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DESIGN OF ROAD BASE AND GEOTEXTILE BY REGRESSION ANALYSIS FROM EXPERIENCE DATA SOURCES

BEMESSUNG VON GEOTEXTILIEN IM STRASSENBAU AUS DER REGRESSIONSBERECHNUNG VON ERFAHRUNGSWERTEN

DIMENSIONNEMENT ROUTIERE AVEC GEOTEXTILES PAR LE CALCUL DE REGRESSION DES VALEURS D'EXPERIENCES

SYNOPSIS

A design method has been developed using complex regression type analysis for mathematical interpretation of a large data base of experience, such as numerous design examples as recommended by the French Committee on Geotextiles, and a technical survey and questionnaire among geotextile specialists in Switzerland and Europe as carried out by the Swiss Association of Geotextile Specialists in 1982/83. This data was then simulated by numerical mathematics and finally resulted in formulas to determine the necessary strength and strain characteristics of a geotextile and depth of road base as needed in a given case. Similarly the minimum required strain or elongation at failure of the geotextile is determined by a separate formula.
Thereafter the mathematics are used to draw design graphs for a set of practical applications.
Finally this report compares the results of the design charts with other literature finding very similar tendencies.

INTRODUCTION

The intent was to summarize present knowledge and experience in the use of geotextiles for unpaved road design. The comparison of existing literature clearly indicates that - in spite of many papers regarding theoretical load distribution and road base reinforcing as well as field test reports - limited information is available for the engineer to specify geotextile strength and elongation characteristics for the given load conditions. The procedures finally adopted largely base on a set of 88 design samples as recommended by the French Geotextile Committee. The Swiss Association of Geotextile Specialists then conducted a survey among Swiss and European specalists to investigate current design practices for use of geotextiles in various fields, such as road base applications and others.

In addition a special study was carried out to adjust the effect in geotextile testing procedures from varying codes. This resulted in roughly 15% difference between French and Swiss methods regarding strain at failure.

Finally the set of data was evaluated and a laborious mathematical regression method was applied. The complexity is caused by the six variables involved and the fact that their interrelation is strictly empirical. Mathematical solutions could therefore be any type of functions or combinations. No straight forward direct solution could possibly be found, but many trial and error type computations were necessary to find the mathematics that simulate the empirical design results.

These procedures are explained because they are rather unusual, and because most of those who observed the developement were reluctant to believe that such numerical simulation procedures with many variables were possible at all. Particular interests in the results of this paper may therefore exist for the practical use of the design charts as well as in the computer aided method of attributing the influence of many variables to a given set of data.

Obviously such simulation procedures never are totally exact and therefore the details of the formulas are not the essential part, but the general tendency of the various effects is of interest.

BASIC EFFECT OF GEOTEXTILE IN A ROAD BASE

Theoretically a road base with geotextile is a composite material similar to reinforced earth or reinforced concrete. Yet engineering methods and analysis are not available today for design methods similar to concrete structures.

On the contrary, more detailed observations indicate that the effect of geotextiles base to a minor part on actual reinforcing but mainly in a combination of the various tasks such as separation, filtration and drainage, as well as a dynamic effect. Furthermore field tests clearly show that loads cause small increase of tensile forces only, because some elongation reduces reinforcing effect but increases overall perfomance. These facts indicate that the effect of geotextiles in a road base cannot be defined by a simple stress-strain type approach. High strain, plastic behavior and special dynamic load effects influence the roadbase behaviour in a complex manner. It is therefore considered more appropriate to use successful case histories and experiences as a main guideline for design instead of a theoretical analysis. The design method presented then uses the mathematics to produce design charts for engineering practice. Future experience should be collected for adjustments of the mathematics and to reduce tolerances and overall construction cost. Thus comments in this regard are highly appreciated.

DEFINITION OF VARIABLES

1. Road Section

The overall road project must be divided into road sections of reasonable length and similar road conditions, particularly similar subsoil conditions. On a road stretch most other variables, such as traffic load, allowable rut depth, and aggregate type are frequently similar. Yet the subsoil conditions may vary and require separate parts of the project.
Remember the method outlined applies for roads without bitumeous or concrete topping.

2. Traffic or Vehicle Load (V - factor)

Vehicle load factor V is defind as follows :

V = 0.5	**very light vehicles**	light vehicles (cars) or track mounted equipment
V = 1	**light vehicles**	few heavy vehicles, max 10 trucks per day, total load carried over temporary road 1000-10'000 to
V = 2	**medium**	many heavy vehicles, 10 to 50 trucks per day total load transported on temporary road 10'000-50'000 to
V = 2.5	**heavy**	very many heavy vehicles 50-100 trucks per day total load on temporary road 50'000-100'000 to.
V = 3.0	**very heavy**	extreemly heavy traffic, more than 100 trucks per day total load on temporary road over 100'000 tons

Notes :

- Cars and light vehicles weigh less than 3.5 to
- Trucks are heavy European large transporters with 36 tons total weight on 4 axles, equals 9 to per axle.
- Extreemly heavy traffic are vehicles with no regular road admission, such as very heavy construction site transporters. Should they have especially high tire pressures and axle loads or circulate in large numbers the V-factor must be evaluated; use V = 4 for example.

3. Rut Depth (R - factor)

The rut depth on a temporary road should not be deeper than a given value. Yet it must be noted that geotextiles are not really selected to reinforce against rut depth.

R = 3-4 rut depth up to 3 cm

R = 5 rut depth up to 5 cm

R = 10 rut depth up to 10 cm

R = 15 rut depth up to 15 cm

The normally allowable rut depth is about 5 cm and may rarely exeed 10 cm because this slows vehicle speed very much. Then the subsoil is overloaded and subsoil deformation soften it up, reducing its future carying capacity. In addition following grader work for leveling top of temporary road decreases geotextile cover locally which then may result in damaging it.

4. Subsoil Quality (U - factor)

Quality of subsoil conditions of road base is normally evaluted by deformation modulus testing for hard soil and particularly field-CBR-testing for softer soils using the English, hand held field penetrometer (stick with gauge). CBR values are then used to define the U-values according to the following table. They correspond with the French subsoil classes.

Table 1: Subsoil and Bearing Capacity (Definition of U)

U	CBR %	c_u kN/m²	ME1 MN/m²	ME2 MN/m²	phi °	VSS class
3 very soft	(1-)2	10-60	1-3	2-5	12-18	~S0
2 soft	2-5	60-150	3-10	5-20	15-25	~S1
1 firm	5-10	150-300	10-25	20-50	25-35	~S2

Notes :

- CBR defines U
- c_u, ME etc are estimated values for comparison only
- The following formulas and diagrams use field CBR and c_u-values as a base. The other values are for rough comparison only. Correlations are not correct in subsoil with coarse, gravel and cobbels and on top of road base.
- The new Swiss subsoil classes are defined S1 to S4. In addition an extra class S0 was added for soft soil.
- CBR, Californa Bearing Ratio, is defined according to Swiss code SNV 670'316 field test or laboratory test SNV 670'320a.
- cu is the undrained shear strength measured by vane test, not precise, but generally called cohesion
- ME is the deformation modulus determined by load plate test dia. 0.3 m as defined by Swiss code SNV 670 317a.This value is nearly equivalent to the German load plate test result EV+ i.e. EV1 = 0.79 * ME1.
- ME2 results from reloading the plate test and corresponds roughly with the German EV2 value i.e. EV2 = 0.79*ME2
- phi, the total angle of friction is a rough estimate only, just as an indication.

5. Aggregate Type of Roadbase (K - factor)

This value defines the type of roadbase material.

K = 0.5 **crushed rock**
partical size 20-80 mm well graded

K = 1 **clean gravel,** max. dia 63 mm, less than 3% fines and well graded or
GW : max. 3% fines, max. dia 250mm or less than half of roadbase depth D

K = 2 **silty gravel,** sandy gravel II : max. dia 100mm, less than 10% fines, or
GM : less than 15% fines, max. dia 250 mm but less than half of base depth D.

Notes:

- The gravel types I and II are defined in Swiss code SNV 670 120.
- In addition to these most commonly used aggregate types for road base, there are more aggregate types available which may especially be economic for temporary roads, such as clean sands and silty sands and gravels (SP, GP, SW, GW, SM, GM according to USCS, Unified Soil Classification System).
- Increasingly there is use of crushed rock or crushed cobbles for road base.
- In case crushed material contains large particals with sharp edges and points, then geotextile damage may occur by unloading or by compaction. In such case strong geotextiles must be used with high failure force, yet even more important, high tear test resistance and large strain at failure and thickness.

6. Roadbase Depth and Number of Geotextiles (D - value)

Construction practice indicates that the road depth must have a certain minimum above the geotextile in order to be practical and successful. The following road depth are evaluted as a minimum :

Table 2 : Minimum roadbase depth (all values in dm)

traffic type	minimum road depth if U = 1	if U = 2	[dm] if U = 3
light vehicles V = 1	3	3.5	4 dm
heavy vehicles V = 2	3.5	4	4.5 dm
very heavy vehic. V = 3	4	4.5	5 dm

Definition of D factor :

D = 3 roadbase depth 0.3-0.4 m thin

D = 4 roadbase depth 0-4-0.5 m medium

D = 5 roadbase depth 0.5-0.8 m very thick

In cases with heavy traffic loads on soft subsoils two layers of geotextiles are used; generally a high strain type geotextile on the grass or subsoil, then a minimum road base cover 0.1-0.2 m thick evenly spread and compacted using light equipment. The second geotextile then is a low strain / high strength type for good reinforcing effect.

Definitions of D in case of two layers of Geotextiles :

D = 6 : medium roadbase depth 0.3-0-4 m + 2 layers

D = 6.5 : medium roadbase depth 0.4-0.5 m + 2 layers

D = 7 : very thick roadb. depth 0.5-0.8 m + 2 layers

7. Geotextile Factor (G - factor)

Most of the data and experience used was with polyester endless fibres, mechanically bonded. Other types of geotextiles have a larger or smaller strain at failure which is to be considered.

The total strength of geotextile depends on the combined effect of failure force r and failure strain ε_r i.e. the failure work a is force times strain.

$$A = r * \varepsilon_r$$

This formula means that geotextiles with higher strain at failure takes large deformations without damage. The geotextile factor G considers this.
In most cases the geotextile factor is G = 1, which means no special consideration is applied. This is correct if the failure strain is above the minimum required strain and the failure force is above the required minimum too.

In cases the failure strain is not as high as determined then a G-value is calculated as follows.

$$G = \varepsilon_r \text{ required } / \varepsilon_r \text{ effective}$$

The G-factor is used for increase of failure force r to r^* only.

$$r^* = r * G$$

Thus for practical purposes G must be 1.0 or above 1.0 yet rarely above 2.0.

MECHANICAL PROPERTY REQUIREMENT FOR GEOTEXTILE IN ROADBASE

1. Empirical Simulation Procedures
Concept and steps of procedures to determine required minimum force and strain εr at failure are outlined in the introduction.

The various advantages of converting large quantities of empirical data into mathematical formulas is their easy use for producing design charts as desired or direct use of the formulas for the individual design case. In addition all variables can be combined as desired and decimals are correct as well.

However the less obvious disadvantage is that strange combinations of such variables may not be within the frame work of original simulation analysis as well as extrapolated values may not necessarily be correct and should be checked by the design engineer in each case.

2. Minimum Failure Force r (= strength of geotextile)
It must be clarified that the textile engineering term of minimum failure force means minimum failure strength in civil engineering terms. The formula is :

$$r = [5 + (2.1 * V1 * R1 * U1 * D1 * K1)] * G \quad (1)$$

The auxiliary variables are defined as follows:

$$V_1 = (V + 0.8)^{0.8} \quad (2)$$

$$R_1 = 4 / (3 * R^{0.8}) \quad (3)$$

$$U_1 = 0.9 * U^{1.2} \quad (4)$$

$$D_1 = 3.6 / D \quad (5)$$

$$K_1 = [1 + (1/K - 1)^2]^{1/4} \quad (6)$$

Tables 3 to 7 for auxilliary factors :

Table 3

V =	0.5	1	2	2.5	3
V1 =	1.23	1.60	2.27	2.59	2.90

Table 4

R =	3	5	7	10	15
R1 =	1.22	1.17	1.14	1.10	1.07

Table 5

U =	1	2	3
U1 =	0.90	2.07	3.36

Table 6

D =	3	4	5	6	7
D1 =	1.20	0.90	0.72	0.60	0.51

Table 7

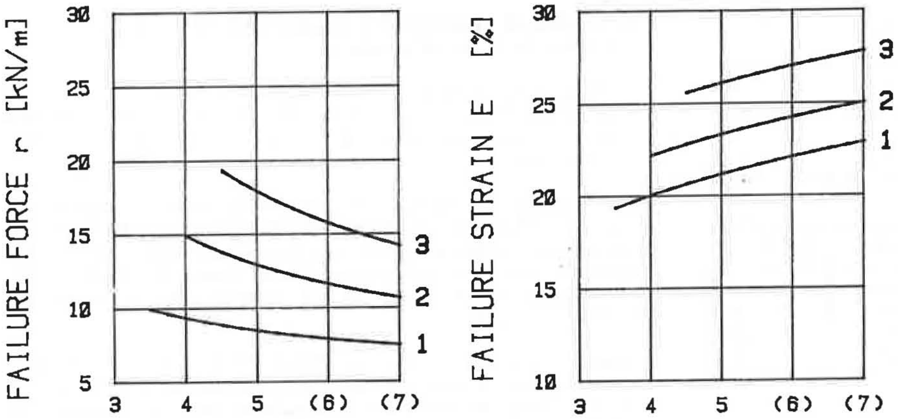
K =	0.5	1	2
K1 =	1.18	1.00	1.06

The complete design formula for minimum failure force is

$$r = [5 + (2.1 * (V + 0.8)^{0.8} * 4/3 * R^{-0.8} * 0.9 * U^{1.2} * 3.6/D * [1 + (1/K - 1)^2]^{1/4}] * G \quad (7)$$

3. Design formula for failure strain :
Similar procedures as outlined for failure forces have been used to determine minimum failure strain. However two additional corrections were added :

- Reduction of minimum failure strain by 1 class as defined in the French recommendation.
- In addition to the above mentioned survey among geotextile specialists in 1982/83 an additional survey was made in December 1984 and January 1985, see report Jaecklin [9]. This survey collected test data using the French and the Swiss (EMPA) method on the very same geotextile materials, resulting in a difference of

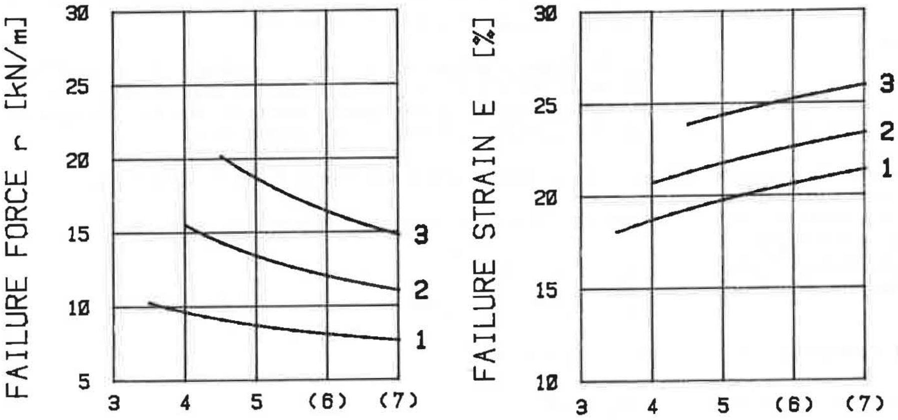


HEAVY VEHICLES

DESIGN CHART 1

HEAVY VEHICLES V=2
RUT DEPTH R= 10 cm
AGGREGATE TYPE K= 1
SUBSOIL TYPE U=1, 2, 3

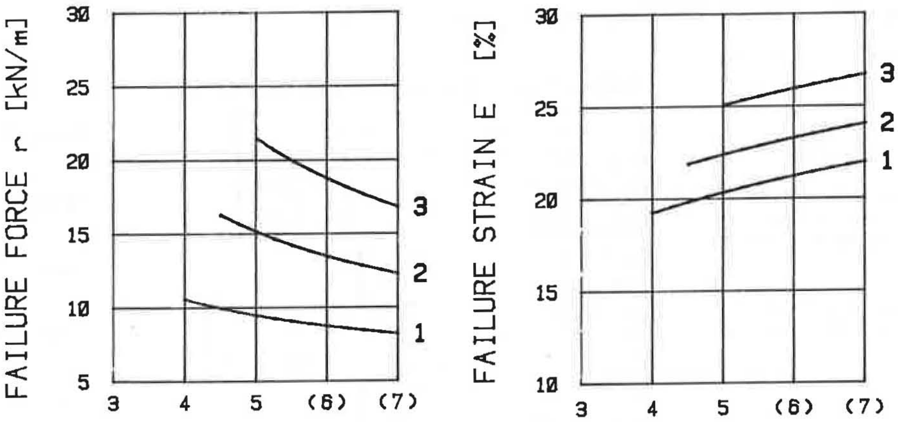
AGGREGATE DEPTH D [dm]



DESIGN CHART 2

HEAVY VEHICLES V=2
RUT DEPTH R= 10 cm
AGGREGATE TYPE K= 2
SUBSOIL TYPE U=1, 2, 3

AGGREGATE DEPTH D [dm]

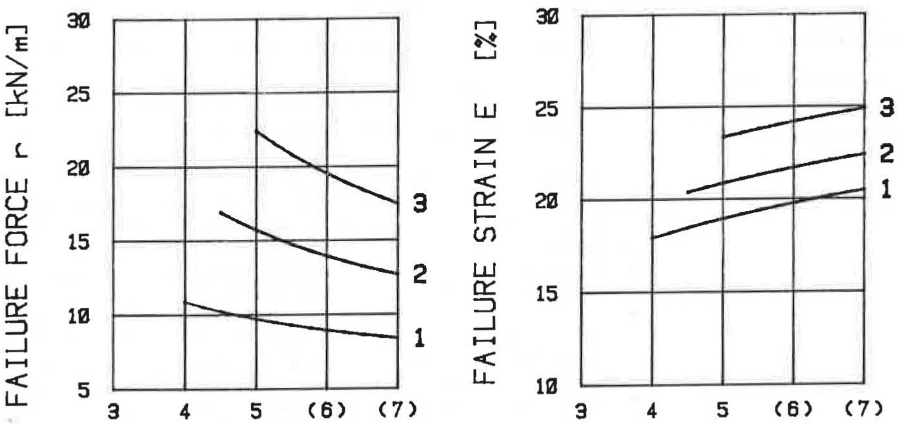


VERY HEAVY VEHICLES

DESIGN CHART 3

VERY HEAVY VEHIC. V=3
RUT DEPTH R= 10 cm
AGGREGATE TYPE K= 1
SUBSOIL TYPE U=1, 2, 3

AGGREGATE DEPTH D [dm]



DESIGN CHART 4

VERY HEAVY VEHIC. V=3
RUT DEPTH R= 10 cm
AGGREGATE TYPE K= 2
SUBSOIL TYPE U=1, 2, 3

AGGREGATE DEPTH D [dm]

about 15%. Accordingly the French values are then multiplied with the transfer factor T = 1.15 for the corresponding Swiss code value. All corrections are included in the design charts.

The formula for required minimum strain of a geotextile at failure is:

$$\varepsilon f = 1.4 * V2 * R2 * (U2 + D2) * K2 \quad \text{(in \%)} \qquad (8)$$

This formula uses the auxiliary values
εf = failure strain ε according to French Recommendation
εr = (εf minus 1 class) * T and T = 1.15 for correction.

Auxiliary variables are defined as follows:

$$V_2 = 1 / V^{0.1} \qquad (9)$$

$$R_2 = \log R \qquad (10)$$

$$U_2 = U^{1.5} \qquad (11)$$

$$D_2 = 10 + 10 * \log D \qquad (12)$$

$$K_2 = 1 / K^{0.1} \qquad (13)$$

consequently the design formula is :

$$\varepsilon f = \frac{1.4 * \log R * (U^{1.5} + 10 + 10 * \log D)}{V^{0.1} * K^{0.1}} \qquad (14)$$

$$P_f = \ln (\varepsilon_f / 6.913)^{(1/0.2457)} \qquad (15)$$

$$P = Pf - 1 \qquad \text{reduction by one class} \qquad (16)$$

Then determine actual failure strain

$$\varepsilon r = 6.913 * e^{0.2457*P} * T \qquad (17)$$

Tables 8 to 12 for auxiliary values

Table 8

V =	0.5	1	2	2.5	3
V_2 =	1.07	1.00	0.93	0.91	0.91

Table 9

R =	3	5	7	10	15
R_2 =	0.48	0.70	0.87	1.00	1.18

Table 10

U =	1	2	3
U_2 =	1.00	2.83	5.20

Table 11

D =	3	4	5	6	7
D_2 =	14.77	16.0	16.99	17.78	18.45

Table 12

K =	0.5	1	2
K_2 =	1.07	1.00	0.93

These values can be used with the simplified formula

$$\varepsilon_r = [(1.4 * V_2 * R_2 * (U_2 + D_2) - 5] * T \qquad (18)$$

The difference to the exact method as shown above is about 1 - 4 % within the range of ε_r = 10 - 30 %.

Notes :

- if rather large deformations are expected on a site, much higher minimal failure strain must be required.
- ε_r = 70 % minimum requirement on failure strain in case of two geotextiles and aggregate layer in between.
- ε_r = 25 % minimum requirement on failure strain if large deformations are to be expected at site.
- ε_r = 50 - 70 % minimum failure strain if very large deformations are expected such as use of aggregate with large cobbles or geotextile on soft subsoil.
- ε_r maximum = 15 - 20 % if there are light vehicles (V = 1), soft subsoil (U = 3), and rut depth of 3 - 4 cm (R = 4). This requirement restricts maximum strain as an exception in order to improve reinforcing effect.
- ε_r maximum = 15 % for second layer of geotextile (for cases where D = 6 - 7) and for the specific purpose of reducing rut depth.

These specifications are in accordance with the Swiss Technical Committe on Geotextiles, exept the last point.

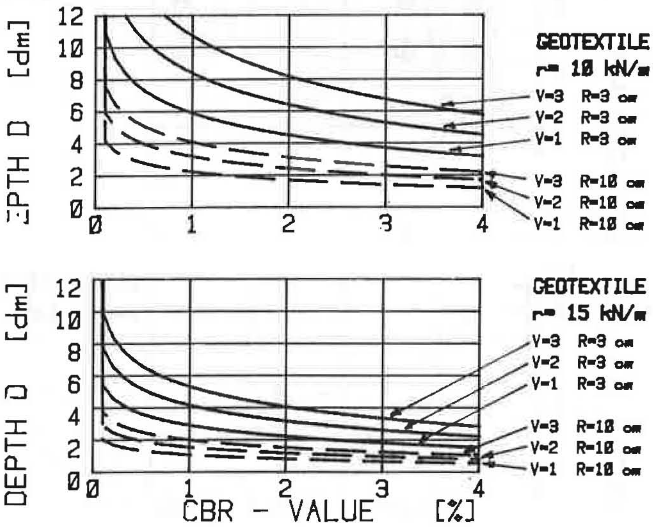
The general requirements for use of coarse aggregate (d85 larger than 30mm) on geotextiles in any type of application call for :

- ε_r min = 20 % in case of very stiff or hard subsoil, Swiss class S3 or S4,CBR above 12%
- ε_r min = 30 % in case of stiff subsoil Swiss class S2, CBR = 6 - 12 %.
- ε_r min = 40 % if d85 is larger than 30 mm and on very soft subsoil.

ADDITIONAL DESIGN CHARTS

A set of additional design charts have been prepared using the very same design formulas as above, yet transfered to the usual coordinates CBR versus aggregate depth in order to evaluate the various implications.

Charts no 5 and 6 illustrate the effect of aggregate depth, rut depth and traffic volume: higher traffic volumes require much higher aggregate depth. Given the same traffic volume, lower aggregate depth results in much more rut depth. These relationships make sense and mistakenly it could be concluded that higher geotextile strength reduces rut depth, or the procedure would allow to design for a certain rut depth using the appropriate geotextile and aggregate depth. However rut depth is a final deformation result caused by a certain traffic volume on well compacted aggregate, on a certain subsoil, and with a certain geotextile strain. Rut depth is not entirely a design value but a result of many phenomenas involved.



Charts 5 and 6 : Effect of traffic and rut depth on required aggregate depth or strength of geotextile.

The exception is if two geotextiles are used, a weak but high strain geotextile directly on the soft subsoil and a strong, low strain geotextile on a first layer of aggregate. This application represents the true reinforcing effect.
Charts no 7 and 8 were prepared to evaluate differing geotextile strain values ε at failure. The graph lines indicate that very heavy traffic (V=3) and deep rut depth (R=10 rsp. 15 cm) on soft soil (low CBR), require high strain geotextiles to follow the soil-aggregate interface without damage. The minimum strain at failure ε required can easily be met by any of the nonwoven geotextiles, but woven geotextiles with ε mostly below 20 % could only be used in soils with CBR above 4 %, no matter what aggregate depth was selected.

COMPARISON OF THIS METHOD WITH OTHERS

Frequently a new design method is checked by comparison to other or previous ones. In this case similarity with the French recommendations are rather obvious, yet still there are quite a few differencies which demonstrate that empirical data may not be as systematic and as continuous as formulas.

Charts no. 9 and 10 use the same mathematics as the design charts no. 1 to 4 for the continuous line. Dashed lines redraw curves from a very recent Tensar publication [11]. The comparable cases demonstrate good accordance. However variations in traffic, geotextile strength, or even more pronounced in rut depth result in lines further apart.

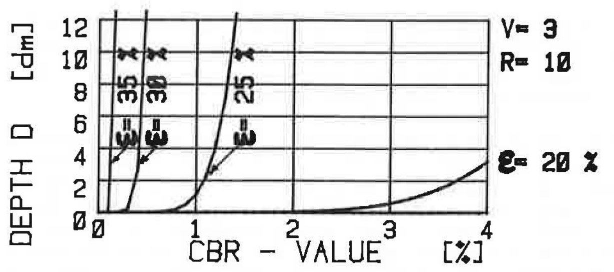


Chart 7 : Very heavy traffic (V=3) and deep ruts (R=10cm) require a minimum ε = 25 % or more if CBR is below 2.

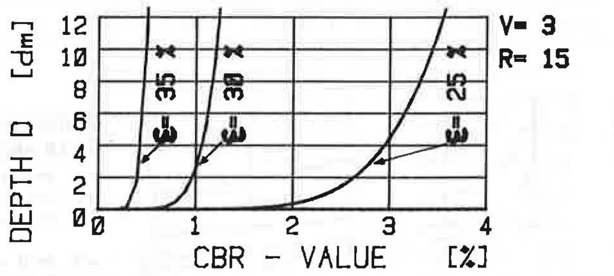


Chart 8 : Similar to chart 7, deeper ruts (R=15) require even higher failure strain ε = 30 % if CBR is below 2.

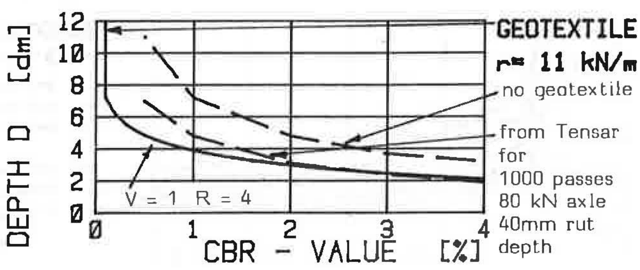


Chart 9 : Calculated contineous line compares to dashed line as redrawn from a recent Tensar publication and shows good accordance.

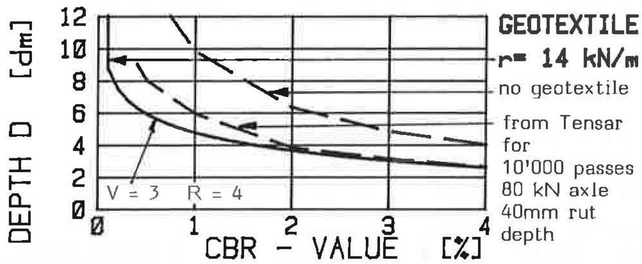


Chart 10 : Similarly to chart 9, the contineous line from calculation compares to the lower dashed line from Tensar for a similar case.

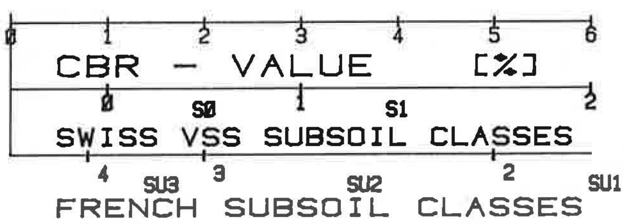


Chart 11 : Definition of different subsoil classes based on CBR-values (for reference only).

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