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DESIGN METHOD AND GUIDELINES FOR GEOTEXTILE APPLICATION IN ROAD CONSTRUCTION

METHODE DE DIMENSIONNEMENT ET RECOMMANDATIONS POUR L'EMPLOI DE GEOTEXTILES EN CONSTRUCTION ROUTIERE

ENTWURFSVERFAHREN UND RICHTLINIEN FÜR DIE VERWENDUNG VON GEOTEXTILIEN IM STRASSENBAU

In this paper the general procedure is elaborated for the application of the geotextiles in unpaved low volume roads. Specifications and guidelines for geotextiles are derived according to the following procedure:
- Identification of relevant functions.
- Identification of relevant geotextile parameters.
- Specification of the geotextile parameters with the aid of proper calculation or design methods.
- Selection of the most appropiate test method.

Special attention is given to the description of mechanisme and calculation methods. The final guidelines and specifications have been compiled into a set of tables and a handy design manual.
These guidelines may be used as well for paved high volume roads under certain conditions.
Considering the use of geotextile in railway construction, only a synoptic state of the art has been given.

Die allgemeine Prozedur für die Verwendung von Geotextilien in unbefestigten Strassen wird ausgearbeitet. Niederländische Anforderungen und Richtlinien für Geotextilien werden anhand folgender Prozedur festgelegt:
- die Bestimmung relevanter Funktionen;
- die Bestimmung relevanter geotextiler Parameter;
- die Spezifizierung der geotextilen Parameter mittels geeigneter Berechnungs- oder Entwurfsverfahren;
- die Auswahl der geeignetesten Untersuchungsmethode.

Besondere Aufmerksamkeit wird der Beschreibung der Mechanismen und der Berechnungsverfahren gewidmet. Die endgültigen Richtlinien und Anforderungen sind in eine Anzahl von Tabellen und in ein handliches Handbuch aufgenommen. Diese Richtlinien können ebenfalls unter bestimmter Bedingungen für befestigte Strassen mit einer hohen Verkehrsbelastung angewandt werden. Hinsichtlich der Verwendung von Geotextilien in Eisenbahnbauten wird ein kurzer Überblick über die derzeitigen Kenntnisse gegeben.

1. ROAD CONSTRUCTION

1.1 Separation

Separation is defined as the function that prevents the penetration of aggregate into the subsoil. So the original dimensions and strength of the aggregate layer is preserved, which reduces maintenance costs. Separation is a very important function of a geotextile in the unpaved road application.

Geotextile parameters, which are relevant in connection with the separation function, are:
- puncture strength, since the geotextile should not be punctured by the aggregate;
- tear strength, since an accidental initial damage should not cause tearing of the geotextile;
- stress-strain energy (i.e. product of mobilized stress and strain), since this parameter is decisive for the compatibility and thus the integrity of the geotextile in the soil geotextile aggregate (s.g.a.) system, especially when the subsoil is very weak.

1.2 Filtration

Filtration is defined as the function that prevents the migration of subgrade into the aggregate. This migration is mainly due to the high pore pressures that are generated by the traffic load (the so called "pumping" effect). This function is very important, since fine particles from the subgrade will increase sensitivity of the aggregate to moisture and frost.

Geotextile parameters, which are important in connection with the filtration function are:
- Effective Opening Size (E.O.S.), since the size of the openings in the geotextile should be sufficient small to retain the fine particles of the subgrade.
- Permeability, especially the long term permeability. This should exceed the permeability of the subgrade to avoid pore pressure build up underneath the geotextile.

1.3 Reinforcement

A geotextile can reinforce a s.g.a. system in different ways. Which way depends on geometry, bearing capacity of the subsoil, traffic load and number of load coverages. If the axle load is heavy, the subsoil very weak or the aggregate layer thin, the subsoil will fail at the first load passes. Generally this failure will involve rather large deformations. The geotextile has to follow these deformations and is consequently stretched. The membrane or catenary action of the geotextile will give a resultant uplift force underneath the wheels and a resultant downward force in the zone between the wheels (fig. 1). This type of reinforcement is called "membrane action".

If, on the other hand, the load and subsoil conditions are more favourable, the subsoil will not fail, but only show some deformation. This deformation will grow slightly with each new load coverage.
The aggregate will also be deformed for reasons of compatibility, which will induce larger shear stresses and load spreading in the aggregate. The geotextile takes lateral stresses and hence reduces shear stresses in the aggregate. This "lateral restraint" effect or more precisely "base restraint" effect enlarges the load spreading capacity of the base. Further also lateral movement of the subgrade is restraint by the geotextile due to the shear stresses between geotextile and subgrade. This reinforcement effect is called "subgrade restraint".

Due to this effect rutting will be reduced or more load coverages can be applied before the same rutting occurs.

Geotextile parameters which are important in connection with the reinforcement function are:

- Modulus of elasticity, since a high modulus geotextile will show more load spreading at the same rut depth, especially in case of "membrane action".
- Tensile strength, since it should be checked that the maximum stress occurring in the geotextile should not exceed its tensile strength.
- Creep and relaxation behaviour, which is especially important for the rutting and load redistribution in case of many load coverages.

Generally the "membrane action" is rather sensitive for geotextile parameters mentioned above, while the "lateral restraint" is less affected.

1.4 Lateral drainage and "sound board" function

Lateral drainage is defined as the ability of the geotextile to drain off water in lateral direction through its plane. However, it is rather doubtful if a geotextile can contribute significantly to lateral drainage especially on a long term.
The "sound board" function is defined as the action of the geotextile that improves the compactibility of the aggregate. It is most probably a mixture of separation and lateral restraint.
Both functions are rather unimportant, and will therefore not be treated here in more detail.

2. CALCULATION AND DESIGN METHODS FOR ROAD CONSTRUCTIONS

2.1 Calculation of "lateral restraint" reinforcement

Lateral restraint effects are reported explicitly many times in literature, e.g. Haliburton [1] and Potter and Currer [2]. Also in many papers reinforcement effects are mentioned, which should be ascribed to lateral restraint, since the used geotextiles were not stiff and strong enough to give significant membrane type reinforcement (e.g. Robnett et al [3], Barenberg [4] and part of the tests of Webster and Watkins [5]).
Steward [6] modifies the results of Barenberg somewhat according to his own experience gained from field tests. In his guidelines he uses $N_c^* = 2.8$ in the case without a geotextile and $N_c^* = 5.0$ for the case with a fabric inclusion.
However, a calculation method with a proper theoretical background has not been made yet. Therefore quantification of the lateral restraint effect must be bease purely on empirical data.
From these it can be stated that the bearing capacity factor N_c^* for the load point at which progressive deformation starts to occur, is about 3 without geotextile and about 5 with geotextile. This increase is due to lateral restraint effects.

2.2 Calculations of membrane type reinforcement

Literature review
Nieuwenhuis [7] considered the equilibrium of the membrane and so the resulting membrane equation for a number of loading cases. The soil reaction was obtained by means of a modulus of subgrade reaction. As the plastic deformation of the subsoil below a geotextile is usually quite large, it is difficult to represent the soil deformation behaviour by a modulus of subgrade reaction. Furthermore, the ultimate bearing capacity of the subsoil was not taken into account.
Nieuwenhuis, Bakker [8], Ludwig [9], Giroud and Noiray [10] use a method based on the ultimate bearing capacity theory of the soil.
However, in his method the equilibrium conditions are not fulfilled for the membrane since the deflection of the membrane is represented in an arbitrary way by broken straight line.
They restrict the plastic wedge to the zone directly below the wheel and they assume the weight of the aggregate at both sides as a counteracting surcharge. However, especially on very soft soil plastic wedge will be much larger due to the load spreading effect of the geotextile. In that case the weight of the aggregate is a driving force together with the traffic load, which should be balanced by the plastic soil reactions. This means that the calculation methods mentioned above are most probably unsafe for very bad subsoil conditions.
The calculation method of Sellmeijer et al [13] is used for the derivation of Dutch specifications for geotextile parameters related to the reinforcement function. Sellmeijer's method also includes right plastic soil behaviour and an empirical dependency of the number of load cycles. The method is described in detail by Kenter and Sellmeijer [14]. The method has been checked a.o. in two test sections, one of which was instrumented with electric strain gauges. Further calculation results were compared with results of test sections of Webster and Watkins [5] and Webster and Alford [11], mentioned in literature. Very good agreement was found. Therefore this calculation method will be described in detail in following paragraphs.

Description of calculation method

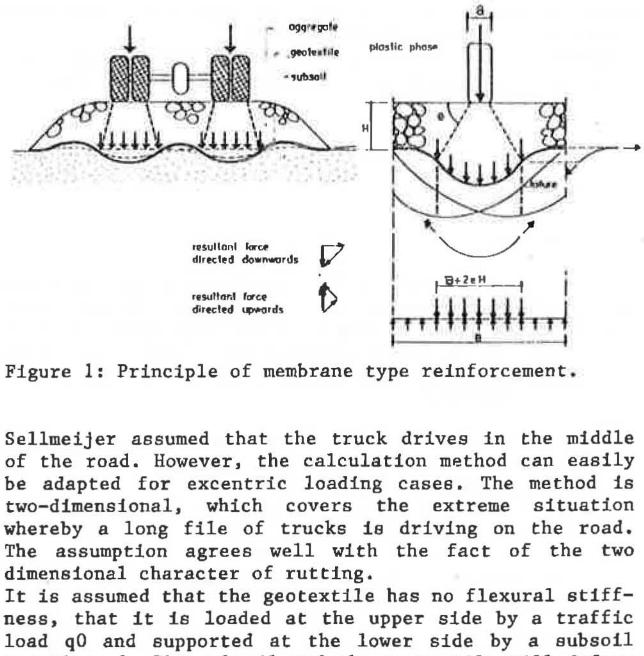


Figure 1: Principle of membrane type reinforcement.

Sellmeijer assumed that the truck drives in the middle of the road. However, the calculation method can easily be adapted for excentric loading cases. The method is two-dimensional, which covers the extreme situation whereby a long file of trucks is driving on the road. The assumption agrees well with the fact of the two dimensional character of rutting.
It is assumed that the geotextile has no flexural stiffness, that it is loaded at the upper side by a traffic load q0 and supported at the lower side by a subsoil reaction q1. The subsoil and the geotextile will deform under the influence of the wheel loads. The geotextile will elongate and is subsequently stressed. This causes a stress relief of the zone directly below the wheel load but the adjoining zones will be additionally stressed. This means that a geotextile will spread the wheel load over a larger area than when no geotextile is used.
The following equations describe the state of equilibrium of the geotextile:

$$S0\ (d^2w/dx^2) = -(q0 - q1) - \gamma H$$

$$S = S0 \sqrt{((dw/dw)^2 + 1)}$$

where:
S = tensile stress in geotextile
SO = horizontal component of s
w = vertical displacement of geotextile
x = horizontal distance to the centre of the truck
γ = unit weight of aggregate
H = aggregate height

It is assumed that the stress-deformation behaviour of the soil is bilinear, so it has an elastic phase and a plastic phase. However, the membrane reinforcement effect of a geotextile is almost negligible when the subsoil is in the elastic phase. So it is not further described.
The width of the plastic zone - the so-called failure width B - can be found from the vertical equilibrium requirement, whereby the sum of the subsoil reaction stresses ql must be equal to the wheel load F/2 plus the weight of the aggregate γ H:

$$Bql = F/(2(a + 2eH)) + \gamma Hb$$

or:

$$B = F/(2(ql - \gamma H)(a + 2eH))$$

where γ is the unit weight of the aggregate and H its thickness.

Three possible locations of the plastic subsoil zone can be distinguished, which is illustrated in figure 2.

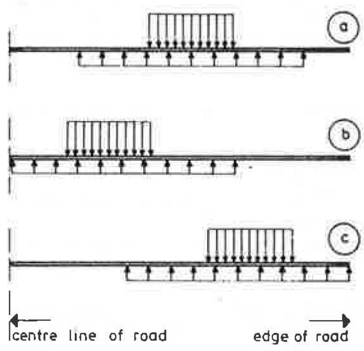


Figure 2: Possible location of plastic zone.

It is supposed that the geotextile is fixed at the edge of the road and can therefore not be pulled inwards to the centre of the road. If it can be expected that the geotextile will be subjected to large forces then proper attention has to be paid to the anchoring at the edges.

The rut depth is obtained as a function of all introduced parameters. It is also possible to start from an acceptable rut depth to determine the required modulus of elasticity and strength of the fabric. When this is done for a series of aggregate heights, an optimum road design can be made in an economical sense with regard to aggregate and fabric costs.

Equivalent axle load for many load cycles
In most cases, many load cycles will be applied, each of which is far below the bearing capacity of the road. But accumulated they can cause cumulative deformation that is decisive for the road design. Now one should design with the bearing capacity factor Nc of progressive deformation. For road foundations without geotextile this factor Nc is about 60% of the ultimate bearing capacity factor, so Nc = 3.

If a geotextile is applied, it is still possible to design with a bearing capacity factor of Nc = 5, because of lateral restraint effects.

In all cases of cumulative deformation due to many load cycles, an equivalent axle load should be introduced. From the results of a test section that was set up especially to test the calculation method, it could be derived that:

$$F_e = F_s \sqrt[6.2]{N}$$

where:
Fs = real axle load
Fe = equivalent axle load
N = number of load coverages

3.3 Separation function

Tear strength
It is always possible that a small damage of a geotextile occurs. For instance by a sharp stone punching through. In general such a small damage causes no harm, often the stone fills up the hole which it made in the geotextile, as long as the initial damage will not continue in the form of tearing.
The tear strength of the geotextile as used here is the force needed to cause continuous tearing of a geotextile when an initial damage occurs. The initial damage width is considered to be 0.02 m. The required tearing strength W (kN) = 0.01 . S (kN/m) in which S is the required working stress of the geotextile.

Puncture resistance

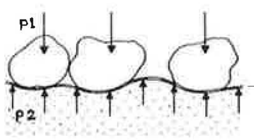


Figure 3: Stones punctu-ring geotextile.

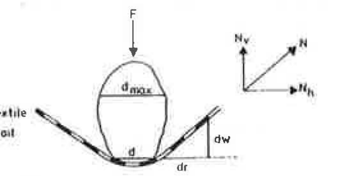


Figure 4: Stress due to puncturing.

Aggregate particles, stones, can punch through the geotextile into the subgrade. The pressure p, from the aggregate is equal to the distributed wheel load and the weight of the road subbase.

$$p1 = \frac{F/2}{(na + 2eH)(a + 2eH)} + \gamma . H$$

in which:
F = axle load $= p . \frac{\pi . d^2}{4}$
a = tire width
n = number of tires at each end of the axle
H = aggregate thickness

The pressure p2 from the subgrade is equal to p1 diminished by the load distribution by the geotextile. In case there is no load distribution by the geotextile (due to membrane type reinforcement) p1 = p2 = p.
At the contact point aggregate particle - geotextile is:

$$\pi . d . S_v = p . \frac{\pi . D^2}{4} - p . \frac{\pi . d^2}{4}$$

$$d . S_v = p/4 \ (D^2 - d^2)$$

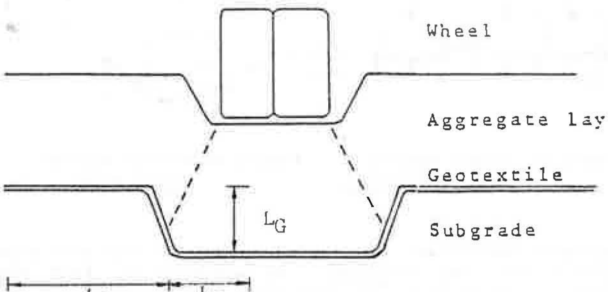
$$S_v = p/4d \ (D^2 - d^2)$$

$$S_v : S = dw : \sqrt{dw^2 + dr^2}$$

$$S_v = S . \frac{dw}{\sqrt{(dw)^2 + (dr)^2}} = S . \frac{1}{\sqrt{1 + (dr)^2/(dw)^2}}$$

So it is possible to determine the required geotextile stress along the circumference of the aggregate particle. The stress is related to the tangens of the geotextile at the contact point, the pressure on the geotextile and the particle shape and size.
This stress S can be translated to a practical value P (N) of the puncture resistance by multiplying S (kN) by the circumference of a contact circle.

Stress and strain
If the distributed wheel load transmits a greater load to the subgrade than the bearing capacity of that subgrade, significant rutting can occur comparable with general shear of the subgrade under the distributed wheel load area.
This mechanism is only valid if a geotextile in situ has a Young's modulus smaller than 100 kN/m, so no significant load distribution due to membrane type support would occur.
If the previously described mechanism of failure occurs, there will be a relatively high strain over a small area. Thus the local strain can be very high whilst the actual elongation is small. If the local actual elongation is not great enough to follow the settlements of the subgrade due to excessive rutting, is is necessary to prevent tearing of the geotextile, so that an additional elongation is provided from the areas on both sides of the overstrained zone which forms the outer edge of the part of the subgrade affected by the distributed wheel load.
This area, from which the required elongation of the geotextile is provided, is in fact the anchorage length over which the stress, that has been developed by the strain in the limited zone, will be reduced to zero due to friction on both sides of the geotextile.
Figure 5 gives a schematic representation of this phenomenon.



L_G = zone where a great local strain occurs.
L1 = area next to the distributed wheel load over which the stress developed in the more vertical zone is reduced to zero (comparable with the anchorage length).
L2 = area of the geotextile under the distributed wheel load over which the stress developed in the more vertical zone is reduced to zero (comparable with the anchorage length).

Figure 5 : Anchorage length of geotextile.

Pull-out test
To quantify the mobilized elongation of the geotextile along the anchorage length, use has been made of a pull-out test. This test consists of a strip of material clamped into a soil mass from which it is pulled out. With the measured force needed to pull the strip out of the soil mass and the anchorage length, one can determine the friction between the soil and the strip of material.

Development of stress, strain and elongation along the anchorage length
Assume that there is a linear Young's modulus of the geotextile. Alghough this assumption is made, it is quite possible to use any non-linear stress-strain behaviour of the geotextile, friction between geotextile and soil depending on relative movement (elongation) and even time effects due to creep and relaxation. The mathematical model and required information on geotextile properties will be more complex (figure 6).

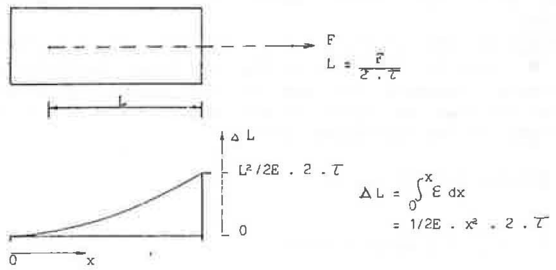


Figure 6: Development of stress, strain and elongation along the anchorage length.

To determine the total developed elongation over the whole anchorage length, the value of L when x = L is important. The equation for calculating this value L, is:

$$\Delta L = F \cdot \varepsilon F \cdot 1/4\,\tau$$

ΔL (m) = developed elongation along the whole anchorage length
F (kN/m) = developed stress in the geotextile at the edge of the soil mass
τ (kN/m^2) = mobilized friction between the geotextile and the surrounding soil mass
εF (-) = strain of the geotextile at the edge of the soil mass

So the total elongation of a geotextile clamped in a soil mass is directly proportional to the multiplication of the stress and strain in the geotextile, which in fact coincides with the multiplication of the Young's modulus of the geotextile and the strain raised to a square of the geotextile at the edge of the soil mass.

Comparison of various geotextiles
In the previous section friction τ (kN/m^2) was the same on both sides of the geotextile. With the application of geotextiles under a road foundation this is generally not the case. Moreover the friction between the geotextile and the surrounding material is not the same in the areas under and next to the distributed wheel load on the subgrade. To make the comparison between the various geotextiles as realistic as possible, the comparison will be made for the geotextile under and next to the distributed wheel load on the subgrade. In both cases the situation is described in which the applied geotextile is tearing. So ε F = strain at break and F = stress at break.
To involve the friction on the lower and upper side of the geotextile in the calculation the formula:

$$\Delta L = F \cdot \varepsilon F \cdot 1/4\tau$$

can be changed into:

$$\Delta L = F \cdot \varepsilon F \cdot 1/2(\tau 0 + \tau b)$$

in which:

$\tau 0$ (kN/m^2) = developed friction between the geotextile and the subgrade
τb (kN/m^2) = developed friction between the geotextile and the aggregate layer

Filtration function
The principle of the filtration function is the prevention of soil particles intruding in the subbase while water is allowed to pass freely.
In general under a road foundation it consists of the cohesive soil. It appears from practice that geotextile with an O_{90} smaller than 700 μm and the gradient smaller than 100.10^{-3} m perform well considering their filtration function. The O_{90} and the gradient are determined with the well-known Ogink procedures of the Delft Hydraulics Laboratory.

3. SELECTION PROCEDURE

The selection procedure is based on the three dominant functions of geotextiles in road foundations:
1. reinforcement function
2. separation function
3. filtration function

The required properties of a geotextile are determined referring to these functions while considering the typical construction data:
A. traffic load on the road
B. road foundation
C. subgrade conditions

Based on the theories mentioned a step by step procedure for designing the geotextile characteristics have been developed. A detailed description is given in the Manual on Geotextiles and Geomembranes in Civil Engineering 15.

SPECIFICATION SHEET GEOTEXTILES IN ROAD FOUNDATIONS

Boundary conditions traffic load, road foundation and subgrade

axle load 100 kN
number of trucks passing before asphalt ±50
load distribution factor aggregate ... (-)
particle shape aggregate rounded/sharp
particle size aggregate ... (m)
aggregate thickness ... (m)
undrained shear strength subgrade ... (kN/m^2)

REQUIRED PROPERTIES GEOTEXTILE			TEST METHODS
E-modulus	E	.... (kN/m)	0.1 of 0.2 m striptest
breaking stress	S	.... (kN/m)	ditto
tearing strength	W	.... (kN)	trapezoid tear test
puncture resistance	P	.... (N)	CBR punch test
sand tightness	O_{90}	.... (10^{-6} m)	Nen-draft
water permeability	Δh	.... (10^{-3} m)	ditto
breaking stress x breaking strain	S.ε	.... (kN/m)	
special endurance requirements			

Table IV: Puncture resistance P (10^2 N) Dmax = 0.04 aggregate form sharp

Cu (kN/m^2)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
H = 0.3 m^2	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23
H = 0.4 m^2	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
H = 0.5 m^2	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
H = 0.6 m^2	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11

Table V: Breaking stress x breaking strain S.ε (kN/m) e = 0.5

Cu (kN/m^2)	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
H = 0.3 m^2	X	X	10	10	2	2	2	2	2	2	2	2	2	2	2	2
H = 0.4 m^2	X	X	10	2	2	2	2	2	2	2	2	2	2	2	2	2
H = 0.5 m^2	X	X	10	2	2	2	2	2	2	2	2	2	2	2	2	2
H = 0.6 m^2	X	X	2	2	2	2	2	2	2	2	2	2	2	2	2	2

Selection procedure

The relevant data concerning traffic load, road foundation and subgrade as well as the required properties of the geotextile should be filled in on the "specification sheet geotextiles in road foundation".

1. What is the load distribution factor of the aggregate?
2. What is the aggregate thickness?
3. What is the Cu of the subgrade?
4. Determine, inclusive reinforcement functions, what the geotextile requirements are for E-modulus, E (kN/m), breaking stress, S (kN/m) and the tearing strength, W (kN); tables I, II, III.
5. What is the maximum particle size of the aggregate? For all cases in which Dmax $\leq$ 0.02 m a minimum P = 500 N is required.
6. What is the particle shape of the aggregate?
7. Determine the separation function and the required geotextile puncture resistance P (N); table IV.
8. Determine the separation function and the required ability of the geotextile to provide elongation expressed as breaking stress x breaking strain, S . ε (kN/m); table V.
9. Determine the separation function and the required tearing strength, W (kN), of the geotextile. Compare with the strength found at point 5; the greatest one must be taken; table III.
10. Determine the required sand tightness, O_{90} (10^{-6} m) and water permeability ΔH (10^{-3} m) of the geotextile.

Table I e = 0,5 E-modules E (kN/m)

Cu (kN/m2)	5	10	15	20	25	30	35	40	45	50
H = 0,3 m	X	X	X	X	3300	1600	700	190		
H = 0,4 m	X	X	X	2900	1000	190				
H = 0,5 m	X	X	X	1000						
H = 0,6 m	X	X	900							

Table II e = 0,5 Breaking stress S (kN/m)

S (kN/m)	5	10	15	20	25	30	35	40	45	50
H = 0,3 m	X	X	X	X	220	140	80	20		
H = 0,4 m	X	X	X	180	90	20				
H = 0,5 m	X	X	X	80						
H = 0,6 m	X	X	110							

Table III Tearing strength W (kN)

W (kN)	5	10	15	20	25	30	35	40	45	50
H = 0,3 m	X	X	X	X	2,2	1,4	0,8	0,2		
H = 0,4 m	X	X	X	1,8	0,9	0,2				
H = 0,5 m	X	X	X	0,8						
H = 0,6 m	X	X	1,1							

Note: X indicates that the conditions (subgrade) are more critical and a separate, more detailed, design approach is advised.

11. If applicable, note special requirements for the endurance of the geotextile. In general for the application in road foundations, geotextiles have sufficient endurance properties, considering chemical and bacteriological attack.

4. RAILWAY CONSTRUCTION

In railway terminology embankments refer to the substructure of the railway line. The ballast, sleepers and railway track are referred to as the superstructure (figure 7).

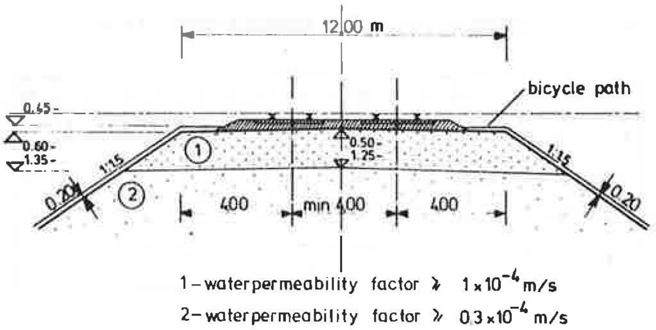


Figure 7: Railway cross-section (double track).

Train loads are transferred via the rails to the sleepers, which in turn transfer the loads to the ballast and, via the embankment, to the subgrade. In this system the embankment forms the actual foundations of the railway line. The ballast bed is a critical link in the load absorption and transfer chain. It must distribute the loads to prevent the track being displaced and it must also provide good drainage, since the superstructure is an open construction from which water must be drained as quickly as possible. Most of the Netherlands railway system is over 100 years old.

Continual maintenance and strengthening was required because of the settlement of the subsoil and the settlement of the embankment itself, resulting from these increasing train loads.

In the last 50 years the embankments of new railway lines have been constructed almost exclusively of sand and strict requirements are set in order to be able to guarantee good permeability, namely a k-value of 1×10^{-4} m/s for the upper 0.75 m and 0.3×10^{-4} m/s for the remainder, down to the original ground level.

In recent years a 0.1 m thick layer of fine gravel has been laid between the ballast and the sand of the embankment to act as a filter layer.

From the previous it is obvious that in the Netherlands there should generally be very permeable sand under the ballast bed of railway lines. Because stone had to be imported, the ballast bed in the Netherlands is relatively light compared with neighbouring countries. In contrast, these countries have much less sand and embankments have to be constructed from less permeable materials such as loam and clay.

The problem of the ballast being contaminated used to be widespread in the Netherlands but now occurs only occasionally because of the conventional construction methods used. As a result, there has been almost no investigations by the Netherlands Railways into the application of geotextiles as a separation layer.

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