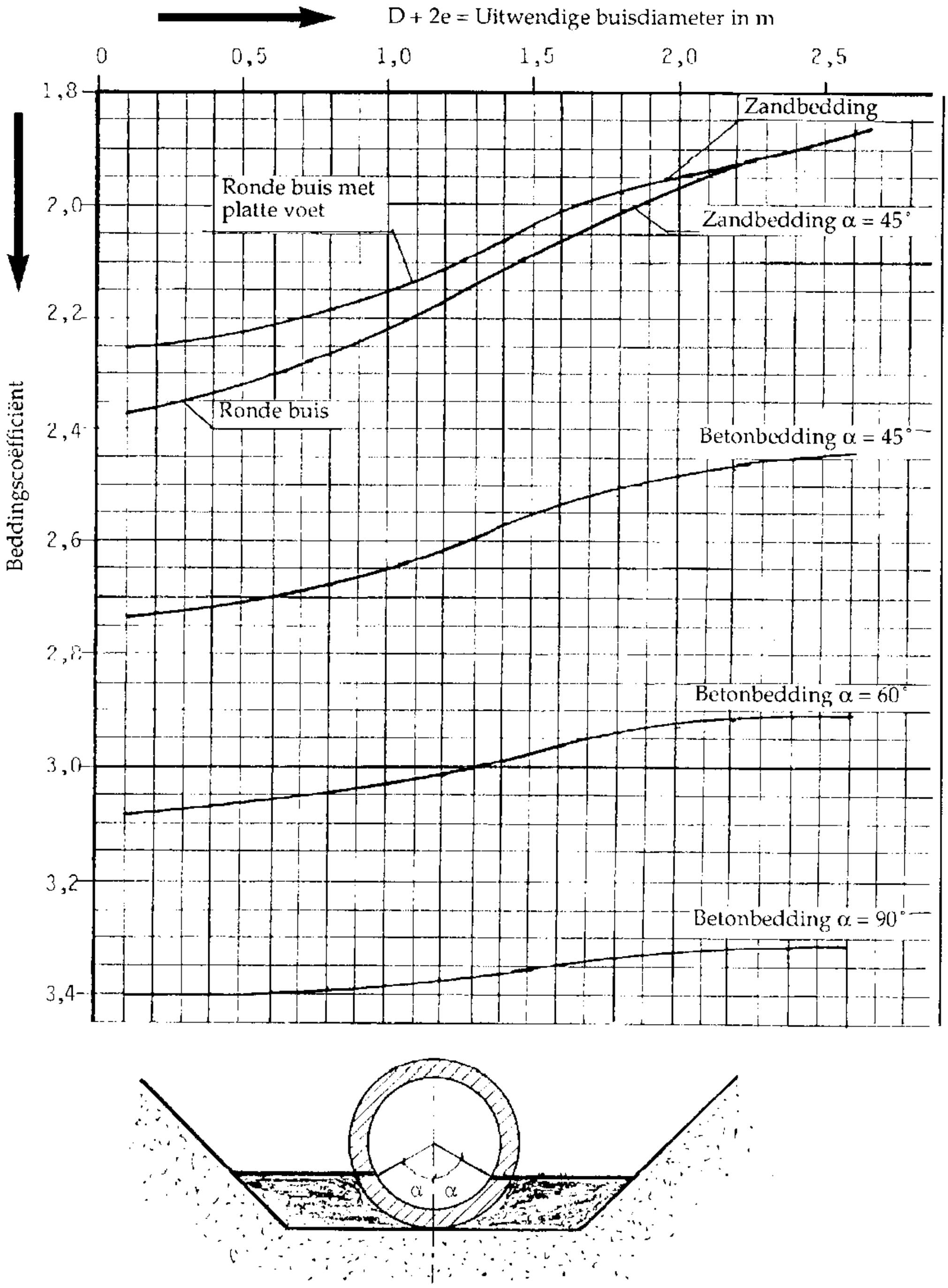
No uniform formulas exist for pipes made from materials other than stone-like materials (these are generally "flexible" pipes). If a pipe is laid in a sand bedding that has been backfilled in accordance with Annex B and n is smaller than 1500, the maximum moment applicable can be calculated in accordance with:

$$M = B \times (D + e) \times \left[0{,}0667 - \frac{0{,}00634\ n}{1 + 0{,}095\ n}\right]$$

For n, see Subsection 3.2

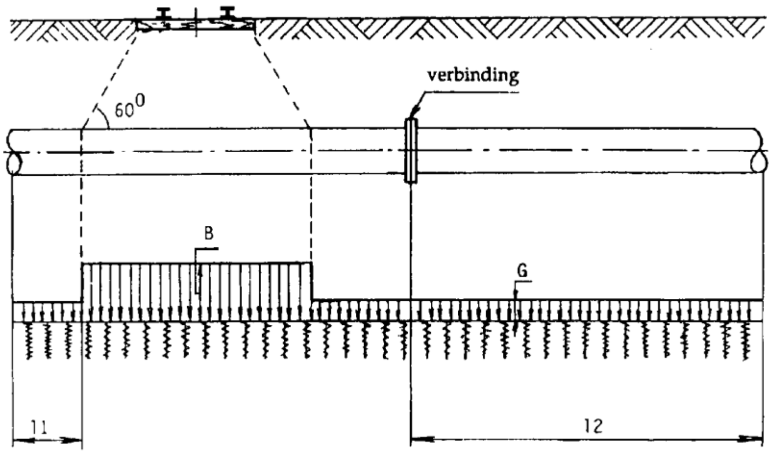
Chart 2

c = beddingscoëfficiënt (volgens: Betonrohe nach DIN 4032 von "Kurt Roske")



4.2. Longitudinal section

For some pipes, it may be necessary to consider the influence of loads and/or "rigid" supports on the longitudinal section (this is not necessary for pipes that consist of a number of "short" sections, such as drains, because of the large number of flexible connections used).
Where pipes without "rigid" supports are concerned, it will not be necessary to take non-uniform settlement into consideration, but only the influence of the concentrated load.
The B and G loads calculated in accordance with Section 3 must be brought in accordance with the figure below.



The load depicted in this manner will be transferred to the subgrade via the elastically supported pipe.
The spring constant of the subgrade must be calculated on the basis of the following:

$$k_0 = 20.000 \text{ kN} / \text{m}^3$$

while the width (b) value required for this calculation must be based on:

$$b = D + 2e$$

On each side of the concentrated load, or any flexible connections, etc. present, a length of $\ell 1$ or $\ell 2$ respectively must be taken into consideration at the very least, equal to:

$$\ell \geq \pi \text{ x } \sqrt[4]{\frac{4 \text{ x E x } I_\ell}{b \text{ x } k_0}}$$

In this formula $I_\ell = \dfrac{\pi D^3 e}{8}$

So, the formulas provided in the book entitled *Beams on elastic foundation* by M. Hetenyi or a computer program for the calculation of elastic supported beams, for example, can be used to calculate deformations, moments and transverse forces.

5. RIGIDITY

5.1. Cross section

As an approximation, the following formula can be used if appropriate:

$$\nu = \frac{B\,(D+e)^3}{E \text{ x } e^3} \text{ x } \left[0{,}135 - \frac{0{,}023\ n}{1+0{,}173\ n} \right]$$

Note:
The time-dependent E must be entered for E for plastic pipes, among other types of pipe.
For n, see Subsection 3.2.

5.2. Longitudinal section

These deformations follow from Subsection 4.2.

6. EXAMPLES

a) A round drain pipe, internal measurement 600 mm and made from mass concrete, in compliance with NEN 7025, is laid under a track with 2.5 m soil cover. The track is used by 140-ton hot roller-wagons. The safety coefficient is required for a pipe to be laid in a concrete bed where á = 60°.

Information about the pipe:

internal diameter	D = 600 mm
wall thickness	e = 80 mm
minimum failure load	P = 60 kN/ m
modulus of elasticity	E = 25,000 N/ mm²

<u>External load:</u>
Soil

$$n = \frac{Eg \times (D + e)^3}{E \times e^3} = \frac{10 \times (600 + 80)^3}{2500 \times 80^3} = 0{,}25$$

n is smaller than 1, so the pipe is "rigid".

It follows from Chart 1 that H = 2.5m and D + 2e = 0.76 m that g = 71 kPa.
So:

$$G = (D + 2e) \times g = 0.76 \times 71 = 53.96 \text{ kN/m.}$$

Track
The impact coefficient to be charged is:

$$S = 1 + \frac{40}{100 + L} - 0{,}1 \times H$$

$$S = 1 + \frac{40}{100 + (0{,}60 + 0{,}08)} - 0{,}1 \times 2{,}5 = 1{,}15$$

The following follows for 140-ton hot roller-wagons (line F) from Chart D1 in Annex D at H =2.50 m:

$$q = 55 \text{ kPa, so:}$$

Total $\quad Q = (D + 2e) \times q \times S = 0.76 \times 55 \times 1.15 = 47.96$ kN/m.

So, the total external load is:

$$B = G + Q = 53.96 + 47.96 = 101.92 \text{ kN/m.}$$

Coefficient of safety

It follows from Chart 2 that

á = 60° and (D + 2e) = 0.76 m that c = 3.05.

According to Table 1, k = 0.99 in case of a test setup in accordance with NEN 7025.

So, the coefficient of safety is:

$$\nu = \frac{P \text{ x } c}{B \text{ x } k} \text{ x } \left(\frac{d}{e}\right)^2$$

$$\nu = \frac{60 \text{ x } 3{,}05}{101{,}92 \text{ x } 0{,}99} \text{ x } \left(\frac{0{,}08}{0{,}08}\right)^2 = 1{,}8$$

b) Steel pipe ö 600 x 6 and then as under a). The stresses applicable and the deformation of the cross section are required.

<u>External load:</u>
Soil

$$n = \frac{10 \text{ x } (60+6)^3}{2{,}1 \text{ x } 10^5 \text{ x } 6^3} = 49{,}1$$

n is bigger than 1, so the pipe is “flexible”

$$G = (D \text{ x } 2e) \text{ x } \gamma \text{ x } H = 0.612 \text{ x } 17 \text{ x } 2.5 = 26.01 \text{ kN/m}$$

Track
The impact coefficient to be charged is:

$$S = 1 + \frac{40}{100 + L} - 0{,}1 \text{ x } H$$

$$S = 1 + \frac{40}{100 + (0{,}60 + 0{,}006)} - 0{,}1 \text{ x } 2{,}5 = 1{,}15$$

The following follows for 140-ton hot roller-wagons at H = 2.5 m from Chart C1 from Annex D:

$$q = 55 \text{ kN/m}^2$$

$$Q = (D + 2e) \text{ q x } S = 0.612 \text{ x } 55 \text{ x } 1.15 = 38.71 \text{ kN/m}$$

Total
So, the total external load is:

$$B = G + Q = 26.01 + 38.71 = 64.72$$

Stress:
The moment applicable is

$$\sigma = \frac{M}{W} = \frac{461}{\frac{1}{6} \times 6^2} = 76{,}8\ N/\ mm^2$$

Deformation:
The vertical deformation follows from

$$\delta\nu = \frac{B\,(D+e)^3}{E \times e^3} \times \left[0{,}135 - \frac{0{,}023 \times n}{1+ 0{,}095 \times n}\right]$$

$$\delta\nu = \frac{64{,}72 \times 0.606^3}{2{,}1e\ S \times 0{,}006^3} \times \left[0{,}135 - \frac{0{,}023 \times 49{,}1}{1+ 0{,}095 \times 49{,}1}\right] =$$

$$\delta\nu = 0.0051\ m = 5.1\ mm$$

7. REFERENCES

Reference is made to the following in this Technical Directive:

VOSB 1963

NEN 7025

The ANSYS finite element method program.

The book entitled *Beams on Elastic Foundation* by M. Hetenyi

Annexes A, B, C and D

Tata Steel drawings:

114.280
536.540
320.805
079.456
525.183
094.357
464.232
307.774
A03.361
278.770
687.904
835.875
184.803
576.135.

8. DECLARATION

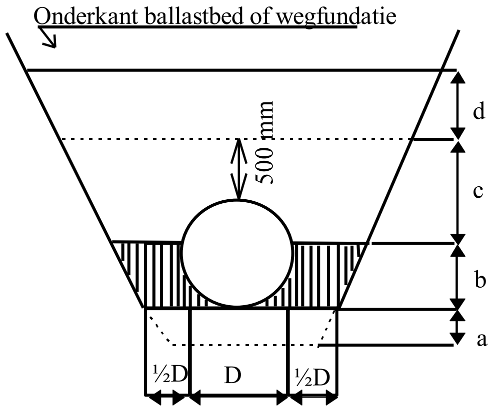
Version 1.0:
This Technical Directive replaces HO standards

51.00.80.002
00.85.05.001
00.85.05.002
00.85.84.001
00.85.84.002.

Version 2.0:
Annex A:
Input file for ANSYS EEM program lapsed.
Logos changed and Hoogovens replaced by Tata Steel.

<u>Annex A</u>
SOIL BACKFILL AND COMPACTING EXCAVATIONS

The backfill and compacting method described below is advised in order to ensure that soil is restored to its original condition after excavation as much as possible. A distinction is made between layers a), b), c) and d). See the figure below.



<u>Layer a)</u>
In certain cases, such as when laying plastic pipes or where tanks are concerned, it will be necessary to dig a trench that is 250 mm deeper and then backfill it with clean sand. Having done this, the trench will have to be compacted with a vibration rammer with a compacting depth of 500 mm.

<u>Layer b)</u>
Apply sand in layers of 250 mm, up to half the height of the pipe. The sand under the pipe is to be compacted with a manual rammer. Each layer is to be compacted mechanically with a vibration rammer with a compacting depth of 500 mm.

<u>Layer c)</u>
Apply backfill in layers of at most 500 mm. Each layer is to be compacted by means of a compacting beam weighing at least 500 kg. Compacting must continue until no settlement is visible with the naked eye any more, and will always consist of at least two courses.

<u>Layer d)</u>
If it is not expected that a road or track will cross the backfill within two years, the remaining sand may be placed in the trench without any further work being required.

Note:
Sand fill may not contain any stones or suchlike. It may not be applied with a bulldozer under 500 mm above the top of the pipe.

A.1. Checking compacting

A sand backfill, compacted in the manner outlined above, will yield a cone penetration resistance value of
5 N/ mm². In practice, checks on whether this value has actually been achieved can be carried out as follows. Take a rod of non-profiled reinforcing steel that is 10 mm round and approximately 1 metre long. Bend this rod to create a handle. Next, push this rod into the soil to be inspected. In a well-compacted backfill, the rod, loaded with 500 N, may not be pushed in to a depth of more than 200 mm.

Annex B
IMPACT COEFFICIENT FOR UNDERGROUND CONSTRUCTIONS

There is no Dutch standard in which the influence of the soil on underground constructions is expressed in the impact coefficient. A number of coefficients are known from literature on the subject. The formulas that follow below have been derived from NEN 1008 in terms of the length of the span and DIN 1072 in terms of the thickness of the soil.

Tracks:

$$S = 1 + \frac{60}{100 + L} - 0{,}3 \times H \quad \text{indien } H < 1 \text{ m is}$$

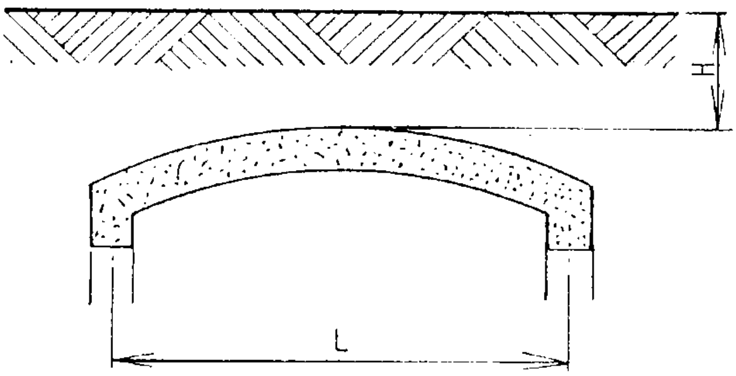
$$S = 1 + \frac{40}{100 + L} - 0{,}1 \times H \quad \text{indien } H >= 1 \text{ m is}$$

Roads:

$$S = 1 + \frac{40}{100 + L} - 0{,}1 \times H$$

In these formulas:

S = impact coefficient (a minimum of 1)
L = span in metres
H = soil cover in metres

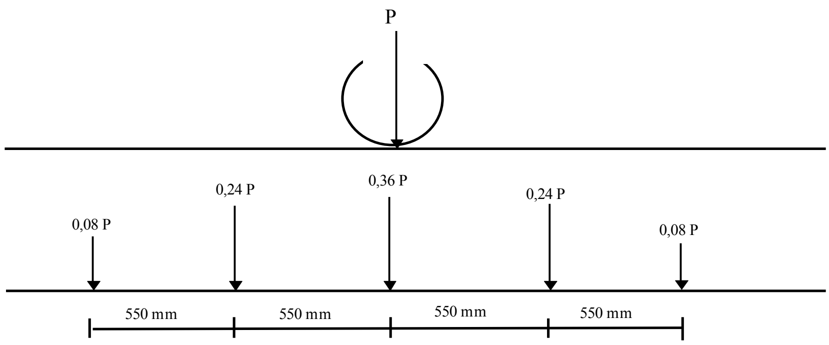


<u>Annex C</u> DISTRIBUTION IN THE SOIL

Given distribution in the soil, underground constructions will be loaded by just a part of the concentrated load on the site. A popular method used to determine distribution is the method developed by Boussinesq. Tests on the Tata Steel site have shown that this method works well here. Therefore, drawing on the formula developed by Boussinesq, vertical soil pressures have been determined for the vehicles known at the current time for tracks and roads.

C.1. Tracks

The rail spreads the wheel load to the sleepers in accordance with the figure below. It is assumed that the sleepers will load the site evenly across the entire length.



Based on the above, the vertical soil pressures have been determined for the rail vehicles named at points a) to n) inclusive for different depths. These are shown in Chart d1. The values shown in this chart are the maximum soil pressures that will apply under track centre. The soil pressure is lower perpendicular to the rail. The soil pressure will vary in the longitudinal direction of the track too, depending on the rail vehicle. However, these deviations will be small within an area of 2 x 2 m, because of which the values shown in the chart can be maintained for the entire area. The influence of one track under track centre (centre-to-centre, 4.5 m) has been determined for a double track.

a) COCKERILL loco 41 tons (drawing 114280)

```
(===========|======|===========)
            |      |
            v      v
   3330       1900      3330
```

Own weight 41 tons. Max. load 0 ton.
Total 41 tons, which is 205 kN/axle.

b) O and K loco 90 tons (drawing 536540)

```
(=======|========|============|========|=======)
        |        |            |        |
        v        v            v        v
  2075     2400       3600       2400     2075
```

Own weight 90 tons. Max. load 0 ton.
Total 90 tons, which is 225 kN/axle.

c) GE loco 92.5 tons (drawing 320805)

```
(=======|========|=============|========|=======)
        |        |             |        |
        v        v             v        v
  1984     2362       3784        2362     1984
```

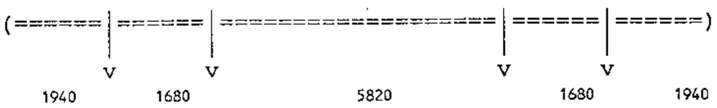
Own weight 92.5 tons. Max. load 0 ton.
Total 92.5 tons, which is 231.25 kN/axle.

d) 100-ton foundry car (drawing 79456)

```
(===|====|===|====|===)
    |    |   |    |
    v    v   v    v
 855  1100 1040 1100  855
```

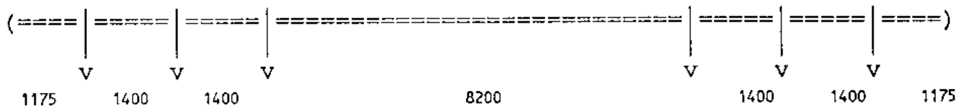
Own weight 20 tons. Max. load 100 tons.
Total 120 tons, which is 300 kN/axle

e) 100-ton flat wagon (drawing 525183)



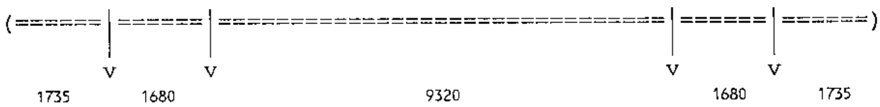
Own weight 42 tons. Max. load 100 tons.
Total 142 tons, which is 355 kN/axle.

f) 140-ton flat wagon with six axles (drawing 94357)



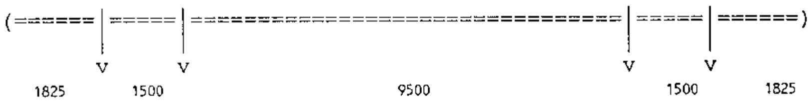
Own weight 34 tons. Max. load 140 ton.
Total 174 tons, which is 290 kN/axle

g) 140-ton flat wagon with four axles, converted (drawing 464232)



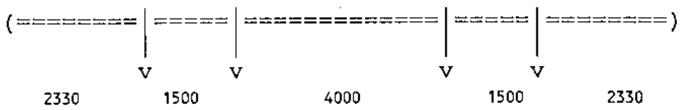
Own weight 34 tons. Max. load 140 tons.
Total 174 tons, which is 435 kN/axle.

h) 200-ton flat wagon (drawing 307774)



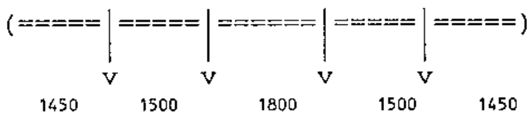
Own weight 41 tons. Max. load 200 tons.
Total 241 tons, which is 602.5 kN/axle.

i) 140-ton hot roller-wagons (drawing A03361)



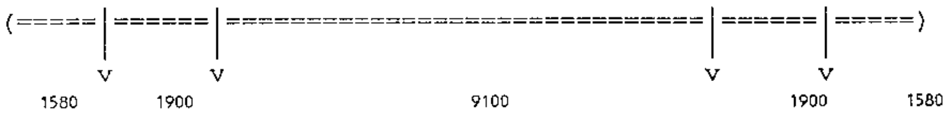
Own weight 46 tons. Max. load 140 tons.
Total 186 tons, which is 465 kN/axle.

j) 200-ton hot roller-wagons (drawing 278770)



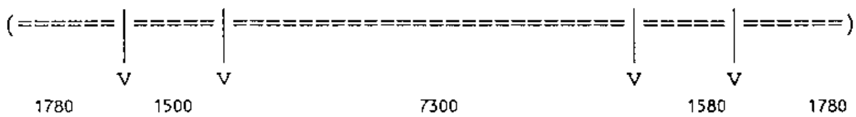
Own weight 37 tons. Max. load 200 tons.
Total 237 tons, which is 592.5 kN/axle.

k) 200-ton Rowagg hot roller-wagons (drawing 687904)



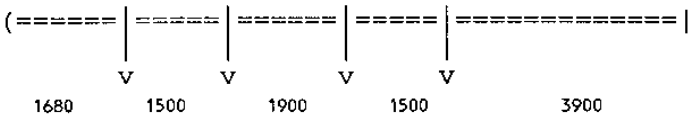
Own weight 36 tons. Max. load 200 tons.
Total 236 tons, which is 590 kN/axle.

l) 200-ton De Vries hot roller-wagons (drawing 835875)



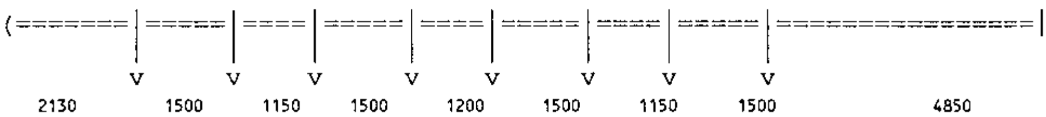
Own weight 36 tons. Max. load 200 tons.
Total 236 tons, which is 590 kN/axle.

m) 200-ton mixer (drawing 184803)



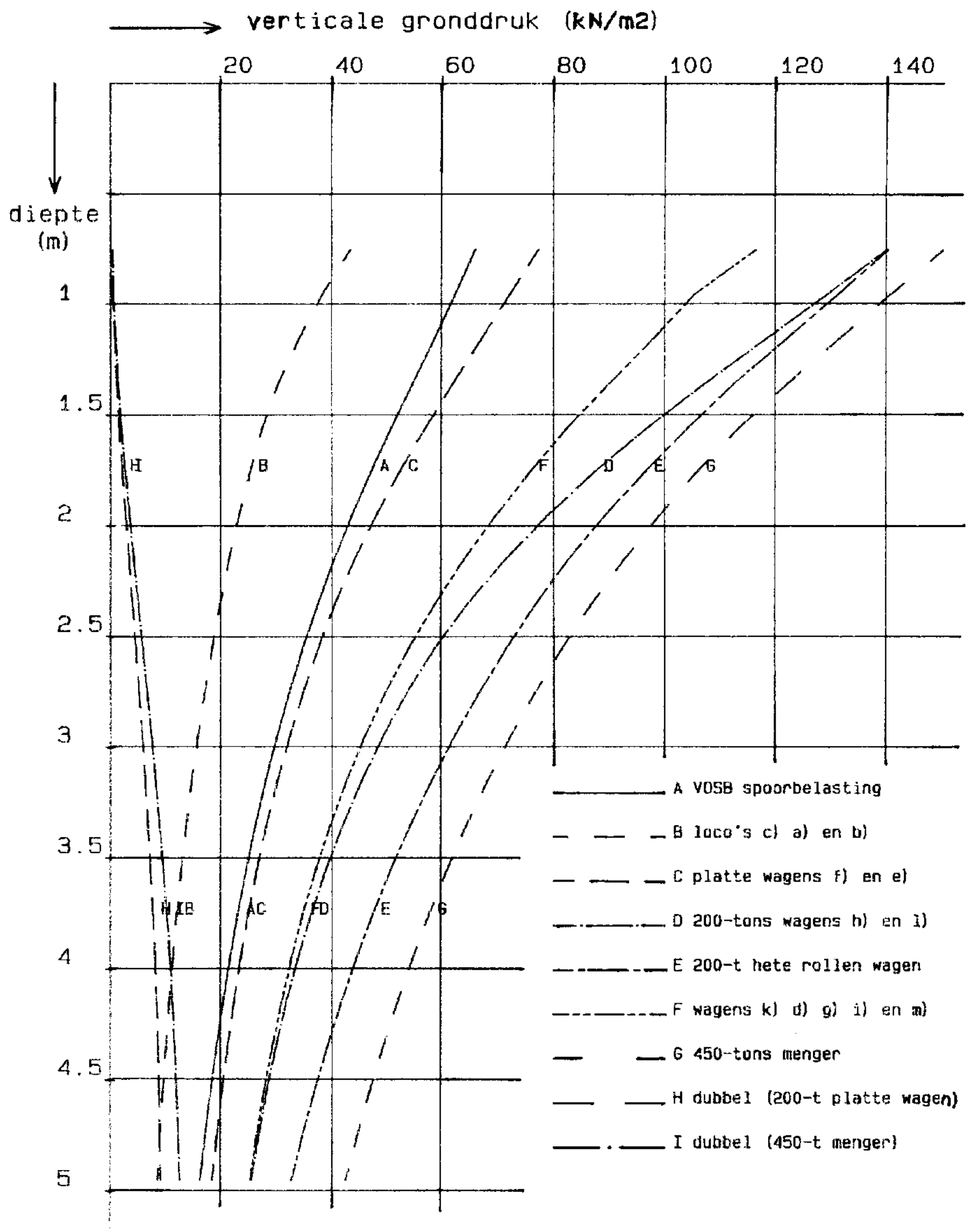
Own weight 172 tons. Max. load 200 tons.
Total 372 tons, which is 465 kN/axle.

n) 450-ton mixer (drawing 576135)



Own weight 375 tons. Max. load 450 tons.
Total 825 tons, which is 515.625 kN/axle.

Chart C1



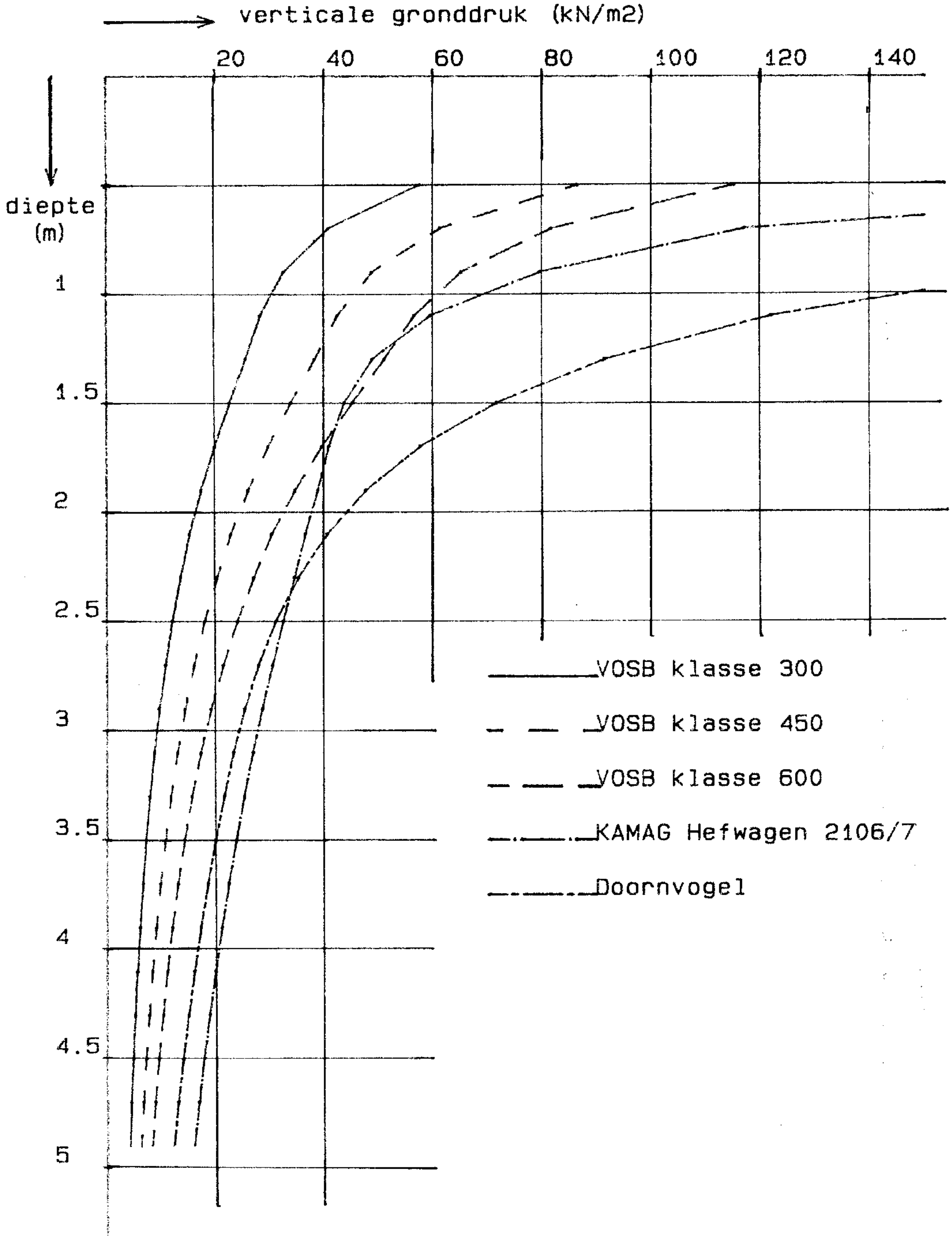
verticale gronddruk (kN/m2)
20
40
60
80
100
120
140
diepte
(m)
1
1.5
2
2.5
3
3.5
4
4.5
5
H
B
A
C
F
D
E
G
A VOSB spoorbelasting
B loco's c) a) en b)
C platte wagens f) en e)
D 200-tons wagens h) en i)
E 200-t hete rollen wagen
F wagens k) d) g) i) en m)
G 450-tons menger
H dubbel (200-t platte wagen)
I dubbel (450-t menger)

C.2. Roads

The road surface ensures the distributed transmission of wheel loads to the soil. It is assumed that the wheel load will be distributed evenly on a surface of (b + 0.25) x (1 + 0.25) m². Here, (b x 1) is the tyre imprint left by a wheel.

The vertical soil pressures applicable for various depths have been determined for the load systems referred to in VOSB 1963, for the KAMAG lift trucks and the Doornvogel based on the above. These are shown in Chart C2. The values shown in this chart are the maximum soil pressures applicable; soil pressures will vary depending on the point under the vehicle considered. However, these deviations will be small within an area of 1 x 1 m, because of which the values shown in the chart can be maintained for the entire area.

Chart C2


verticale gronddruk (kN/m2)
20
40
60
80
100
120
140
diepte
(m)
1
1.5
2
2.5
3
3.5
4
4.5
5
VOSB klasse 300
VOSB klasse 450
VOSB klasse 600
KAMAG Hefwagen 2106/7
Doornvogel