HUESKER

Justification de la géogrille de renforcement Malleville sur le Bec (27)

Géogrilles type Fortrac® 150 T

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Synthèse des modifications

AVERTISSEMENT :

Le présent document d'application a été préparé pour vous de façon personnalisée et a été établi de manière confidentielle. Il sert uniquement de justification et ne constitue pas encore un projet détaillé. L'utilisation de ce document sans autorisation expresse écrite de la société HUESKER France SAS n'est pas autorisée.

Toutes les informations de ce document - incluant géométrie, charges, sols, géosynthétiques proposés etc. avec toutes leurs caractéristiques ainsi que phase de conception, durée de chargement et d'utilisation - s'appliquent uniquement pour le système décrit ici. Tout écart risque de compromettre la sécurité et/ou la bonne fonctionnalité et est à convenir avec les auteurs. En cas contraire, toute responsabilité pour d'éventuels dommages sera exclue.

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Sommaire

Introduction

Cette note est une justification du choix de la géogrille de renforcement de type Fortrac® T pour le projet de casier.

Documents de référence

Les documents généraux de bases sont les suivants :

1. NF EN 13249 : Aout 2005 « Géotextile et produits apparentés – Caractéristiques requises pour l'utilisation dans la construction des routes et autres zones de circulation. »
2. EN 1997-1 : EUROCODE 7– Calcul géotechnique- Partie 1 : règles générales,
3. Guide ISO /TR 20432 : 2007 Lignes directrices pour la détermination de la résistance à long terme des géosynthétiques pour le renforcement des sols,
4. Guide ISO /TS 13434 : Géosynthétiques – Lignes directrices concernant la durabilité.
5. BBA Certificat N°13/H197 version 2014 établit renouvelé en 2014

Documents fournis :

- CCTP
- Rapport n°affaire B19014A

Caractéristiques techniques des géogrilles Fortrac® :

Pour assurer la stabilité de l'ouvrage, il sera mis en place une géogrille Fortrac® 150 T adaptée aux matériaux et à la géométrie du remblai tels que définis ci-après.

Ces géogrilles sont livrées sous forme de rouleaux. Les caractéristiques techniques des géogrilles proposées sont résumées dans les fiches techniques jointes dans l'annexe 1.

Le justificatif du choix des géogrilles Fortrac 150 T selon la méthode retenue en prenant en compte les hypothèses fournies est joint dans l'annexe 2.

Les géogrilles Fortrac® 150 T sont fabriquées par la société HUESKER Synthetic GmbH – Fabrikstrasse 13-15 – 48712 Gescher, représentée en France par la société HUESKER France SAS, basée rue Jacques Coulaux – F-67190 Gresswiller.

Durabilité

Fortrac dispose d'avis techniques reconnus de manière européenne par accords multilatéraux. Les coefficients réducteurs appliqués pour ce type de géogrille et pour cette utilisation y sont définis et validés par un organisme extérieur.

La résistance ultime des géogrilles Fortrac® T est calculée d'après ces certificats dans l'annexe 3 et le certificat BBA en cours de validité sont joints dans l'annexe 4.

Qualité

Chaque rouleau est identifié par étiquetage précisant le numéro du rouleau et le type de produit conformément à la norme NF EN ISO 10320 ceci permettant la traçabilité dans le cadre de l'ISO 9001 : 2008.

Nous effectuons des tests de contrôle dans notre laboratoire certifié NF EN ISO/IEC 17025. Ces rapports d'essai vous sont adressés sur simple demande.

Les certificats en cours de validité sont joints dans les annexes 5 et 6.

Procédure de contrôle.

1. Contrôle lors de la livraison et du déchargement : Le contrôle est un contrôle visuel dont les résultats sont consignés sur un bordereau sur lequel sont notés les numéros des rouleaux ainsi que leur état.

2. Contrôle de la pose de la géogrille : Le contrôle est un contrôle visuel permettant de vérifier l'absence de plis, la propreté des surfaces de recouvrement, la largeur des surfaces de recouvrement.

3. Contrôle de la mise en œuvre de la couche de confinement : Le contrôle est un contrôle altimétrique vérifiant que l'épaisseur de matériaux mise en œuvre à l'avancement est conforme.

Disposition environnementale.

Les géosynthétiques contribuent activement à la diffusion de modes de construction écologiques et se sont imposés dans tous les secteurs de la géotechnique. Les géosynthétiques HUESKER sont produits sur des installations performantes dans les usines de Gescher et Dülmen. La production est particulièrement peu gourmande en ressources compte tenu du procédé de tissage utilisé. La consommation d'eau au cours du processus de fabrication est nulle. La consommation de courant des métiers à tisser et des systèmes d'enduction et la consommation de gaz sont faibles. Les trajets relativement courts ont des répercussions immédiates sur l'émission totale de CO_2 à l'échelle de la chaîne de valeur. Chez HUESKER, le traitement des déchets obéit à trois grands principes: éviter, réduire, recycler. Réduire la quantité des déchets présente des avantages aussi bien d'un point de vue écologique qu'économique et revêt donc une priorité absolue.

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Annexe 1 :

Fiche Technique Fortrac® 150 T

Fiche Technique

HUESKER

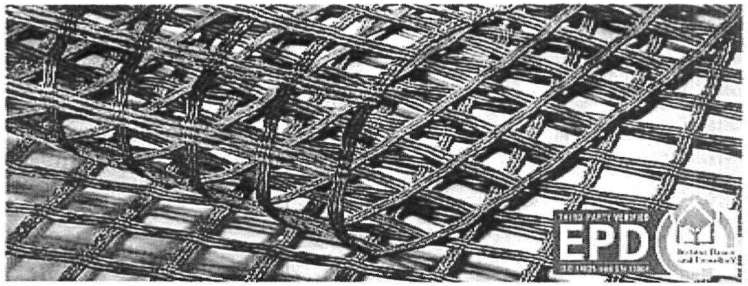
Fortrac® | Type 150 T

Description du Produit

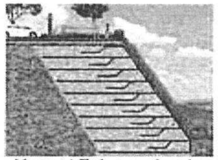
Fortrac® | type T est une géogrille flexible qui permet de construire des ouvrages de manière économique et écologique. Les géogrilles Fortrac® | type T sont caractérisées par :

- Un fort module et un faible taux de fluage
- Une bonne résistance contre les endommagements mécaniques
- Une bonne résistance à la dégradation chimique pour les sols naturels (4 < pH < 9)

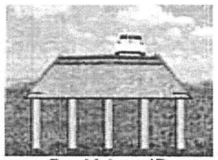
Les géogrilles Fortrac® génèrent l'ossature d'un sol sans en perturber les écoulements hydrauliques. La flexibilité et le conditionnement assurent aux géogrilles Fortrac® une facilité de mise en œuvre et un gain de temps non négligeables sur chaque chantier.



Domaines d'utilisation standards de la géogrille Fortrac® T



Murs et Talus renforcés



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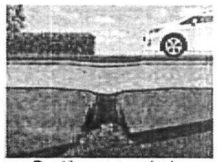

Système parachute

Fiche Technique

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Fortrac® | Type 150 T

Géogrille certifiée IVG selon fonction

Renforcement ☑
Filtration
Séparation

Gütüberwachung IVG Geokunststoffe n° 3392

01. Matière première		**PET**	
02. Enduction		**Polymère**	
03. Ouverture des mailles (env.)		**≈ 25 x 25**	mm x mm
04. Masse surfacique (NF EN ISO 9864)		**440**	g/m²
05. Résistance à la traction (NF EN ISO 10319)	longitudinale transversale	**≥ 150** **≥ 20**	kN/m kN/m
06. Allongement à la résistance à la traction nominale (NF EN ISO 10319)	longitudinal	**≤ 10**	%
07. Dimensions standards	largeur x longueur Surface d'un rouleau	**5,00 x 200,0** **1000**	m x m m²

Remarque : Les géogrilles Fortrac® | type T disposent d'un avis technique garantissant leurs coefficients réducteurs vis-à-vis du fluage, de l'agression mécanique et de l'environnement chimique ainsi que les extrapolations afin d'assurer la viabilité de l'ouvrage jusqu'à 120 ans

Votre interlocuteur :

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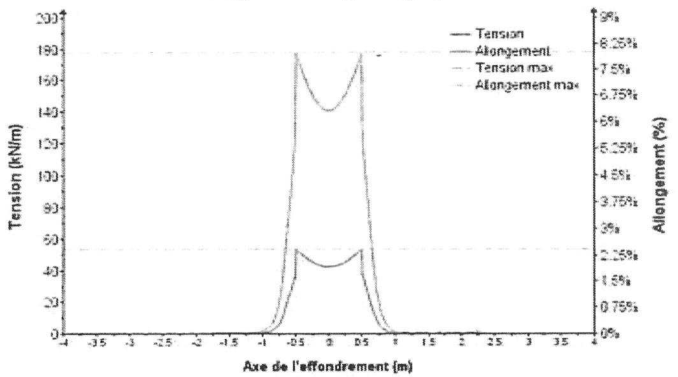
5. Graphe de la tension à reprendre à long terme et de l'allongement dans la géogrille Fortrac

Tension / allongement le long de la géogrille Fortrac



6. Valeur à retenir à long terme pour la détermination de la géogrille Fortrac

Le dimensionnement est réalisé à la rupture de la géogrille, à l'ELU

	unité	durée de service de l'ouvrage
Tension	kN/m	54
sous un allongement max de	%	8,0%

Annexe 3 :
Résistance à la traction à long terme Fortrac® 150 T selon Certificat BBA N° 13/H197 version 2014

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Annexe 2 :
Dimensionnement de la géogrille de renforcement

1. Données géotechniques

Les caractéristiques géotechniques sont résumées dans le tableau ci-dessous :

	unité	Nouveau Déchet	Couche drainante	Barrières passives	Couche d'égalisation
Poids volumique	kN/m^3	10	16	19	19
Epaisseur	m	8	0,3	0.5	0.25
Angle de frottement	°	18	35	28	28
Cohésion	kN/m^3	20	0	15	15

2. Diamètre nominal de l'affaissement localisé.

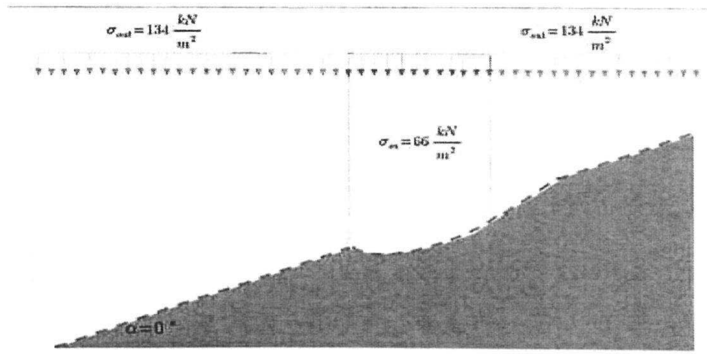
Le diamètre nominal de l'affaissement localisé est pris égal à : $D := 1\ m$
Le coefficients pour tenir compte de l'effet voûte est pris égal à $n := 3$
L'inclinaison du talus éxstant vaut: $\alpha := 0°$

3. Surcharges permanentes et temporaires

Les surcharges permanentes correspondent aux surcharges d'exploitation. En phase finale de l'ouvrage, elle sont considérées comme n'ayant pas d'influence sur les barrières active et passive.
On ne considère pas de surcharge temporaire.

	unité	Permanente	Temporaire
Surcharge	kN/m^3	0	0

4. Contraintes appliquées au dessus et en dehors de la zone d'affaissement



Détermination de la résistance à la traction admissible pour les géogrilles Fortrac® 150 T

Les géogrilles de renforcement Fortrac® sont adaptées pour les applications de renforcement de sol, à court et à long terme. Pour cela, les géogrilles répondent aux exigences de durabilité et en particulier sont capables de supporter la charge prévue pour la durée de service exigée, à la température de dimensionnement, en fonction de l'agressivité du matériau du remblai et de l'environnement. Des procédures d'évaluation sont définies et normalisées selon les Guides ISO/TR 20432 : 2007 et ISO/TS 13434 :2008. L'ensemble des paramètres ci-dessous sont validés par un organisme extérieur indépendant : le «British Board of Agrément».

La résistance à la traction admissible $R_{t,a}$ dans la géogrille Fortrac® 150 T est définie comme suit :

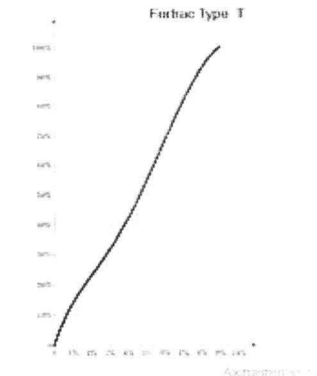
$$R_{t,a} = \frac{R_{t,k}}{(\Gamma_{instal} \times \Gamma_{vieill} \times \Gamma_{ftu}) \times f_s}$$

dans laquelle :

$R_{t,k}$: Résistances en traction "à court terme" caractéristique du produit. Cet effort est la borne inférieure de l'intervalle de confiance à 95 % des résistances en traction mesurées lors d'essais de traction conformes à la norme NF EN ISO 10319, réalisés sur des échantillons intacts du produit.

Cette courbe, illustre le ratio de la résistance à la traction $R_{t,k}$ en fonction de l'allongement de la géogrille. Elle permet d'estimer rapidement la raideur utile / requise d'un produit

Il s'agit de valeur à court terme, sur un produit neuf.



Courbe ratio $R_{t,k}$ / allongement selon la norme NF EN ISO 10319

Γ_{instal} : coefficient réducteur correspondant à l'endommagement des géogrilles de renforcement produit par leur installation et le compactage des remblais. En l'absence d'essai, des valeurs par défaut définies dans différentes normes/ recommandations, tel que NF 94270, XP G 38064, sont :

Tableau C.3 — Valeurs forfaitaires de Γ_{instal}

	Conditions de mise en œuvre			
	Peu sévère	Moyennement sévère	Sévère	Très sévère
Tous géosynthétiques	1.15	1.25	1.50	2.50

Tableau C.1 — Degré de sévérité des conditions de mise en œuvre

Matériau	$D_{max} \leq 50$ mm			$D_{max} > 50$ mm
	Sols fins, Sables	Sols graveleux, graves sableuses		Matériaux avec des gros éléments
		alluvionnaires	concassés	roulés ou anguleux
Classification NF P 11-300	A, B, D1	B, D	B, D	C, CA, CB, D
Énergie de compactage moyenne	peu sévère	moyennement sévère	sévère	très sévère
Énergie de compactage intense	moyennement sévère	sévère	très sévère	non recommandée

NOTE L'énergie de compactage est établie en relation avec l'objectif de densification retenu. Le GTR SETRA-LCPC de 2000 définit trois niveaux d'énergie de compactage (faible, moyenne, intense) en fonction des paramètres du cas de compactage. Une énergie plus grande peut être obtenue en réduisant l'épaisseur de la couche compactée, en augmentant le nombre de passes ou en réduisant la vitesse de translation du compacteur.

Pour la gamme de géogrilles Fortrac®, nous avons fait établir un certain nombre de tests résumés dans l'avis technique BBA certificat N° 13/H197 version 2014.

Conditions de mise en œuvre	Exemple pour Fortrac type	
	80/30-20 T	110/30-20 T
Peu sévères, D_{90} < 10 mm	1.15	1.05
Moyennement sévères, D_{90} < 35 mm	1.15	1.05

Pour ce chantier, en contact avec des matériaux fins, nous considérons un coefficient d'endommagement de 1.05.

Γ_{vsi} : coefficient réducteur lié au vieillissement des géogrilles de renforcement dépendant des conditions d'environnement du produit. En l'absence d'essai, des valeurs par défaut définies dans différentes normes/ recommandations, tel que NF 94270, XP G 38064, sont :

B.3.3 Coefficients de réduction par défaut relatifs au vieillissement (autre que climatique) pour les polymères les plus courants et les conditions d'utilisation courantes

En absence d'essais réalisés suivant le Guide ISO/TR 20432, il convient d'utiliser les coefficients par défaut du Tableau B.2. Ils ne peuvent être pris en compte que dans les conditions suivantes :

— les températures de service moyennes annuelles (température environnant le massif) ne doivent pas être supérieures à 20 °C (ce qui est le cas général en France métropolitaine) et doivent être supérieures à 0 °C (sol au contact) ; pour des plages de température différentes une étude spécifique doit être réalisée ;

— les sols concernés sont des sols naturels non pollués ;

— pour les polyesters PET la masse moléculaire doit être supérieure à 25 000, et le % groupe carboxyle terminaux (GCT) doit être inférieur à 30 meq/kg ;

— pour les PEHD la densité est comprise entre 0,940 et 0,960.

Tableau B.2 — Coefficients de réduction par défaut relatifs au vieillissement des polymères les plus courants et les situations les plus courantes

Classe de durée d'utilisation	pH	PET (fils)	PA	PEHD (extrudés)	PP
1 à 3	4 à 8	1,05	1,1	1,05	1,05
4 et 5		1,2	a)	1,3	1,3
1 à 3	8 à 9	1,1	1,1	1,05	1,05
4 et 5		1,3	a)	1,3	1,3

a) Utilisation du guide ISO/TR 20432.

Pour la gamme de géogrilles Fortrac®, nous avons fait établir ce coefficient résumé dans l'avis technique BBA certificat N° 13/H197 version 2014.

Durée d'utilisation de 120 ans	Γ_{vsi}
2 < pH < 9	1.06

En complément et pour tenir compte des effets climatiques (incluant les U.V.), un coefficient réducteur de 1,13 est pris en compte pour une couverture de la géogrille sous un mois.

<u>Remarque :</u> Si les géogrilles sont recouvertes dans la journée de pose et il est possible de prendre en compte un coefficient réducteur de 1,00 conformément au certificat BBA

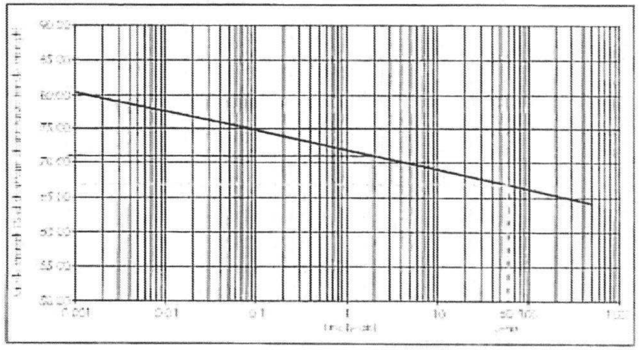
Γ_{flu} coefficient réducteur lié au comportement en fonction du temps des géogrilles. L'application de ce coefficient permet, pour la durée de service de l'ouvrage, de considérer l'influence du fluage sur la résistance en traction. En l'absence d'essai, des valeurs par défaut définies dans différentes normes/ recommandations, tel que NF 94270, XP G 38064, sont :

A.4 Coefficient de réduction par défaut (en absence d'essai)

Dans le cas d'absence d'essai de fluage, on retiendra les coefficients suivants, quant à la limitation à la rupture du renforcement.

Polymère	Valeur par défaut pour Γ_{flu}
PP / PE	6
PEHD	5
PET	3
PVA	3
AR	3

Pour la gamme de géogrilles Fortrac®, nous avons fait établir ce coefficient résumé dans l'avis technique BBA certificat N° 13/H197 version 2014.

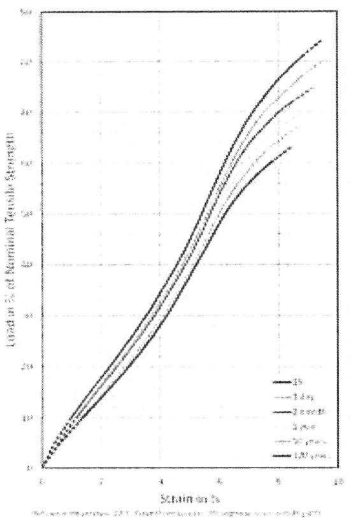


Courbe de rupture au fluage – régression linéaire en % de la résistance à la traction à court terme pour une température de 20 °

On retient donc à la durée de service de 120 ans, un coefficient de fluage ρ_{flu} = 66% , soit Γ_{flu} = 1,52

Durée d'utilisation *)	Fortrac® type T 10 ans	60 ans	120 ans
ρ_{flu}	68,5 %	66,8 %	66,0 %
Γ_{flu} = 1/ ρ_{flu}	1.46	1.50	1.52

Les déformations liées au fluage sont illustrées par les isochrones ci-dessous :



Courbes isochrones ratio / allongement

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f_s Pour tenir compte des extrapolations, le guide ISO/TR 20432 (§ 10 page 28 et 29), impose un facteur de sécurité défini comme suit :

$$f_s = 1 + \sqrt{(1-R_1)^2 + (1-R_2)^2}$$

Où

- R_1 est un facteur dépendant de la durée / nature des essais de fluage / durée d'utilisation désirée
- R_2 est un facteur dépendant de la durée / nature des essais de vieillissement / durée d'utilisation désirée.

Pour la gamme de géogrilles Fortrac®, nous avons fait établir ce coefficient f_s, résumé dans l'avis technique BBA certificat N° 13/H197, version 2014.

Durée d'utilisation	fs
60 ans	1.07
120 ans	1.11

Pour les géogrilles Fortrac® 150 T, nous avons donc retenu une résistance admissible de calcul à long terme à partir des hypothèses ci-dessus et de l'avis technique BBA certificat N° 13/H197, version 2014 :

$$R_{t,c} = \frac{150}{(1{,}05 \times 1{,}06 \times 1{,}13 \times 1{,}52) \times 1{,}11} = 70{,}6\ kN/m$$

Remarque : Il est important de ne pas confondre f_s et $\gamma_{M,t}$. Le premier coefficient est un coefficient de sécurité pour les extrapolations, il dépend de la durée et de la nature des essais effectués sur la géogrille. Le deuxième provient de l'EN 7 et s'applique pour tout type de matériau, il est lié au dimensionnement.

La résistance à la traction ultime de calcul à prendre en compte, en tenant compte du facteur partiel pour la résistance à la traction des éléments de renforcement de l'EN 7 $\gamma_{M,t}$ = 1.25, est donc :

$$R_{t,d} = \frac{R_{t,c}}{\gamma_{M,t}} = 56{,}4\ kN/m$$

La résistance à la traction $R_{t,c}$ est supérieure à la résistance à la traction de calcul de 54 kN/m à la rupture du produit calculé en annexe 2.

Annexe 4 :
Certificat BBA N° 13/H197 version 2014

HAPAS

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BBA APPROVAL INSPECTION TESTING CERTIFICATION
TECHNICAL APPROVALS FOR CONSTRUCTION

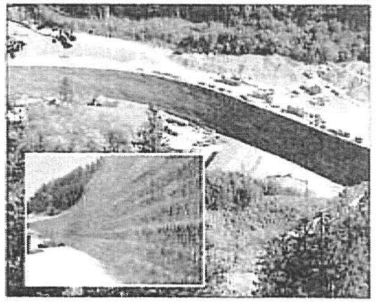
HAPAS Certificate
13/H197
Product Sheet 3

FORTRAC GEOSYNTHETICS

FORTRAC T AND R-T GEOGRIDS

This HAPAS Certificate Product Sheet[1] is issued by the British Board of Agrément (BBA), supported by the Highways Agency (HA) (acting on behalf of the Overseeing Organisations of the Department for Transport; Transport Scotland; the Welsh Assembly Government and the Department for Regional Development, Northern Ireland), the Association of Directors of Environment, Economy, Planning and Transport (ADEPT), the Local Government Technical Advisers Group and industry bodies. HAPAS Certificates are normally each subject to a review every five years.
(1) Hereinafter referred to as 'Certificate'.

This Certificate relates to Fortrac T and R-T Geogrids, polymeric geogrids consisting of polyester fibres coated with a black styrene butadiene polymer for use as reinforcement in embankments with slope angles up to 70°.



CERTIFICATION INCLUDES:
- factors relating to compliance with HAPAS requirements
- factors relating to compliance with Regulations where applicable
- independently verified technical specification
- assessment criteria and technical investigations
- design considerations
- installation guidance
- regular surveillance of production
- formal five-yearly review

KEY FACTORS ASSESSED

Soil/geogrid interaction — interaction between the soil and geogrids has been considered and coefficients relating to direct sliding and pull-out resistance proposed (see section 6).

Mechanical properties — short- and long-term tensile strength and elongation properties of the geogrids and loss of strength due to installation damage have been assessed and reduction factors established for use in design (see section 7).

Durability — the resistance of the geogrids to the effects of hydrolysis, chemical and biological degradation, UV exposure and temperature conditions normally encountered in civil engineering practice have been assessed and reduction factors established for use in design (see sections 8 and 11).

The BBA has awarded this Certificate to the company named above for the products described herein. These products have been assessed by the BBA as being fit for their intended use provided they are installed, used and maintained as set out in this Certificate.

On behalf of the British Board of Agrément

Date of Second issue: 5 September 2014

Brian Chamberlain
Head of Approvals — Engineering

Claire Curtis-Thomas
Chief Executive

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Requirements

In the opinion of the BBA, Fortrac T and R-T Geogrids when used in accordance with the provisions of this Certificate, will meet the requirements of the Highways Agency and local Highway Authorities for the design and construction of reinforced soil embankments with slope angles up to 70°.

Regulations

Construction (Design and Management) Regulations 2007

Construction (Design and Management) Regulations (Northern Ireland) 2007

Information in this Certificate may assist the client, CDM co-ordinator, designer and contractors to address their obligations under these Regulations.

See sections: 1 *Description* (1.2), 3 *Delivery and site handling* (3.1, 3.4 and 3.5) and the *Installation* part of this Certificate.

Additional Information

CE marking

The Certificate holder has taken the responsibility of CE marking the products in accordance with harmonised European Standard BS EN 13251 : 2001. An asterisk (*) appearing in this Certificate indicates that data shown is given in the manufacturer's Declaration of Performance.

Technical Specification

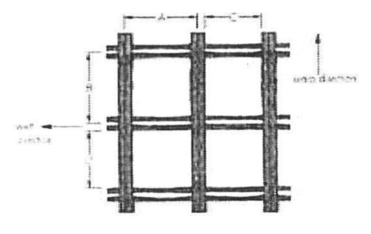
1 Description

1.1 Fortrac T and R-T Geogrids are planar structures consisting of a regular open network of woven, integrally connected tensile elements of yarn. The yarn is made from high modulus polyester fibres of polyethylene terephthalate (PET). The woven grid is coated with a protective layer of black styrene butadiene polymer.

1.2 The geogrids are manufactured in sixteen standard grades of various strengths and mesh sizes. A typical geogrid is illustrated in Figure 1 and the range and specification of the geogrids assessed by the BBA are listed in Tables 1 and 2.

1.3 The warp (machine) direction is along the roll length and is indicated by a paper tape (see Figure 1).

Figure 1 Fortrac T and R-T Geogrids



A and B: warp grid size
C and D: weft aperture size

Table 1 General specification

Grade	Nominal mass (g m⁻²)	Average grid size warp x weft (mm) A × B	Average aperture size warp x weft (mm) C × D	Colour code	Nominal roll weight for standard 5 m width roll	[illegible]
35T	185	29.6 × 30.0	26.0 × 24.0	Red	150	[illegible]
55T	240	29.0 × 30.0	25.0 × 24.0	Green	250	[illegible]
65T	280	29.0 × 30.0	25.0 × 23.0	Orange	240	[illegible]
80T	320	29.0 × 30.0	25.0 × 23.0	Pink	330	[illegible]
110T	350	29.0 × 30.0	24.0 × 23.0	Yellow	360	200
150T	440	29.0 × 30.0	23.0 × 23.0	No colour	450	200
200T	530	30.0 × 30.0	23.0 × 23.0	No colour	540	200
35/20-20T	210	23.1 × 23.0	21.0 × 18.0	Red	230	200
55/30-20T	280	23.0 × 25.5	20.0 × 20.5	Green	300	200
80/30-20T	350	25.0 × 23.0	20.0 × 18.0	Pink	370	200
110/30-20T	420	25.1 × 22.8	20.0 × 18.0	Yellow	480	200
R150/30-30T	520	41.7 × 32.8	33.0 × 27.0	No colour	630	200
R200/30-30T	630	40.0 × 32.5	31.0 × 27.0	No colour	750	200
R400/50-30T	1200	67.0 × 33.5	37.0 × 27.5	No colour	650	100
R600/50-30T	1650	50.0 × 33.0	30.0 × 28.0	No colour	900	100
R800/100-30T	2400	90.0 × 35.0	30.0 × 25.0	No colour	1250	100

(1) R denotes the geogrid is knitted.
(2) Mass/unit area measured in accordance with BS EN ISO 9864 : 2005.
(3) Reference dimensions (see Figure 1).
(4) In accordance with BS EN ISO 10320 : 1999.

Table 2 Performance characteristics

Grade	Machine Direction (MD)				Cross Machine Direction (CMD)			
	Short-term tensile strength (kN m⁻¹)			Strain at maximum tensile strength (%)(*)	Short-term tensile strength (kN m⁻¹)			Strain at maximum tensile strength (%)(*)
	Mean value (*)	Tolerance (*)	T_{char}		Mean value (*)	Tolerance (*)	T_{char}	
35T	35	-0	35	9.5 (±1.5)	20	-0	20	9.5 (±1.5)
55T	55	-0	55	9.5 (±1.5)	20	-0	20	9.5 (±1.5)
65T	65	-0	65	9.5 (±1.5)	20	-0	20	9.5 (±1.5)
80T	80	-0	80	9.5 (±1.5)	20	-0	20	9.5 (±1.5)
110T	110	-0	110	9.5 (±1.5)	20	-0	20	9.5 (±1.5)
150T	150	-0	150	9.5 (±1.5)	20	-0	20	9.5 (±1.5)
200T	200	-0	200	9.5 (±1.5)	20	-0	20	9.5 (±1.5)
35/20-20T	35	-0	35	10 (+0/-3)	20	-0	20	10 (+0/-3)
55/30-20T	55	-0	55	10 (+0/-3)	30	-0	30	10 (+0/-3)
80/30-20T	80	-0	80	11 (+0/-3)	30	-0	30	11 (+0/-3)
110/30-20T	110	-0	110	11 (+0/-3)	30	-0	30	10 (+0/-3)
R150/30-30T	150	-0	150	11 (+0/-3)	30	-0	30	11 (+0/-3)
R200/30-30T	200	-0	200	10 (+0/-3)	30	-0	30	10 (+0/-3)
R400/50-30T	400	-0	400	10 (+0/-3)	50	-0	50	10 (+0/-3)
R600/50-30T	600	-0	600	10 (+0/-3)	50	-0	50	10 (+0/-3)
R800/100-30T	800	-0	800	10 (+0/-3)	100	-0	100	10 (+0/-3)

(1) Tests in accordance with BS EN ISO 10319 : 2008; the values given are the mean and tolerance values in accordance with BS EN 13251 : 2001.

2 Manufacture

2.1 Fortrac T and R-T Geogrids are manufactured from yarn woven or knitted into grids and coated with a protective layer of black styrene butadiene polymer.

2.2 As part of the assessment and ongoing surveillance of product quality, the BBA has:

- agreed with the manufacturer the quality control procedures and product testing to be undertaken
- assessed and agreed the quality control operated over batches of incoming materials

- monitored the production process and verified that it is in accordance with the documented process
- evaluated the process for management of nonconformities
- checked that equipment has been properly tested and calibrated
- undertaken to carry out the above measures on a regular basis through a surveillance process, to verify that the specifications and quality control operated by the manufacturer are being maintained.

2.3 The management system of Huesker Synthetic GmbH has been assessed and registered as meeting the requirements of BS EN ISO 9001 : 2008 by TÜV NORD CERT GmbH, Germany (Certificate 04 100 970084)

3 Delivery and site handling

3.1 The rolls of geogrid are delivered to site stacked and strapped to timber pallets. The rolls are 5.0 metres wide and between 0.5 m to 0.9 m diameter dependent on the product grade and roll length (see Table 1).

3.2 Each roll is wrapped for transit and site protection in black polythene film and is labelled with the geogrid grade and identification (see Figure 2).

Figure 2 Label

3.3 The ends of the rolls are sprayed with colour-coded paint to assist identification of a particular grade of geogrid on site (Table 1) in accordance with BS EN ISO 10320 : 1999.

3.4 Rolls should be stored in clean, dry conditions and protected from mechanical or chemical damage, exposure to direct sunlight and extreme temperatures. When laid horizontally, the rolls may be stacked up to five high. No other loads should be stored on top of the stack. The packaging should not be removed until immediately prior to installation.

3.5 Toxic fumes are given off if the geogrids catch fire and therefore the necessary precautions should be taken following the instructions of the material safety data sheet for the product.

Assessment and Technical Investigations

The following is a summary of the assessment and technical investigations carried out on Fortrac T and R-T Geogrids.

4 General

4.1 When designed and installed in accordance with this Certificate, Fortrac T and R-T Geogrids are satisfactory for the reinforcement of soil embankments with maximum slope angles of 70°.

4.2 Structural stability is achieved through the frictional interaction of soil particles and the geogrids and the tensile strength of the geogrids.

4.3 The fill specification and method of placement and compaction, design strength of the reinforcement and length of reinforcement embedded within the compacted fill are the key design factors.

4.4 Prior to the commencement of work, the designer must satisfy the design approval and certification procedures of the relevant Highway Authority.

4.5 Particular attention should be paid in design to the following issues:

- site preparation and embankment construction
- fill material properties

- drainage
- protection of the product against damage from site traffic and installation equipment
- the stability of existing structures in close proximity
- design of the embankment facing.

4.6 The working drawings should show the correct orientation of the geogrids. Each layer of reinforcement must be continuous in the direction of load, ie without overlaps.

5 Practicability of installation

The products are designed to be installed by trained contractors in accordance with the specifications and construction drawings (see the Installation part of this Certificate).

Design methodology

6.1 Reinforced soil embankments constructed using Fortrac T and R-T Geogrids should be designed in accordance with BS 8006-1 : 2010 and the Specification for Highway Works.

6.2 The typical service life given in Table 7 of BS 8006-1 : 2010 for reinforced soil embankments is 60 years.

Geogrid reinforcement

6.3 In accordance with the methodology set out in BS 8006-1 : 2010, Annex 3, the design strength of the reinforcement (T_D) is calculated as:

$T_D = T_{CR}/f_m$

where:

T_{CR} is the long term tensile creep rupture strength of the reinforcement at the specified design life and design temperature

f_m is the material safety factor to allow for the strength reducing effects of installation damage, weathering (including exposure to sunlight), chemical and other environmental effects and to allow for the extrapolation of data required to establish the above reduction factors.

6.4 The long-term tensile creep rupture strength (T_{CR}) for each grade of geogrid is calculated using the formula:

$T_{CR} = T_{char}/RF_{CR}$

where:

T_{char} is the characteristic short-term strength of the geogrid taken from Table 2

RF_{CR} is the reduction factor for creep (see Section 7)

6.5 The material safety factor (f_m) is calculated as:

$f_m = RF_{ID} \times RF_{W} \times RF_{CH} \times f_s$

where:

RF_{ID} is the reduction factor for installation damage

RF_{W} is the reduction factor for weathering, including exposure to ultra violet light

RF_{CH} is the reduction factor for chemical/environmental effects

f_s is the factor of safety for the extrapolation of data

6.6 Recommended values for RF_{CR}, RF_{ID}, RF_{W}, RF_{CH} and f_s are given in sections 7, 8 and 9 of this Certificate. Conditions of use outside the scope for which the reduction factors are defined are not covered by this Certificate and advice should be sought from the Certificate holder.

Soil/geogrid interaction

6.7 There are two limiting modes of interaction between the soil and the reinforcement that need to be considered and for which the length of reinforcement necessary to maintain equilibrium needs to be determined:

- direct sliding — in which the soil slides over the layer of reinforcement
- pullout — in which the layer of reinforcement pulls out of the soil after it has mobilised the maximum available bond stress.

6.8 In CIRIA SP123, 1996, sections 4.5 and 4.6 describe the following methods for determining resistance to direct sliding and maximum available bond, to which the appropriate partial factors should be applied in accordance with BS 8006-1 : 2010.

6.9 The theoretical expression for resistance to direct sliding is:

$f_{ds} \times \tan \phi'$

where:

f_{ds} is the direct sliding coefficient.

ϕ' is the effective angle of friction of soil

6.10 The direct sliding coefficient (f_{ds}) is calculated as:

$f_{ds} = \alpha_s \times [\tan \delta/\tan \phi'] + (1 - \alpha_s)$

where

α_s is the proportion of plane sliding area that is solid

δ is the angle of skin friction soil on planar reinforcement surface

$\tan \delta/\tan \phi'$ is the coefficient of skin friction between the soil and geogrid material.

6.11 For initial design purposes, the coefficient of skin friction [$\tan \delta/\tan \phi'$] for determining the resistance to direct sliding for the product when buried in compacted frictional fill may be conservatively assumed to be 0.6. Values for the proportion of plane sliding area that is solid (α_s) are given in Table 3.

Table 3 Soil geogrid interaction parameters for T and R-T Fortrac Geogrids

Grade	α_s [1]	Ratio of bearing surface to plan area $\alpha_b \times B/2S$ [2]
35T	0.28	0.009
55T	0.31	0.009
65T	0.34	0.009
80T	0.34	0.009
110T	0.37	0.008
150T	0.39	0.008
200T	0.41	0.008
35/20-20T	0.29	0.014
55/30-20T	0.30	0.014
80/30-20T	0.37	0.017
110/30-20T	0.37	0.016
R150/30-30T	0.35	0.014
R200/30-30T	0.36	0.016
R400/50-30T	0.55	0.013
R600/50-30T	0.49	0.015
R800/100-30T	0.72	0.017

(1) [illegible]

(2) [illegible]

6.12 For detailed design, the resistance to direct sliding should be determined from soil and geogrid specific shear box testing.

6.13 The theoretical expression for maximum available bond stress is:

$f_b \times \tan \phi'$

where

f_b is the bond coefficient

ϕ' is the effective angle of friction of soil.

6.14 The bond coefficient may be calculated as:

$f_b = \alpha_s \times (\tan \delta/\tan \phi') + [\sigma'_b/\sigma'_n] \times [\alpha_b \times B/2S] \times (1/\tan \phi')$

where

α_s is the proportion of plane sliding area that is solid

ϕ' is the effective angle of friction of soil

$\tan \delta/\tan \phi'$ is the coefficient of skin friction between the soil and geogrid material

σ'_b/σ'_n is the bearing stress ratio,

$\alpha_b \times B/2S$ is the ratio of bearing surface to plan area

δ is the angle of skin friction, soil on planar reinforcement surface

σ'_b is the effective bearing stress on the reinforcement

σ'_n is the normal effective stress

6.15 For initial design purposes the coefficient of skin friction [$\tan \delta/\tan \phi'$] for determining the bond coeffic[illegible] the product when buried in frictional fill may be conservatively assumed to be 0.6. Values for the ratio of bearin[illegible] surface to plan area ($\alpha_b \times B/2S$) are given in Table 3. Typical values for the bearing stress ratio (σ'_b/σ'_n) are [illegible] CIRIA SP123, 1996, Table 4.1.

6.16 The BBA recommends that site-specific pullout tests are carried out to confirm the value of bond coeffic[illegible] used in the final design.

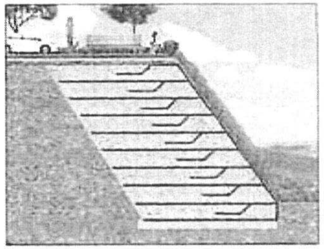
Fill material

6.17 The designer should specify the relevant properties of fill material deemed acceptable for the purpose of the design. Acceptable materials should meet the requirements of BS 8006-1 : 2010, and the Highways Agency's Specification for Highway Works.

Facings

6.18 A typical wrap around facing detail formed using the geogrid is shown in Figure 3. Where the geogrids are used to form the facing, natural or artificial protection must be provided to the grids and fill material to protect the products against damage from ultraviolet light (UV), fire and vandalism, and to protect the fill material from erosion.

Figure 3 Facings



6.19 Other types of facing including preformed panels, gabions/gabion sacks and other proprietary systems may be used, but are outside the scope of this Certificate. Further guidance is given in BS 8006-1 : 2010.

7 Mechanical properties

Tensile strength — short-term

7.1 Characteristic short-term tensile strength (T_{char}) and strain at maximum strength for the product range are given in Table 2.

Tensile strength — long-term

7.2 The long-term creep performance of the geogrids has been determined in accordance with the principles of PD ISO/TR 20432 : 2007 using conventional and stepped isothermal method (SIM) creep rupture test data. The resultant creep rupture diagram is shown in Figure 4.

7.3 For a 60-year design life and design temperature of 20°C, the long-term tensile strength (T_{CR}) of Fortrac T and R-T Geogrids is 66.8% of the characteristic short-term tensile strength (T_{char}), giving a long-term creep reduction factor (RF_{CR}) of 1.50.

7.4 For a 120-year design life and design temperature of 20°C, the long-term tensile strength (T_{CR}) of Fortrac T and R-T Geogrids is 66.0% of characteristic short-term tensile strength (T_{char}) giving a long-term creep reduction factor (RF_{CR}) of 1.52.

Installation damage

7.5 To allow for loss of strength due to mechanical damage that may be sustained during installation, the appropriate value for RF_{ID} should be selected from Table 4. These reduction factors have been established from full-scale installation damage tests using a range of materials whose gradings can be seen in Figure 5. For fills not covered by Table 4, appropriate values of RF_{ID} may be determined from site-specific trials or the engineer may exercise engineering judgment to interpolate between the values given.

Figure 4 Creep rupture diagram — Regression line for the expectancy at constant stress defined by % of characteristic short-term strength at 20°C

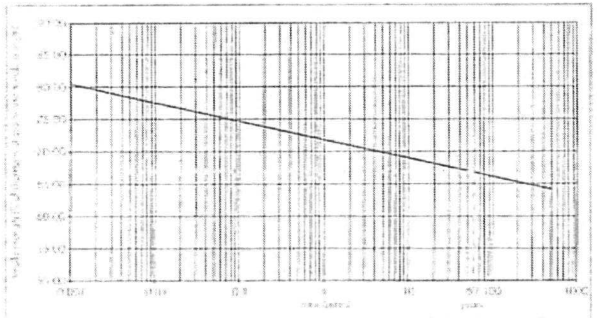


Figure 5 Particle size distributions of fills used in installation damage testing

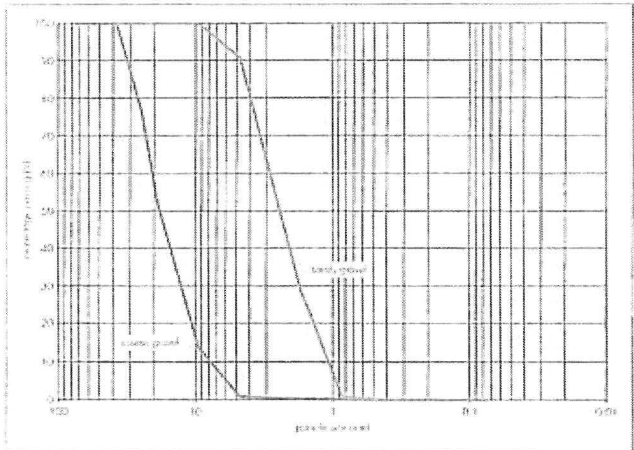


Table 4 Partial safety factor – installation damage (RF_{ID})

Soil type(1)	D_{50} particle size (mm)	Grade	RF_{ID}
Sandy gravel	≤ 10	35T	1.15
		55T	1.15
		65T	1.15
		80T	1.15
		110T	1.10
		150T	1.10
		200T	1.10
		35/20-20T	1.15
		55/30-20T	1.15
		80/30-20T	1.15
		110/30-20T	1.10
		R150/30-30T	1.10
		R200/30-30T	1.10
		R400/50-30T	1.10
		R600/50-30T	1.05
		R800/100-30T	[illegible]
Coarse gravel	≤ 35	35T	1.20
		55T	1.20
		65T	1.20
		80T	1.15
		110T	1.10
		150T	1.10
		200T	1.10
		35/20-20T	1.20
		55/30-20T	1.20
		80/30-20T	1.15
		110/30-20T	1.10
		R150/30-30T	1.10
		R200/30-30T	1.10
		R400/50-30T	1.05
		R600/50-30T	1.05
		R800/100-30T	1.05

(1) Compacted soil thickness 200 mm, weight of vibrating roller [illegible] kg.

(2) Detailed particle size distributions are shown in Figure 5.

8 Effects of environmental conditions

Weathering (including exposure to sunlight)

8.1 The geogrids have adequate resistance to weathering and exposure to sunlight, when protected from exposure in accordance with recommendations of this Certificate. A reduction factor (RF_W) of 1.13 may be used for design provided the periods of exposure are limited to a maximum of one month. A reduction Factor (RF_W) of 1.00 may be used where the product is covered within one day.

Chemical/environmental effects

8.2 Within a soil environment where pH ranges from 4.0 to 9.0, the geogrids have adequate resistance to hydrolysis for applications where sustained soil temperatures are not higher than 25°C.

8.3 The geogrids are highly resistant to microbiological attack.

8.4 When designed and installed in accordance with the requirements of BS 8006-1 : 2010, BS EN 14475 : 2006 and this Certificate, the geogrids are suitable for use in soils at temperatures normally encountered in reinforced soil embankments in the UK. Long-term resistance to chemical and microbiological attack at temperatures greater than 25°C or lower than 0°C are outside the scope of this Certificate. Where geogrids may be exposed to temperatures outside this range, the advice of the Certificate holder should be sought.

8.5 To take account of chemical/environmental effects including hydrolysis, resistance to acids and alkaline liquids and biological/microbial attack, the appropriate value for RF_{CH} shown in Table 5 may be used for design temperatures up to 25°C and pH levels in the range 4.0 to 9.0.

Table 5 Reduction factor RF_{CH}

Design life (years)	RF_{CH}
60	1.03
120	1.05

9 Factor of safety for the extrapolation of data (f_e)

9.1 For Fortrac T and R-T Geogrids, the factor of safety for the extrapolation of data (f_e) should be taken as:

Table 6 *Factor of safety for extrapolation of data*

Design life (years)	f_e
60	1.07
120	1.11

9.2 The above values has been calculated in accordance with PD ISO/TR 20432 : 2007, using the R_1 and R_2 values given in Table 7.

Table 7 R_1 and R_2

Factor	Taking account of	Design life (years)	
		60	120
R_1	Extrapolation of creep-rupture data	1.05	1.05
R_2	Extrapolation of chemical data	1.05	1.10

10 Maintenance

As the product is confined within the soil and has suitable durability, maintenance is not required.

11 Durability

The geogrids will have adequate durability for a design life of up to 120 years when used and installed in accordance with this Certificate.

12 General

12.1 The construction of reinforced soil embankments incorporating the geogrids should be in accordance with the Certificate holder's *Installation instructions*, BS EN 14475 : 2006 and the *Specification for Highway Works*.

12.2 Care should be exercised to ensure Fortrac T and R-T Geogrids are laid with the warp (longitudinal) direction parallel to the direction of principal stress. Design drawings should indicate geogrid orientation (see section 4.6).

13 Procedure

13.1 The geogrid is laid by unrolling the grid to the length required and cutting with a sharp knife or scissors. The unrolling of the grid may be carried out manually or mechanically.

13.2 The grids should be laid flat without folds, parallel with widths in contact to each other. Each reinforcing layer must be continuous in the direction of loading and there should be no overlapping of the grids. Strip misalignment must not exceed 50 mm over a distance of 5 m. Pins or a stretching device may be used to control alignment and also to induce a small prestressing load prior to filling.

13.3 Particular care should be taken to ensure that the grids are adequately covered before compaction or trafficking. Construction traffic will damage unprotected geogrids.

13.4 Fill materials and the thickness and compaction of the fill should be in accordance with Highways Agency's *Specification for Highway Works* and in line with those conditions used to determine the installation damage partial safety factors in the design (see section 7.5).

13.5 Facings are positioned as detailed on the engineer's design drawing. Where the geogrids are used as part of the facing, the geogrid must be wrapped around and anchored back into the fill and must be protected from exposure to ultra violet (UV) light as detailed in Sections 0.18 and 8.1. Formwork is used to assist in maintaining the shape of the facing. Facings, prefabricated or otherwise, are beyond the scope of this Certificate. A typical example is shown in Figure 3.

14.1 The manufacturing process of the geogrids was examined, including the methods adopted for quality control, and details were obtained of the quality and composition of the materials used.

14.2 An examination was made of data relating to:

- evaluation of long- and short-term tensile properties
- chemical degradation
- resistance to hydrolysis
- resistance to biological attack
- resistance to weathering
- effects of temperature
- site damage trials and resistance to mechanical damage
- coefficients of interaction between the geogrids and the soil fill
- installation procedures and typical details

14.3 Calculations were made to establish the plane sliding area that is solid and the ratio of bearing surface to plane area.

14.4 The practicability and ease of handling and installation were assessed.

Bibliography

BS 8006-1 : 2010 *Code of practice for strengthened/reinforced soils and other fills*

BS EN 12224 : 2000 *Geotextiles and geotextile-related products. Determination of the resistance to weathering*

BS EN 12225 : 2000 *Geotextiles and geotextile-related products. Method for determining the microbiological resistance by a soil burial test*

BS EN 12447 : 2000

BS EN 13251 : 2001 *Geotextiles and geotextile-related products — Characteristics required for use in earthworks, foundations and retaining structures*

BS EN 14475 : 2006 *Execution of special geotechnical works — Reinforced fill*

BS EN ISO 9001 : 2008 *Quality Management systems — Requirements*

BS EN ISO 9864 : 2005 *Geosynthetics — Test method for the determination of mass per unit area of geotextiles and geotextile-related products*

BS EN ISO 10319 : 2008 *Geotextiles — Wide-width tensile test*

BS EN ISO 10320 : 1999 *Geotextiles and geotextile-related products — Identification on site*

CIRIA SP123 : 1996 *Soil Reinforcement with Geotextiles* : Jewell R A

PD ISO/TR 20432 : 2007 *Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement*

Manual of Contract Documents for Highway Works, Volume 1 Specification for Highway Works

Manual of Contract Documents for Highway Works, Volume 2 Notes for Guidance on the Specification for Highway Works

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Conditions of Certification

15 Conditions

15.1 This Certificate:

- relates only to the product/system that is named and described on the front page
- is issued only to the company, firm, organisation or person named on the front page — no other company, firm, organisation or person may hold or claim that this Certificate has been issued to them
- is valid only within the UK
- has to be read, considered and used as a whole document — it may be misleading and will be incomplete to be selective
- is copyright of the BBA
- is subject to English law.

15.2 Publications, documents, specifications, legislation, regulations, standards and the like referenced in this Certificate are those that were current and/or deemed relevant by the BBA at the date of issue or reissue of this Certificate.

15.3 This Certificate will remain valid for an unlimited period provided that the product/system and its manufacture and/or fabrication, including all related and relevant parts and processes thereof:

- are maintained at or above the levels which have been assessed and found to be satisfactory by the BBA
- continue to be checked as and when deemed appropriate by the BBA under arrangements that it will determine
- are reviewed by the BBA as and when it considers appropriate.

15.4 The BBA has used due skill, care and diligence in preparing this Certificate, but no warranty is provided.

15.5 In issuing this Certificate, the BBA is not responsible and is excluded from any liability to any company, firm, organisation or person, for any matters arising directly or indirectly from:

- the presence or absence of any patent, intellectual property or similar rights subsisting in the product/system or any other product/system
- the right of the Certificate holder to manufacture, supply, install, maintain or market the product/system
- actual installations of the product/system, including their nature, design, methods, performance, workmanship and maintenance
- any works and constructions in which the product/system is installed, including their nature, design, methods, performance, workmanship and maintenance
- any loss or damage, including personal injury, howsoever caused by the product/system, including its manufacture, supply, installation, use, maintenance and removal
- any claims by the manufacturer relating to CE marking.

15.6 Any information relating to the manufacture, supply, installation, use, maintenance and removal of this product/system which is contained or referred to in this Certificate is the minimum required to be met when the product/system is manufactured, supplied, installed, used, maintained and removed. It does not purport in any way to restate the requirements of the Health and Safety at Work etc. Act 1974, or of any other statutory, common law or other duty which may exist at the date of issue or reissue of this Certificate; nor is conformity with such information to be taken as satisfying the requirements of the 1974 Act or of any statutory, common law or other duty of care.

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Annexe 5 :
Certificat ISO 9001 : 2008 de l'usine de production

SGS TÜV SAAR

SGS

Certificat DE18/819943759

Le système de management de

HUESKER

HUESKER Synthetic GmbH

Fabrikstraße 13-15
D-48712 Gescher

a été audité et certifié selon les exigences de

ISO 9001:2015

Pour les activités suivantes

Développement, production, contrôle, vente et utilisation technique de géosynthétiques et textiles techniques

Ce certificat est valable du 16.05.2018 au 15.05.2021 et reste valide jusqu'à décision satisfaisante à l'issue des audits de suivi. L'audit de renouvellement doit avoir lieu avant 01.04.2021
Version 1
Date d'audit de certification: 02.01.2018
Date d'expiration du precedent certificat 15.05.2018

Ceci est une certification multisite
La liste des sites additionnels est mentionnée dans la page suivante

Autorisé par

ppa Jan Meeuwsen
Director CEE Germany

Hagen Sanne
Head of Certification Body

DAkkS Deutsche Akkreditierungsstelle D-ZM-12086-01-00

SGS-TÜV Saar GmbH
Am TÜV 1 66280 Sulzbach (Germany)
e-mail: de.cbo.zertifizierung@sgs.com www.sgs-tuev-saar.com

Page 1 de 2

Annexe 6 :
Certificat NF EN ISO IEC 17025 de notre laboratoire de contrôle

BETA ENVIRONNEMENT
9 Le Cerny - 85170 Le Poiré sur Vie
Tél : 06 46 75 48 10
SIRET 803 775 477 R.C.S. LA ROCHE-SUR-YON
S.A.S. au capital de 5 000,00 € - A.P.E. 7112B
TVA FR 48 803 775 477

DAkkS
Deutsche
Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

Entrusted according to Section 8 subsection 1 AkkStelleG in connection with Section 1 subsection 1 AkkStelleGBV
Signatory to the Multilateral Agreements of EA, ILAC and IAF for Mutual Recognition

Accreditation

The Deutsche Akkreditierungsstelle GmbH attests that the testing laboratory

HUESKER Synthetic GmbH
Fabrikstraße 13-15, 48712 Gescher

is competent under the terms of DIN EN ISO/IEC 17025:2018 to carry out tests in the following fields:

mechanical and thermoanalytic tests on textiles, technical textiles, especially geotextiles (geosynthetics) and geotextile-related products and fiber-reinforced plastics

The accreditation certificate shall only apply in connection with the notice of accreditation of 20.06.2019 with the accreditation number D-PL-19299-01. It comprises the cover sheet, the reverse side of the cover sheet and the following annex with a total of 4 pages.

Registration number of the certificate: D-PL-19299-01-00

Berlin, 13.05.2019	Dr. Heike Manke Head of Division	Translation issued: 09.07.2019	Head of Division

The certificate together with its annex reflects the status at the time of the date of issue. The current status of the scope of accreditation can be found in the database of accredited bodies of Deutsche Akkreditierungsstelle GmbH.
https://www.dakks.de/en/content/accredited-bodies-dakks

This document is a translation. The definitive version is the original German accreditation certificate.

Deutsche Akkreditierungsstelle GmbH

Office Berlin Spittelmarkt 10 10117 Berlin	Office Frankfurt am Main Europa-Allee 52 60327 Frankfurt am Main	Office Braunschweig Bundesallee 100 38116 Braunschweig

The publication of extracts of the accreditation certificate is subject to the prior written approval by Deutsche Akkreditierungsstelle GmbH (DAkkS). Exempted is the unchanged form of separate disseminations of the cover sheet by the conformity assessment body mentioned overleaf.

No impression shall be made that the accreditation also extends to fields beyond the scope of accreditation attested by DAkkS.

The accreditation was granted pursuant to the Act on the Accreditation Body (AkkStelleG) of 31 July 2009 (Federal Law Gazette I p. 2625) and the Regulation (EC) No 765/2008 of the European Parliament and of the Council of 9 July 2008 setting out the requirements for accreditation and market surveillance relating to the marketing of products (Official Journal of the European Union L 218 of 9 July 2008, p. 30). DAkkS is a signatory to the Multilateral Agreements for Mutual Recognition of the European co-operation for Accreditation (EA), International Accreditation Forum (IAF) and International Laboratory Accreditation Cooperation (ILAC). The signatories to these agreements recognise each other's accreditations.

The up-to-date state of membership can be retrieved from the following websites:
EA: www.european-accreditation.org
ILAC: www.ilac.org
IAF: www.iaf.nu

DAkkS Deutsche Akkreditierungsstelle

Deutsche Akkreditierungsstelle GmbH

Annex to the Accreditation Certificate D-PL-19299-01-00 according to DIN EN ISO/IEC 17025:2018

Valid from: 07.05.2019
Date of issue: 13.05.2019

Holder of certificate:

HUESKER Synthetic GmbH
Fabrikstraße 13-15, 48712 Gescher

Tests in the fields:

mechanical and thermoanalytic tests on textiles, technical textiles, especially geotextiles (geosynthetics) and geotextile-related products and fiber-reinforced plastics

The testing laboratory is permitted, without being required to inform and obtain prior approval from DAkkS, to use standards or equivalent testing methods listed here with different issue dates. The testing laboratory maintains a current list of all testing methods within the flexible scope of accreditation.

This document is a translation. The definitive version is the original German annex to the accreditation certificate.

Abbreviations used: see last page

The certificate together with its annex reflects the status at the time of the date of issue. The current status of the scope of accreditation can be found in the database of accredited bodies of Deutsche Akkreditierungsstelle GmbH: https://www.dakks.de/en/content/accredited-bodies-dakks

DAkkS Deutsche Akkreditierungsstelle

mechanical and thermoanalytic tests on textiles, technical textiles, especially geotextiles (geosynthetics) and geotextile-related products

DIN 4102-1 1998-05	Fire behaviour of building materials and building components - Part 1: Building materials; concepts, requirements and tests
DIN 53859-5 1992-12	Testing of textiles - tear growth test on textile fabrics - trapezoid test
DIN 75200 1980-09	Determination of burning behaviour of interior in motor vehicles
DIN EN 12447 2002-03	Geotextiles and geotextile-related products - Screening test method for determining the resistance to hydrolysis in water
DIN EN 29073-3 1992-08	Textiles - test method for nonwovens - part 3: determination of tensile strength and elongation
DIN EN ISO 527-5 2010-01	Plastics - Determination of tensile properties - Part 5: Test conditions for unidirectional fibre-reinforced plastic composites
DIN EN ISO 1421 2013-03	Rubber- or plastics-coated fabrics - Determination of tensile strength and elongation at break
DIN EN ISO 2062 2010-04	Textiles - Yarns from packages - Determination of single-end breaking force and elongation at break
DIN EN ISO 9863-1 2005-05	Geosynthetics - Determination of thickness at specified pressures - Part 1: Single layers
DIN EN ISO 9864 2005-05	Geosynthetics - Test method for the determination of mass per unit area of Geotextiles and geotextile-related products
DIN EN ISO 10319 2008-10	Geotextiles - Wide-width tensile test
DIN EN ISO 10321 2008-08	Geotextiles - Tensile test for joints/seams by wide-width method
DIN EN ISO 11058 2010-11	Geotextiles and geotextile-related products - Determination of water permeability characteristics normal to the plane, without load

-Translation-

Valid from: 07.05.2019
Date of issue: 13.05.2019

BETA ENVIRONNEMENT
9 Le Cerny - 85170 Le Poiré sur Vie
Tél : 06 46 05 48 10
SIRET 803 775 477 R.C.S. LA ROCHE-SUR-YON
S.A.S. au capital de 5 000,00 € - A.P.E. 7112B
TVA FR 48 803 775 477

DAkkS Deutsche Akkreditierungsstelle

DIN EN ISO 12236 2006-11	Geotextiles and geotextile-related products - Static puncture test (CBR-Test)
DIN EN ISO 12956 2010-08	Geotextiles and geotextile-related products - Determination of the characteristic opening size
DIN EN ISO 13433 2006-10	Geosynthetics - Dynamic perforation test (con drop test)
DIN EN ISO 13934-1 2013-08	Textiles - Tensile properties of fabrics - Part 1: Determination of maximum force and elongation at maximum force using the strip method
DIN EN ISO 13934-2 2014-06	Textiles - Tensile properties of fabrics - Part 2: Determination of maximum force using the grab method
DIN EN ISO 13438 2005-02	Geotextiles and geotextile-related products - Screening test method for determining the resistance to oxidation (only test procedure A)
DIN EN ISO 14215 2011-05	Fibre-reinforced plastic composites - Determination of flexural properties
ASTM D 4533 2011	Standard Test Method for Trapezoid Tearing Strength of Geotextiles
ASTM D 4595 2011	Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method
ASTM D 4632 2013	Standard Test Method for Grab Breaking Load and Elongation of Geotextiles
ASTM D 4833 2007	Standard Test Method for Index Puncture of Geomembranes and Related Products
ASTM D 4884 2013	Standard Test Method for Strength of Sewn or Thermally Bonded Seams of Geotextiles
ASTM D 5199 2012	Standard Test Method for Measuring Nominal Thickness of Geosynthetics
ASTM D 5261 2010	Standard Test Method for Measuring Mass per Unit Area of Geotextiles

-Translation-

DAkkS Deutsche Akkreditierungsstelle

ASTM D 6241 2009	Standard Test Method for the static Puncture Strength of Geotextiles and Geotextile-Related Products Using a 50-mm Probe
NF G38-019 1988-12	Textiles - Articles for industrial use - Tests for geotextiles: determination of resistance to stamping.
Prüfanweisung HS 04 2013-06	DSC-test - determination of melting temperature and melting curve
Prüfanweisung HS 06 2013-11	Test method for the determination of dimension stability of geogrids

Abbreviations used:

ASTM	American Society for Testing and Materials
DIN	Deutsches Institut für Normung e. V.
EN	Europäische Norm
ISO	International Organisation for Standardisation
NF	Norme Française (französische Norm)
Prüfanweisung HS xx	Test procedure from HUESKER Synthetic GmbH Labority

-Translation-

HUESKER à travers le monde:

HUESKER France SAS

Rue Jacques Coulaux
F 67190 Gresswiller
Tél : + 33 3 88 78 26 07
Fax : +33 3 88 78 26 19
Courriel : info@HUESKER.fr
Internet : www.HUESKER.fr

HUESKER

Version A1 : 10/2013

Fiche Technique

HUESKER
Ideen. Ingenieure. Innovationen.

Fortrac® | Type 150 T

Géogrille certifiée IVG selon fonction

Renforcement ☑
Filtration
Séparation

GÜTEÜBERWACHUNG IVG GEOKUNSTSTOFFE
n° 3392

01. Matière première		**PET**	
02. Enduction		**Polymère**	
03. Ouverture des mailles (env.)		**≈ 25 x 25**	mm x mm
04. Masse surfacique (NF EN ISO 9864)		**440**	g/m²
05. Résistance à la traction (NF EN ISO 10319)	longitudinale	**≥ 150**	kN/m
	transversale	**≥ 20**	kN/m
06. Allongement à la résistance à la traction nominale (NF EN ISO 10319)	longitudinal	**≤ 10**	%
07. Dimensions standards	largeur x longueur	**5,00 x 200,0**	m x m
	Surface d'un rouleau	**1000**	m²

Remarque : Les géogrilles Fortrac® | type T disposent d'un avis technique garantissant leurs coefficients réducteurs vis-à-vis du fluage, de l'agression mécanique et de l'environnement chimique ainsi que les extrapolations afin d'assurer la viabilité de l'ouvrage jusqu'à 120 ans

Votre interlocuteur :

HUESKER France SAS
Parc de la Manufacture
F-67190 Gresswiller
Tel : + 33(0) 3 88 78 26 07
Fax : + 33(0) 3 88 78 26 19
Courriel : info@huesker.fr
Internet : www.huesker.fr

Fiche Technique

HUESKER
Ideen. Ingenieure. Innovationen.

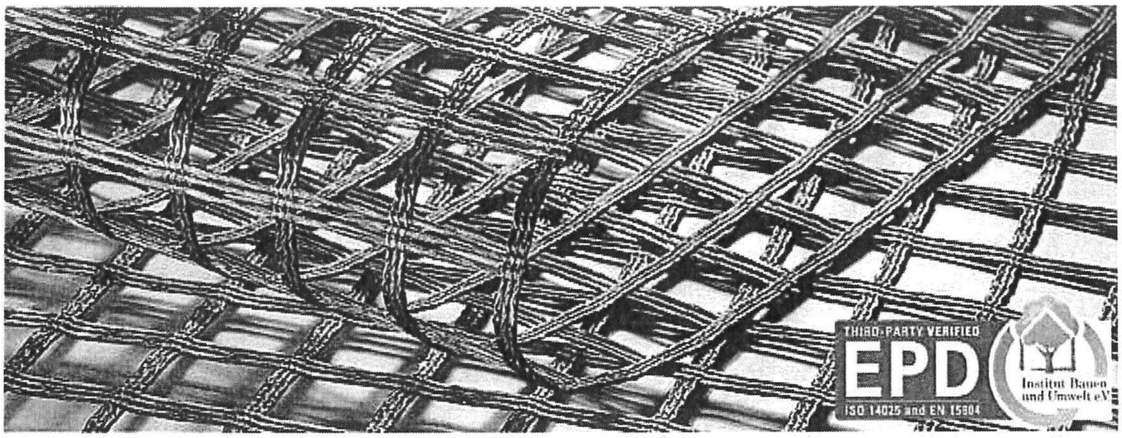
Fortrac® | Type 150 T

Description du Produit

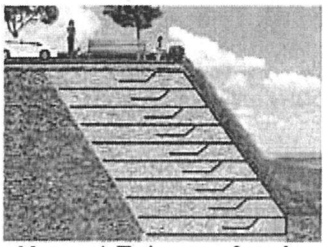
Fortrac® | type T est une géogrille flexible qui permet de construire des ouvrages de manière économique et écologique. Les géogrilles Fortrac® | type T sont caractérisées par :

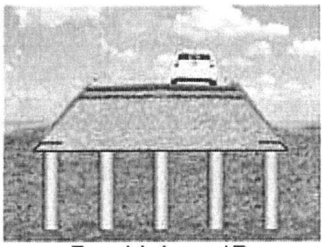
- Un fort module et un faible taux de fluage
- Une bonne résistance contre les endommagements mécaniques
- Une bonne résistance à la dégradation chimique pour les sols naturels (4 < pH < 9)

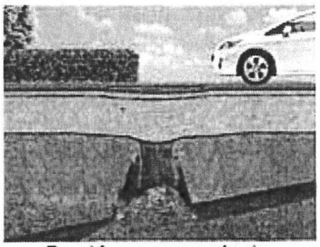
Les géogrilles Fortrac® génèrent l'ossature d'un sol sans en perturber les écoulements hydrauliques. La flexibilité et le conditionnement assurent aux géogrilles Fortrac® une facilité de mise en œuvre et un gain de temps non négligeables sur chaque chantier.



Domaines d'utilisation standards de la géogrille Fortrac® T


Murs et Talus renforcés

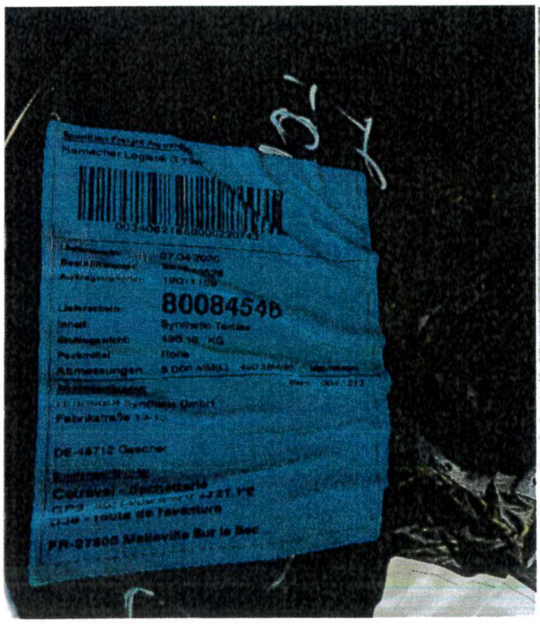

Remblai sur IR

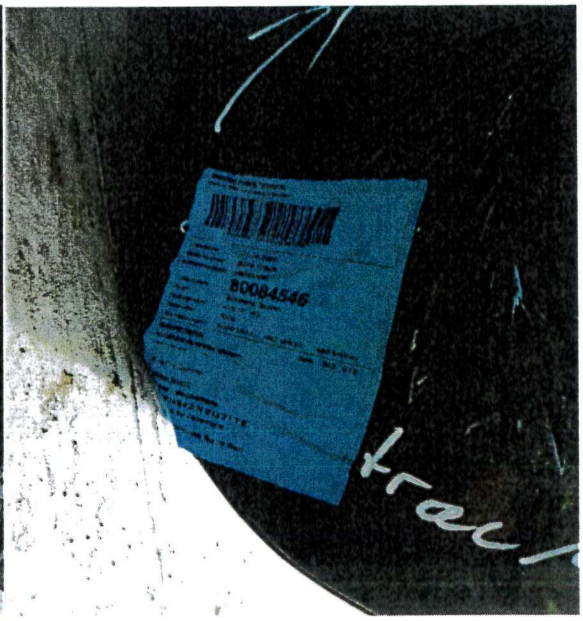

Système parachute

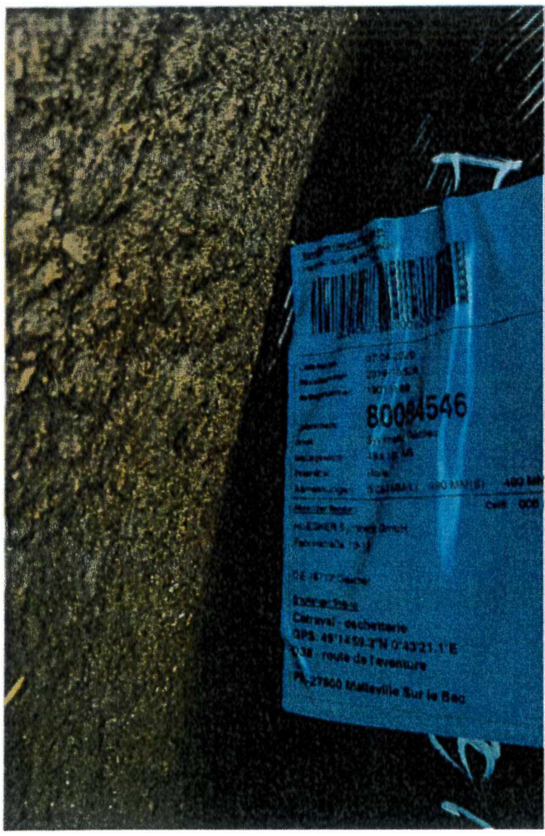
HUESKER Synthetic GmbH

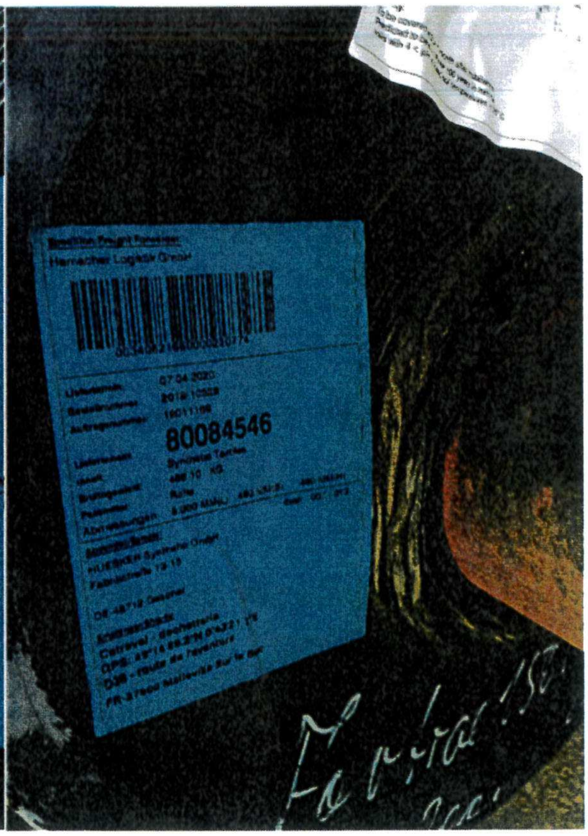
Référence des rouleaux

Référence Rouleaux Géogrille Casier Amiante

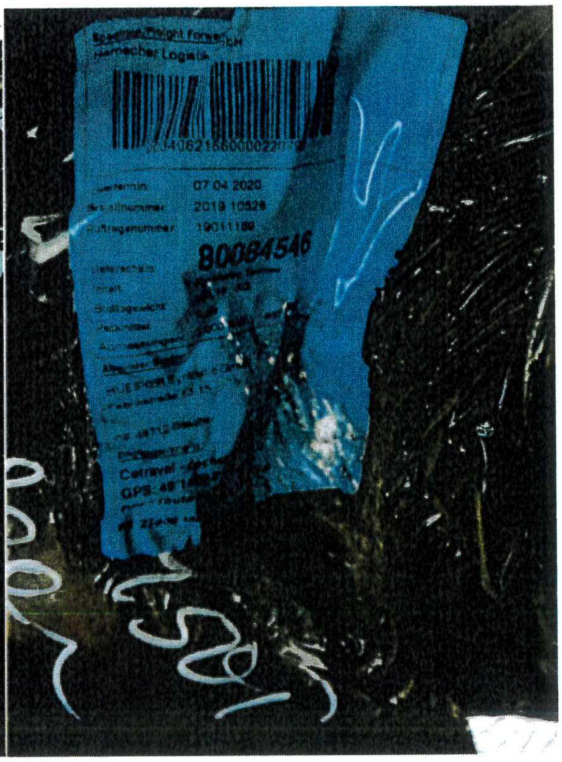


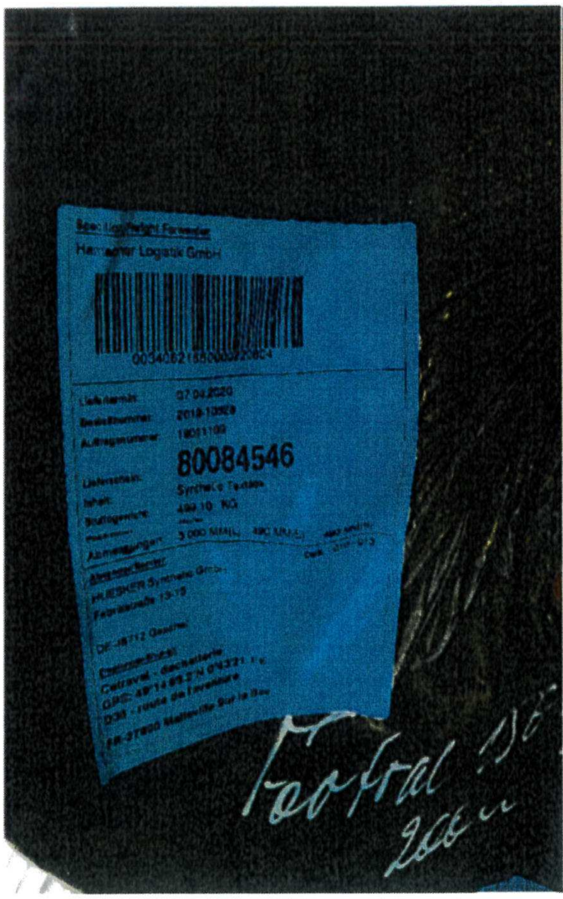




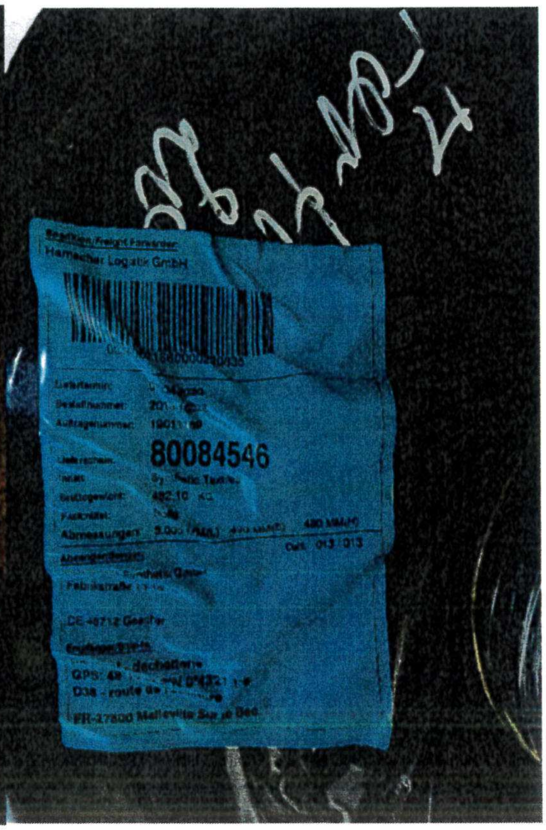



80084546

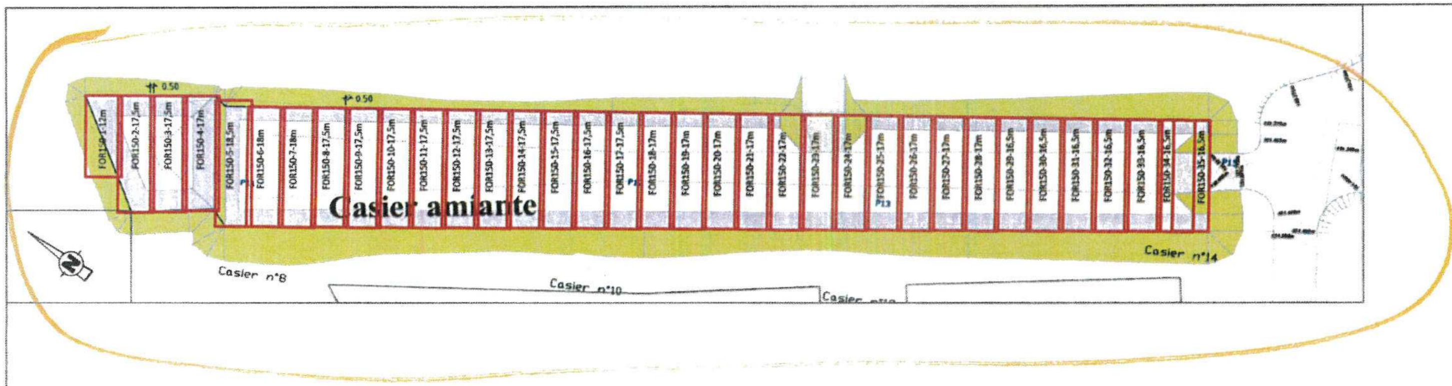

Hamacher Logistik
07.04.2020
80084546

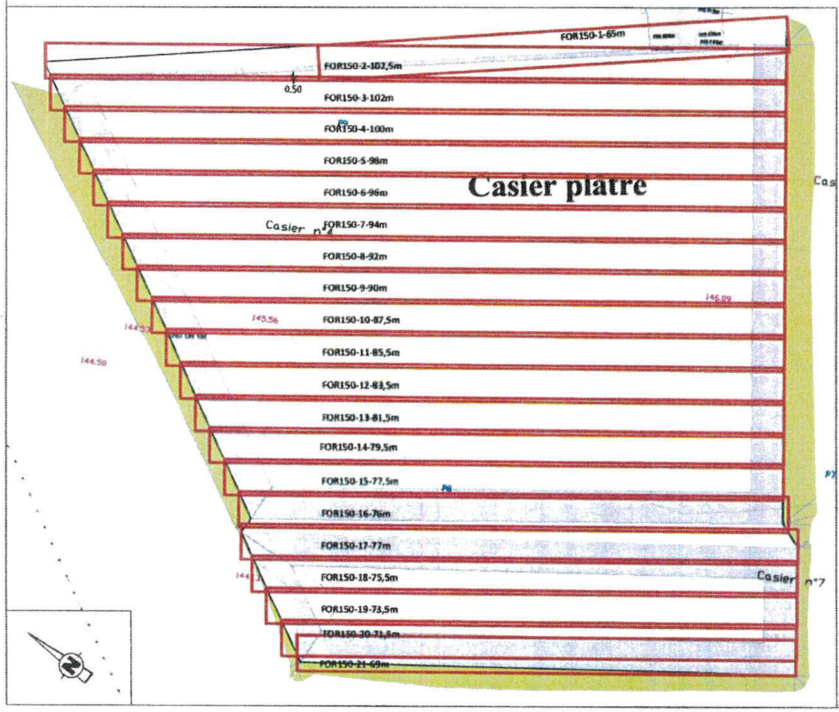

Hamacher Logistik GmbH
07.04.2020
80084546

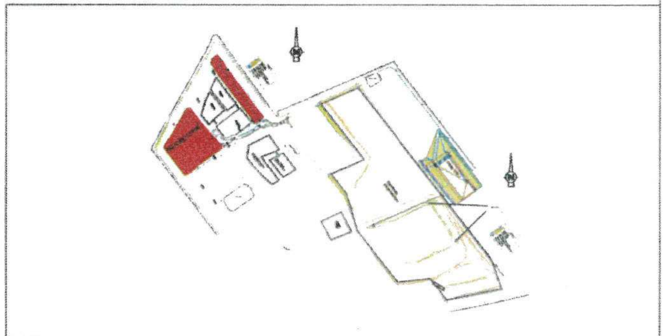

Hamacher Logistik GmbH
07.04.2020
80084546


80084546
Abmessungen:
Fabrikstraße 13-15
FR-27800

Hamacher Logistik GmbH
80084546
Abmessungen:

Plan de calepinage

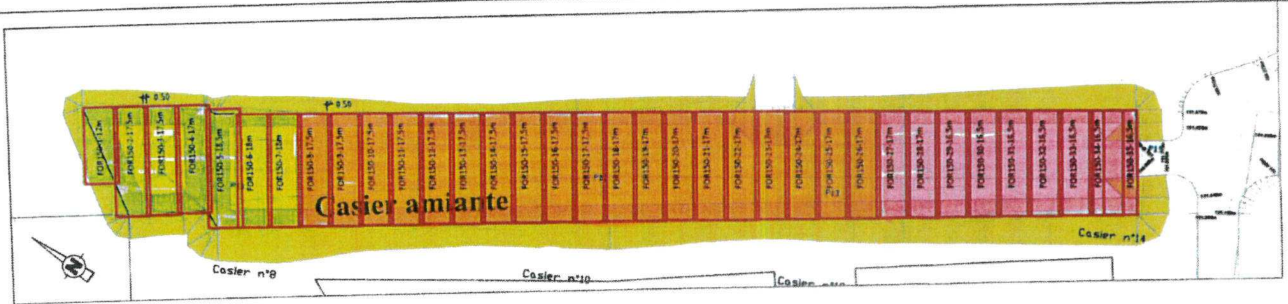






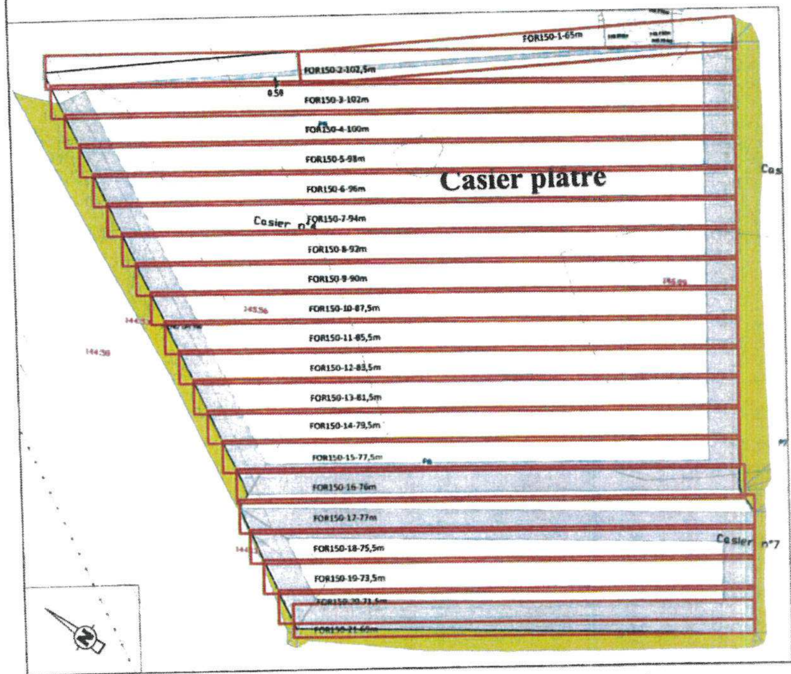
Indice	Modification	par	Date
c			
b			
a			

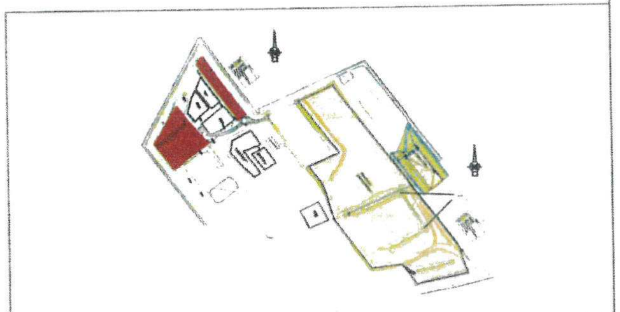
Projet Casier SDMODE - CETRAVAL (27); France				Numéro/projet	2013910-1E-Dö
				Numéro/dessin	2013910_1E-01
Objet Plan d'installation				Statut	Concept
				Date	21.10.2019
Produit	Fortrac 150 T	Date	par		
échelle	1:500	Conception	18.10.2019	R. Beuker	
Taille/feuille	594x420	Dessiné par	21.10.2019	Dö	
Plan/sur	01	Vérifié par	21.10.2019	R. Durand	



le 15/07/20 le Matin | le 15/07/20 Après midi | le 16/07/20 le Matin

Pose de la géogrille sur Casier Amiante





Indice	Modification	par	Date
c			
b			
a			

Projet	Casier SOMODE - CETRAVAL (27); France			Numéro/projet	2013910-1E-Dö
				Numéro/dessin	2013910_1E-01
Objet	Plan d'installation			Statut	Concept
				Date	21.10.2019
Produit	Fortrac 150 T	Date	par		
échelle	1:500	Conception	18.10.2019	R. Baumer	
Taille/feuille	594x420	Dessiné par	21.10.2019	Dö	
Plan/sur	01	Vérifié par	21.10.2019	R. Durand	

Association des rouleaux

Association rouleaux

Explication:
P1, P2... sont les lés du casier Plâtre
A1, A2... sont les lés du casier Amiante
R1, R2... sont les rouleaux de 5x200 m par association des lés du casier Plâtre et casier Amiante

Rouleau assemblé	constitué des lés	Longueur
		m
R1	P4, P5	198
R2	P3, P6	198
R3	P2, P7	196,5
R4	P8, P9, A2	199,5
R5	P1, P10, A1, A3, A4	199
R6	P11, P12, A5	187,5
R7	P13, P14, A6, A7	197
R8	P15, P16, A8, A9	188,5
R9	P17, P18, A10, A11	187,5
R10	P19, P20, A12, A13, A14	197,5
R11	P21, A15 à A21	189,5
R12	A22 à A32	185
R13	A33 à A35	49,5

13 rouleaux de 5x200 m = 13 000 m²

Casier Amiante

	Produit	Numéro	Longueur	Surface	Dénomination plan
		Lé	m	par lé, m²	Lé
1	FOR150	A1	12,00	60	FOR150-1-12m
2	FOR150	A2	17,50	86	FOR150-2-17,5m
3	FOR150	A3	17,50	85,5	FOR150-3-17,5m
4	FOR150	A4	17,00	84,5	FOR150-4-17m
5	FOR150	A5	18,50	92,5	FOR150-5-18,5m
6	FOR150	A6	18,00	88	FOR150-6-18m
7	FOR150	A7	18,00	88	FOR150-7-18m
8	FOR150	A8	17,50	87,5	FOR150-8-17,5m
9	FOR150	A9	17,50	87,5	FOR150-9-17,5m
10	FOR150	A10	17,50	87	FOR150-10-17,5m
11	FOR150	A11	17,50	87	FOR150-11-17,5m
12	FOR150	A12	17,50	86,5	FOR150-12-17,5m
13	FOR150	A13	17,50	86,5	FOR150-13-17,5m
14	FOR150	A14	17,50	86	FOR150-14-17,5m
15	FOR150	A15	17,50	86	FOR150-15-17,5m
16	FOR150	A16	17,50	85,5	FOR150-16-17,5m
17	FOR150	A17	17,50	85,5	FOR150-17-17,5m
18	FOR150	A18	17,00	85	FOR150-18-17m
19	FOR150	A19	17,00	85	FOR150-19-17m
20	FOR150	A20	17,00	84,5	FOR150-20-17m
21	FOR150	A21	17,00	84,5	FOR150-21-17m
22	FOR150	A22	17,00	84,5	FOR150-22-17m
23	FOR150	A23	17,00	84	FOR150-23-17m
24	FOR150	A24	17,00	84	FOR150-24-17m
25	FOR150	A25	17,00	83,5	FOR150-25-17m
26	FOR150	A26	17,00	83,5	FOR150-26-17m
27	FOR150	A27	17,00	83	FOR150-27-17m
28	FOR150	A28	17,00	83	FOR150-28-17m
29	FOR150	A29	16,50	82,5	FOR150-29-16,5m
30	FOR150	A30	16,50	82,5	FOR150-30-16,5m
31	FOR150	A31	16,50	82	FOR150-31-16,5m
32	FOR150	A32	16,50	82	FOR150-32-16,5m
33	FOR150	A33	16,50	81,5	FOR150-33-16,5m
34	FOR150	A34	16,50	81,5	FOR150-34-16,5m
35	FOR150	A35	16,50	81	FOR150-35-16,5m
			596,0	**2947,0**	
			Somme	Somme	

Réception du support

Galopin Génie étanchéité	PROCES-VERBAL DE RECEPTION DU SUPPORT D'ETANCHEITE	QUAL-FORM 12/3 08/04/2020 Page **1** sur **2**

CHANTIER

CHANTIER	BASSIN CASIER AMIANTE

CONTRÔLE VISUEL DU SUPPORT

1.	LE SUPPORT EST-IL PLAN ?	☒ Oui	☐ Non	
2.	LE SUPPORT PRESENTE-T-IL DES ELEMENTS POINÇONNANT ?	☐ Oui	☒ Non	
3.	Y A-T-IL DE L'EAU OU DE LA BOUE ?	☐ Oui	☒ Non	
4.	LE SUPPORT EST-IL STABLE ?	☒ Oui	☐ Non	
5.	L'ANCRAGE EST-IL OUVERT ?	☐ Oui	☒ Non	
6.	SI OUI, DIMENSIONS DE LA TRANCHEE ?	Banquette : 0,50 m	Profondeur : 0,4 m	Largeur : 0,4 m
7.	PRESENCE DE DEBOUCHES ?	☒ Oui	☐ Non	Canalisations sur plaque PE
8.	LES OUVRAGES EN BETON SONT-ILS REALISES ?	☐ Oui	☒ Non	
9.	~~SI OUI, EST-IL POSSIBLE DE REALISER LES FIXATIONS MECANIQUES ?~~	☐ Oui	☐ Non	
10.	~~AVEZ-VOUS REALISE UN ESSAI DE PERÇAGE ?~~	☐ Oui	☐ Non	

RECEPTION DES ZONES

ZONE	DESCRIPTION / PLAN / SCHEMA	RECEPTION	REPRISES A REALISER	DATE DE REPRISE
Bassin Amiante	Plan d'exé	☐ Partielle ☒ Totale	Reprises faites sous débouchés.	17/09/2020
		☐ Partielle ☐ Totale		__/__/__
		☐ Partielle ☐ Totale		__/__/__
		☐ Partielle ☐ Totale		__/__/__

Galopin Génie étanchéité	PROCES-VERBAL DE RECEPTION DU SUPPORT D'ETANCHEITE	QUAL-FORM 12/3 08/04/2020 Page 2 sur 2

REMARQUES

Tassement sous débouchés en point bas repris par LE FOLL avec comblement avec matériaux argileux de la zone impactée.

VISAS

Entreprise		Nom du representant	Date	Visa
Maitre d'ouvrage			__/__/__	
Maitre d'œuvre			__/__/__	
Controleur exterieur			__/__/__	
Entreprise de terrassement	Le Foll	B. Richer	17/09/20	[signature]
Entreprise d'etancheite	EGC Galopin	A. DAVERGNE [signature]	17/09/20	EGC GALOPIN 46 Rue Jacques Mugnier 68200 MULHOUSE Tél. : 03.89.33.44.59 - Fax : 03.89.42.05.7! [signature]

Essai labo casier Amiante

Essai de plaque

LE FOLL LABORATOIRE Agrément LABOROUTE N° 00-57 BP-2 27500 Corneville / Risle Tel : 02.32.57.00.38 Fax : 02.32.57.18.40	ENREGISTREMENTS RELATIFS A LA QUALITE AGREMENT LABOROUTE N° Dossier : L19-028	REF : 96/RAPPORT Date de révision : 13/02/12 Indice d'évolution : G

FICHE DE COMPTE RENDU JOURNALIER N° : 5

CHANTIER : SDOMODE, Malleville sur le Bec Casier Amiante **Date :** 15/07/2020

PRESTATIONS CONTROLEES :

* *Granulats*
* *Filler*
* *Liant hydraulique*
* *Liant hydrocarboné*
* *Sondages*
* *Fond de forme*
* *Remblais*
* *Couche de forme*
* *Graves et sables non traités*
* *Graves et sables traités*
* *Béton*
* *Béton pour GBA et DBA*
* *Grave bitume*
* *Béton bitumineux de liaison*
* *Béton bitumineux de roulement*
* *Autres*

CONTROLES EFFECTUES : ***Les essais en caractéres gras font partie de la liste des essais agréés LABOROUTE pour notre laboratoire.***

* ***Proctor sol NF EN 13286-2***
* ***Proctor grave NF EN 13286-2***
* ***Teneur en eau NF P 94-410-1***
* ***Analyse granulométrique sol NF P 94056***
* ***Indice de portance NF EN 13286-47***
* ***Limites d'Atterberg NF P 94051***
* ***Valeur de bleu des sols NF P 94068***
* ***Teneur en liant soluble et analyse granulometrique NF EN 12697-1 et 2***
* ***Analyse granulométrique NF EN 933-1***
* ***Ecoulement des sables NF EN 933-6***
* ***Essai de propreté P 18591***
* ***Valeur de bleu à la tâche EN 933.9***
* ***Masse volumique à l'eau NF EN 1097-5 et 6***
* ***Masse volumique à l'huile P 18559***
* ***Essai de Rigden NF EN 1097-4***
* *Viscosité du bitume (Mode opératoire)*
* ***Pénétrabilité du bitume NF EN 1426***
* ***TBA sur bitume NF EN 1427***
* ***Densité sur bitume NF EN ISO 3838***
* ***Teneur en eau émulsion NF EN 1428***
* ***Teneur en eau bitume NF T 60113***
* ***Teneur en paraffine NF EN 12606-1***
* ***Pesées hydrostatiques NF EN 12697-6***
* ***Densités en place NF P 98241.1***
* ***PMT NF EN 13036.1***
* ***Essai à la plaque NF P 94117.1***
* *Réglages de la centrale de fabrication*
* *Carottages*
* *Autres*

Le présent procès-verbal comporte pages et / annexes de / pages. Sauf accord écrit, la reproduction même partielle de ce procès-verbal, dans un but commercial, est interdite

LE TECHNICIEN	LE CHEF DE SECTION	DESTINATAIRES
Visa	Date et visa 17/07/20	1 exemplaire MO 1 exemplaire laboratoire LE FOLL

LE FOLL

FICHE D' ESSAI A LA PLAQUE- ESSAI DE DEFORMABILITE

109 Rue des Douves
27500 Corneville Sur Risle

Tél : 02.32.57.81.31
Fax. : 02 32.57.18.40

(Mode opératoire CT-2 / NFP 94-117.1)
Dérogation*
REF 96/PLAQUE

Date et indice de révision : 11/10/12 indice D

Dossier n° : L19-028	Matériau : Argile à silex
Date des essais : 15/07/2020	
Demandeur : LE FOLL	Provenance : in situ
Destinataires : LE FOLL	Appareillage : Poutre de Benkelmann
N° rapport : 217 IS 20	
Lieu des essais : SDOMODE, Malleville sur le Bec	Durée de l'intervention : 1h
	Opérateur : RODE J.

Référence			Déflexion en mm		Déflexion en mm			Modules			
									CT2	94-117.1	CT2
ESSAI N°	PK - PR	EMPLACEMENT	$W_{0,1}$	$W_{0,7}$	W_1	W_R	W_2	Westergaard	EV_1 MPa	EV_2 MPa	K
1	-	voir schéma			4,35	3,17	4,25		13	42	3,2
2	-	voir schéma			1,87	1,05	1,84		30	57	1,9
3	-	voir schéma			1,35	0,68	1,33		42	69	1,7
4	-	voir schéma			2,44	1,40	2,33		23	48	2,1
5	-	voir schéma			1,01	0,53	0,98		56	100	1,8
6	-	voir schéma			4,54	3,18	4,48		12	35	2,8

COMMENTAIRES :

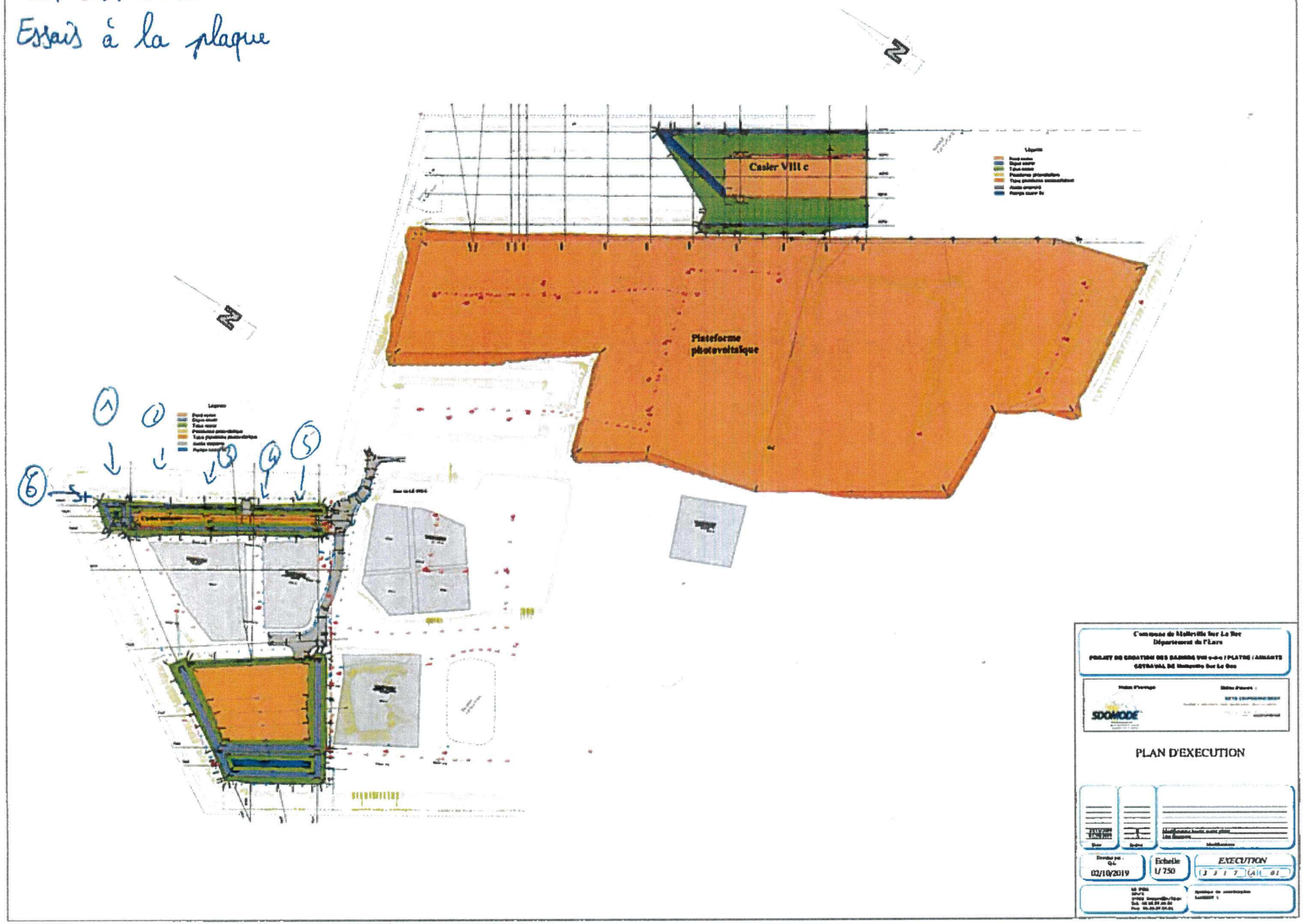
* (EV2) la distance d'appui est inférieure à 1,2m

* (Westergaard) la distance d'appui est inférieure à 0.9m

$1MN/m^2$ = 1 Mpa = 10 bars / Module de Westergaard en Bars/cm

Le responsable du laboratoire

15/07/2020
Essais à la plaque



LE FOLL **LABORATOIRE** **Agrément LABOROUTE N° 00-57** BP-2 27500 Corneville / Risle Tel : 02.32.57.00.38 Fax : 02.32.57.18.40	**ENREGISTREMENTS RELATIFS A LA QUALITE** AGREMENT LABOROUTE	**REF : 96/RAPPORT**
	N° Dossier : L19-028	**Date de révision : 13/02/12** **Indice d'évolution : G**

FICHE DE COMPTE RENDU JOURNALIER N° : 6

CHANTIER : SDOMODE, Malleville sur le Bec Casier Amiante . Sur confinement . **Date : 20/07/2020**

PRESTATIONS CONTROLEES :

* *Granulats*
* *Filler*
* *Liant hydraulique*
* *Liant hydrocarboné*
* *Sondages*
* *Fond de forme*
* *Remblais*
* *Couche de forme*
* *Graves et sables non traités*
* *Graves et sables traités*
* *Béton*
* *Béton pour GBA et DBA*
* *Grave bitume*
* *Béton bitumineux de liaison*
* *Béton bitumineux de roulement*
* *Autres*

CONTROLES EFFECTUES : ***Les essais en caractéres gras font partie de la liste des essais agréés LABOROUTE pour notre laboratoire.***

* ***Proctor sol NF EN 13286-2***
* ***Proctor grave NF EN 13286-2***
* ***Teneur en eau NF P 94-410-1***
* ***Analyse granulométrique sol NF P 94056***
* ***Indice de portance NF EN 13286-47***
* ***Limites d'Atterberg NF P 94051***
* ***Valeur de bleu des sols NF P 94068***
* ***Teneur en liant soluble et analyse granulometrique NF EN 12697-1 et 2***
* ***Analyse granulométrique NF EN 933-1***
* ***Ecoulement des sables NF EN 933-6***
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* ***Valeur de bleu à la tâche EN 933.9***
* ***Masse volumique à l'eau NF EN 1097-5 et 6***
* ***Masse volumique à l'huile P 18559***
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* ***Viscosité du bitume (Mode opératoire)***
* ***Pénétrabilité du bitume NF EN 1426***
* ***TBA sur bitume NF EN 1427***
* ***Densité sur bitume NF EN ISO 3838***
* ***Teneur en eau émulsion NF EN 1428***
* ***Teneur en eau bitume NF T 60113***
* ***Teneur en paraffine NF EN 12606-1***
* ***Pesées hydrostatiques NF EN 12697-6***
* ***Densités en place NF P 98241.1***
* ***PMT NF EN 13036.1***
* ***Essai à la plaque NF P 94117.1***
* *Réglages de la centrale de fabrication*
* *Carottages*
* *Autres*

LE TECHNICIEN	LE CHEF DE SECTION	DESTINATAIRES
Visa	Date et visa 20/07/2020	1 exemplaire MO 1 exemplaire laboratoire LE FOLL

FICHE D' ESSAI A LA PLAQUE- ESSAI DE DEFORMABILITE

109 Rue des Douves
27500 Corneville Sur Risle

Tél : 02.32.57.81.31
Fax. : 02.32.57.18.40

(Mode opératoire CT-2 / NFP 94-117.1)

Dérogation*

REF 96/PLAQUE

Date et indice de révision : 11/10/12 Indice D

Dossier n° : L19-028
Date des essais : 20/07/2020
Demandeur : LE FOLL
Destinataires : LE FOLL
N° rapport : 222 IS 20
Lieu des essais : SDOMODE, Malleville sur le Bec

Matériau : Limon + 0,25 de géogrille sur confinement
Provenance : in situ
Appareillage : Poutre de Benkelmann

Durée de l'intervention : 1h

Opérateur : BOUKHERCHOUFA M.

Référence			Déflexion en mm		Déflexion en mm			Modules			
									CT2	94-117.1	CT2
ESSAI N°	PK - PR	EMPLACEMENT	$W_{8,1}$	$W_{8,7}$	W_1	W_R	W_2	Westergaard	EV_1 MPa	EV_2 MPa	K
1	-	voir schéma			1,55	0,30	1,52		36	37	1,0
2	-	voir schéma			1,77	0,86	1,74		32	51	1,6
3	-	voir schéma			1,88	1,10	1,83		30	62	2,1
4	-	voir schéma			1,74	0,68	1,73		32	43	1,3
5	-	voir schéma			1,42	0,90	1,38		40	94	2,4
6	-	voir schéma			2,54	1,00	2,48		22	30	1,4

COMMENTAIRES :

* (EV2) la distance d'appui est inférieure à 1,2m

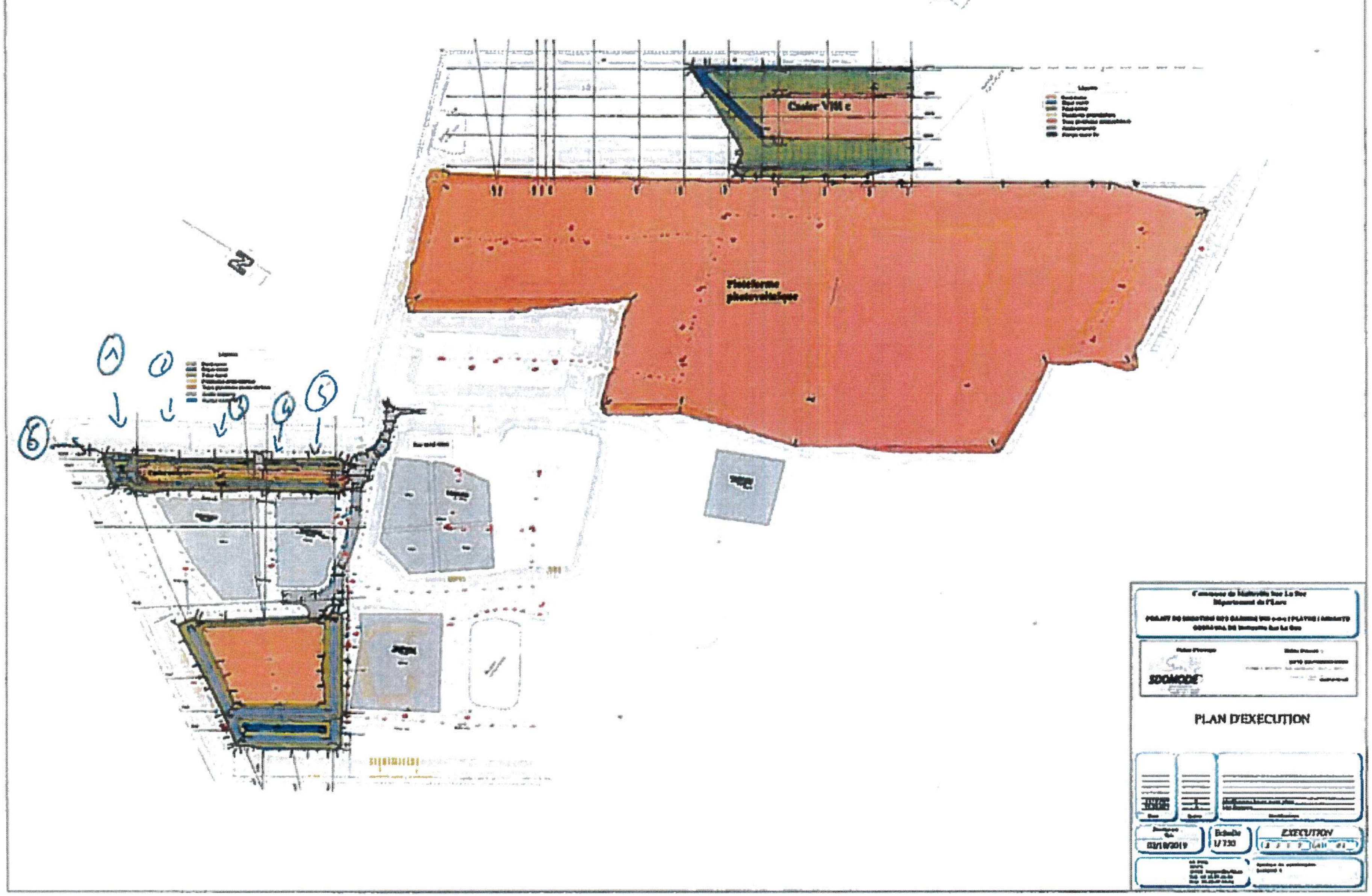
* (Westergaard) la distance d'appui est inférieure à 0,9m

1MN/m² = 1 Mpa = 10 bars / Module de Westergaard en Bars/cm

Le responsable du laboratoire

20/07/20

Essais à la plaque



Gammadensimétre

NextRoad ENGINEERING	MESURE DE LA MASSE VOLUMIQUE DES MATERIAUX EN PLACE (matériaux blancs)	Rapport RSM7-200417-11 AGRÉMENT N°18-143 LABOROUTE

Chantier :	SDOMODE - Malleville / Bec	N° Dossier:	S20.04.017
Localisation /élément fonctionnel	Casier amiante	Date essais :	21/07/2020
		Technicien	Pascal FROEHLICH

Type d'appareil de mesure :	Nucléogammadensimètre troxler 3450	Norme :	NF P98-241 1
Référence de l'appareil :	73 495	Couche :	1ere couche

Nature du matériau :	Argile A2	Provenance du matériau :	Site
Epaisseur de la couche (cm) :	33 cm	Profondeur de mesure (cm):	30 cm
Conditions météorologiques :	Ensoleillée	Compacteur :	Vibrant à pieds dameurs - 4 p.
Références Proctor OPN:	Densité Sèche t/m3: 1,790 Teneur en Eau % : 14,7	Coefficient correcteur teneur en eau troxler	1,00

Humidification	N° point	Densité humide	% eau Troxler	% eau Corrigée	Densité sèche	Taux de compactage	Conformité / point
Pas d'humidification	1	2,076	15,2	15,20	1,802	100,7	C
	2	2,062	14,3	14,30	1,804	100,8	C
	3	2,121	15,7	15,70	1,833	102,4	C
	4	2,042	14,1	14,10	1,790	100,0	C
	5	2,022	14,5	14,50	1,766	98,7	C
	6	2,052	13,9	13,90	1,802	100,6	C
	7	2,077	14,4	14,40	1,816	101,4	C
	8	2,011	15,1	15,10	1,747	97,6	C
	9				-	-	C
	10				-	-	C
	11				-	-	C
	12				-	-	C
	13				-	-	C
	14				-	-	C
	15				-	-	C
	16				-	-	C
	17				-	-	C
	18				-	-	C
	19				-	-	C
	20				-	-	C
	Moyenne	2,058	14,7	14,7	1,795	100,3	

Correction des teneurs en eau	N° point	1	2	3	4	5	Moyenne
	W troxler						
	W étuve						
	Coefficient correcteur w moyen						

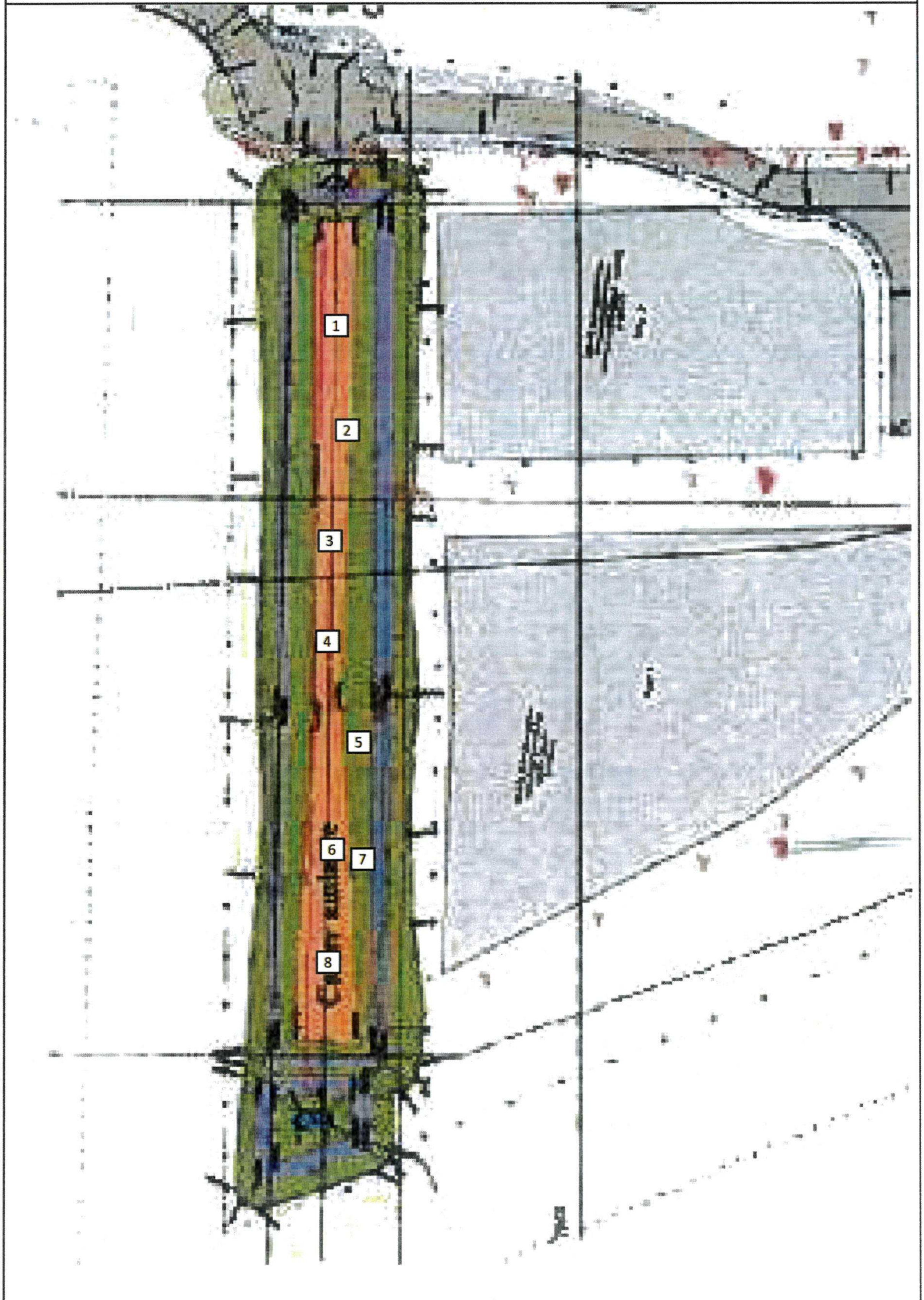
Objectifs selon marché SDOMODE		
	ydmoy ≥ 95 % OPN	Conforme
	100% des valeurs ≥ 90% OPN	Conforme

Plan de situation	Observations
Cf page 2	**Compacité moyenne conforme à l'exigence du marché** **100% des valeurs ≥ 90% OPN** **Moyenne ≥ 95 % OPN**
	Visa Pascal FROEHLICH

NextRoad ENGINEERING	MESURE DE LA MASSE VOLUMIQUE DES MATERIAUX EN PLACE (matériaux blancs)	Rapport RSM7-200417-11 AGRÉMENT N°18-143 LABOROUTE

Chantier :	SDOMODE - Malleville / Bec	N° Dossier:	S20.04.017
Localisation /élément fonctionnel	Casier amiante	Date essais :	21/07/2020
		Technicien	Pascal FROEHLICH

Plan de situation



NextRoad ENGINEERING	MESURE DE LA MASSE VOLUMIQUE DES MATERIAUX EN PLACE (matériaux blancs)	Rapport RSM7-200417-12 AGRÉMENT N°18-143 LABOROUTE

Chantier :	SDOMODE - Malleville / Bec	N° Dossier:	S20.04.017
Localisation /élément fonctionnel	Casier amiante	Date essais :	21/07/2020
		Technicien	Pascal FROEHLICH

Type d'appareil de mesure :	Nucléogammadensimètre troxler 3450	**Norme :**	NF P98-241 1
Référence de l'appareil :	73 495	**Couche :**	2e couche
Nature du matériau :	Argile A2	**Provenance du matériau :**	Site
Epaisseur de la couche (cm) :	33 cm	**Profondeur de mesure (cm):**	30 cm
Conditions météorologiques :	Ensoleillée	**Compacteur :**	Vibrant à pieds dameurs - 4 p.
Références Proctor OPN:	Densité Sèche t/m3: **1,790** Teneur en Eau % : **14,7**	Coefficient correcteur teneur en eau troxler	**1,00**

Humidification	N° point	Densité humide	% eau Troxler	% eau Corrigée	Densité sèche	Taux de compactage	Conformité / point
Pas d'humidification	1	2,032	13,7	13,70	1,787	99,8	C
	2	1,964	14,3	14,30	1,718	96,0	C
	3	1,990	15,1	15,10	1,729	96,6	C
	4	1,919	12,8	12,80	1,701	95,0	C
	5	2,010	13,9	13,90	1,765	98,6	C
	6	1,961	12,4	12,40	1,745	97,5	C
	7	1,973	15,3	15,30	1,711	95,6	C
	8	1,990	14,0	14,00	1,746	97,5	C
	9				-	-	C
	10				-	-	C
	11				-	-	C
	12				-	-	C
	13				-	-	C
	14				-	-	C
	15				-	-	C
	16				-	-	C
	17				-	-	C
	18				-	-	C
	19				-	-	C
	20				-	-	C
	Moyenne	1,980	13,9	13,9	1,738	97,1	

Correction des teneurs en eau	N° point	1	2	3	4	5	Moyenne
	W troxler						
	W étuve						
	Coefficient correcteur w moyen						

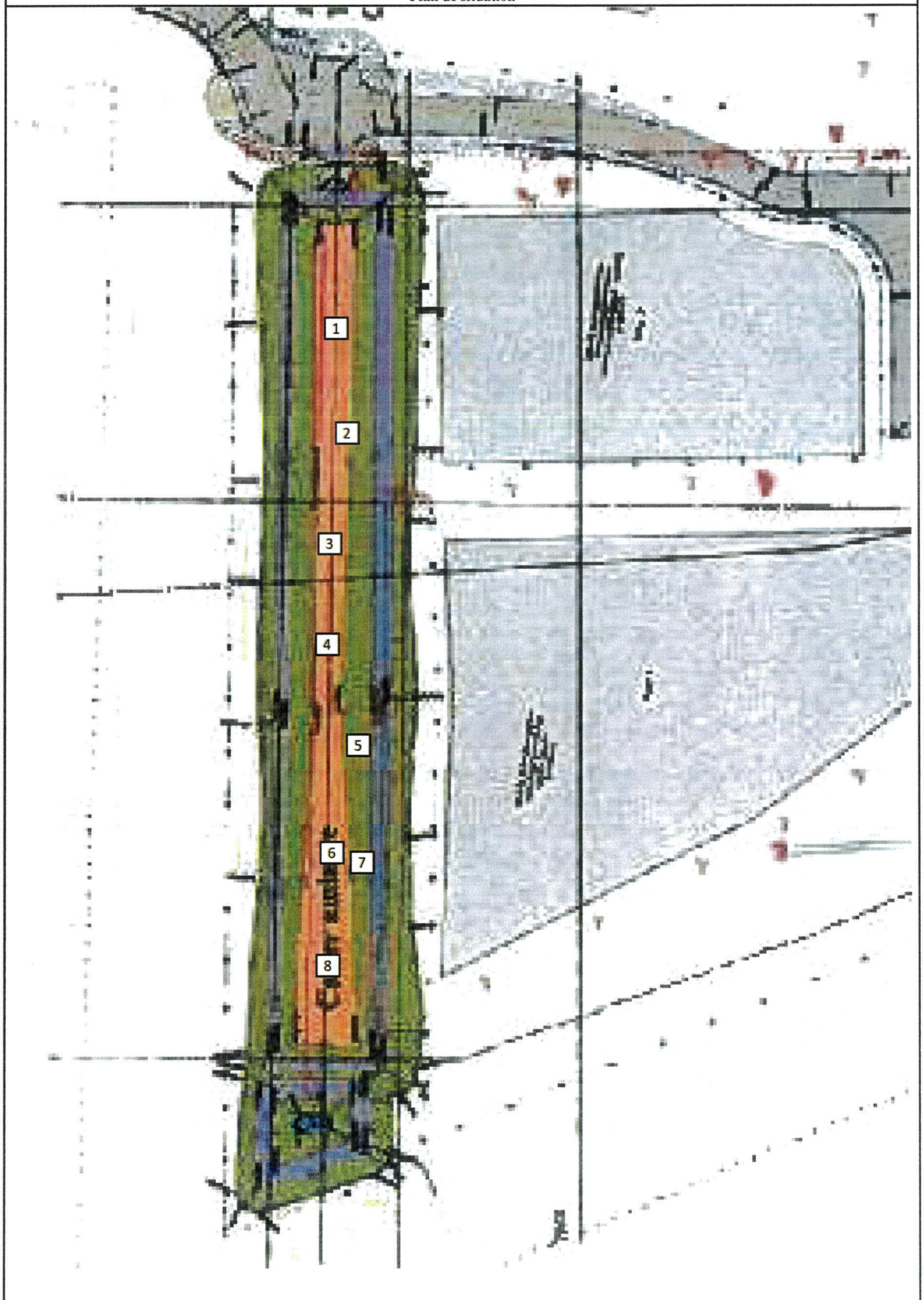
Objectifs selon marché SDOMODE		
	ydmoy ≥ 95 % OPN	Conforme
	100% des valeurs ≥ 90% OPN	Conforme

Plan de situation	Observations
Cf page 2	**Compacité moyenne conforme à l'exigence du marché** **100% des valeurs ≥ 90% OPN** **Moyenne ≥ 95 % OPN**
	Visa Pascal FROEHLICH

NextRoad ENGINEERING	MESURE DE LA MASSE VOLUMIQUE DES MATERIAUX EN PLACE (matériaux blancs)	Rapport RSM7-200417-12 AGRÉMENT N°18-143 LABOROUTE

Chantier :	SDOMODE - Malleville / Bec	N° Dossier:	S20.04.017
Localisation /élément fonctionnel	Casier amiante	Date essais :	21/07/2020
		Technicien	Pascal FROEHLICH

Plan de situation



Suivi visuel des travaux de mise en oeuvre des matériaux des digues

Suivi Visuel des travaux de mise en œuvre des matériaux (digues)
Casier Amiante


CAT

Annexe IX : Note justificative du des PV de travaux QUAL-FORM12/03 du 08/04/2020

Note justificative concernant le PV de réception de support BEP casier Amiante lié par l'entreprise Galopin

Le bassin d'eaux pluviales du casier amiante lié est équipé d'un système de vidage manuel. Ce dernier correspond à l'aménagement, en partie centrale du bassin, d'un débit de fuite.

En phase travaux, une zone de tassement est apparue au niveau de ce système suite à un événement pluvieux (point bas du bassin). Ces tassements, très légers, ont fait l'objet d'une reprise par la société de terrassement Le Foll avant la mise en place du PEHD par la société GALOPIN.

	BEP en cours de terrassement. Buse drain casier Point bas de purge
	Fin travaux de terrassement Buse drain casier Point bas de purge

	Photo suite événement pluvieux Tassement en point bas
	Photo de reprise de tassement

	<u>Photo fin de travaux d'étanchéité</u>

Annexe X : **BBA certificat avec l'ISO 20432 et ISO 13434**

HAPAS

HUESKER Synthetic GmbH

Fabrikstrasse 13–15
D-48712 Gescher
Germany

Tel: 00 49 2542 701-0   Fax: 00 49 2542 701-499
e-mail: info@HUESKER.de
website: www.HUESKER.com

HAPAS Certificate
13/H197
Product Sheet 3

FORTRAC GEOSYNTHETICS

FORTRAC T AND R-T GEOGRIDS

This HAPAS Certificate Product Sheet(1) is issued by the British Board of Agrément (BBA), supported by National Highways (acting on behalf of the Overseeing Organisations of the Department for Transport; Transport Scotland; the Welsh Government and the Department for Infrastructure, Northern Ireland), the Association of Directors of Environment, Economy, Planning and Transport (ADEPT), the Local Government Technical Advisers Group and industry bodies. HAPAS Certificates are normally each subject to a review every three years.
(1) Hereinafter referred to as 'Certificate'.

This Certificate relates to Fortrac T and R-T Geogrids, polymeric geogrids consisting of polyester fibres coated with a protective black polymer, for use as reinforcement in embankments with slope angles up to 70°.

CERTIFICATION INCLUDES:
- factors relating to compliance with HAPAS requirements
- factors relating to compliance with Regulations where applicable
- independently verified technical specification
- assessment criteria and technical investigations
- design considerations
- installation guidance
- regular surveillance of production
- formal three-yearly review.

KEY FACTORS ASSESSED

Soil/geogrid interaction — interaction between the soil and geogrids has been considered and coefficients relating to the direct sliding and pull-out resistance proposed (see section 6).

Mechanical properties — short- and long-term tensile strength, elongation properties of the geogrids and loss of strength due to installation damage have been assessed and reduction factors established for use in design (see section 7).

Effects of environmental conditions/Durability — the resistance of the geogrids to the effects of hydrolysis, chemical and biological degradation, UV exposure and temperature conditions normally encountered in civil engineering practice have been assessed, and reduction factors established, for use in design (see sections 8 and 11).

The BBA has awarded this Certificate to the company named above for the products described herein. These products have been assessed by the BBA as being fit for their intended use provided they are installed, used and maintained as set out in this Certificate.

On behalf of the British Board of Agrement

Date of Fourth issue: 25 November 2021

Originally certificated on 20 March 2013

Hardy Giesler
Chief Executive Officer

The BBA is a UKAS accredited certification body – Number 113.
The schedule of the current scope of accreditation for product certification is available in pdf format via the UKAS link on the BBA website at www.bbacerts.co.uk
Readers MUST check the validity and latest issue number of this Agrément Certificate by either referring to the BBA website or contacting the BBA directly.
Any photographs are for illustrative purposes only, do not constitute advice and should not be relied upon.

British Board of Agrément
Bucknalls Lane
Watford
Herts WD25 9BA
tel: 01923 665300
clientservices@bbacerts.co.uk
www.bbacerts.co.uk

Requirements

In the opinion of the BBA, Fortrac T and R-T Geogrids, when used in accordance with the provisions of this Certificate, will meet the requirements of National Highways and local Highway Authorities for the design and construction of reinforced soil embankments with slope angles up to 70°.

Regulations

Construction (Design and Management) Regulations 2015
Construction (Design and Management) Regulations (Northern Ireland) 2016

Information in this Certificate may assist the client, designer (including Principal Designer) and contractor (including Principal Contractor) to address their obligations under these Regulations.

See sections: 1 *Description* (1.2), 3 *Delivery and site handling* (3.1, 3.4 and 3.5) and the *Installation* part of this Certificate.

Additional Information

CE marking

The Certificate holder has taken the responsibility of CE marking the products, in accordance with harmonised European Standard BS EN 13251 : 2016.

Technical Specification

1 Description

1.1 Fortrac T and R-T Geogrids are planar structures consisting of a regular open network of woven, integrally connected tensile elements of yarn. The yarn is made from high-modulus polyester fibres of polyethylene terephthalate (PET). The woven grid is coated with a protective layer of protective black polymer.

1.2 The geogrids are manufactured in standard grades of various strengths and mesh sizes. A typical geogrid is illustrated in Figure 1 and the range and specification of the geogrids assessed by the BBA are listed in Tables 1 and 2.

1.3 The warp (machine) direction is along the roll length and is indicated by a paper tape (see Figure 1).

Figure 1 Fortrac T and R-T Geogrids

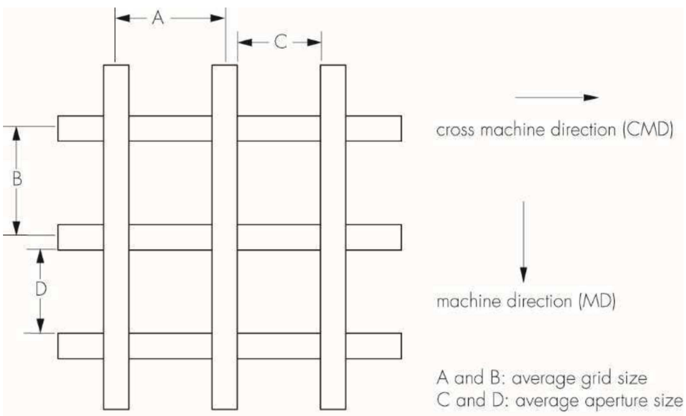


Table 1 General geogrid specifications						
Grade[1]	Nominal mass[2] ($g{\cdot}m^{-2}$)	Average grid size[3] warp/weft (mm) *A x B*	Average aperture size[3] warp/weft (mm) *C x D*	Colour code[4]	Nominal roll weight for standard 5 m width rolls	Standard roll length (m)
35T	185	29 x 30	26 x 24	Red	200	200
55T	240	29 x 30	25 x 24	Green	255	200
65T	280	29 x 30	25 x 23	Orange	295	200
80T	320	29 x 30	25 x 23	Pink	335	200
110T	350	29 x 30	24 x 23	White	365	200
150T	440	29 x 30	23 x 23	No colour	455	200
200T	530	30 x 30	23 x 23	No colour	545	200
R300/50-30T	900	43 x 34	31 x 25	No colour	510	100
R400/50-30T	1200	43 x 34	30 x 25	No colour	660	100
R600/50-30T	1650	50 x 33	30 x 25	No colour	885	100
R800/100-30T	2400	50 x 40	26 x 30	No colour	1260	100
R1000/100-30T	2700	126 x 40	22 x 29	No colour	1410	100

(1) R denotes that the geogrid is knitted.
(2) Mass/unit area measured in accordance with BS EN ISO 9864 : 2005.
(3) Reference dimensions (see Figure 1).
(4) In accordance with BS EN ISO 10320 : 2019.

Table 2 Performance characteristics								
Grade	Machine Direction (MD)				Cross Machine Direction (CMD)			
	Short-term tensile strength[1] $kN{\cdot}m^{-1}$			Strain at maximum tensile strength[1] (%)	Short-term tensile strength[1] $kN{\cdot}m^{-1}$			Strain at maximum tensile strength[1] (%)
	Mean value	Tolerance	T_{char}		Mean value	Tolerance	T_{char}	
35T	35	-0	35	9.5 (±1.5)	20	-0	20	9.0 (±2.0)
55T	55	-0	55	9.5 (±1.5)	20	-0	20	9.0 (±2.0)
65T	65	-0	65	9.5 (±1.5)	20	-0	20	9.0 (±2.0)
80T	80	-0	80	9.5 (±1.5)	20	-0	20	9.0 (±2.0)
110T	110	-0	110	9.5 (±1.5)	20	-0	20	9.0 (±2.0)
150T	150	-0	150	9.5 (±1.5)	20	-0	20	9.0 (±2.0)
200T	200	-0	200	9.5 (±1.5)	20	-0	20	9.0 (±2.0)
R300/50-30T	300	-0	300	9.5 (±1.5)	50	-0	50	9.0 (±2.0)
R400/50-30T	400	-0	400	9.5 (±1.5)	50	-0	50	9.0 (±2.0)
R600/50-30T	600	-0	600	9.5 (±1.5)	50	-0	50	9.0 (±2.0)
R800/100-30T	800	-0	800	9.5 (±1.5)	100	-0	100	9.0 (±2.0)
R1000/100-30T	1000	-0	1000	9.5 (±1.5)	100	-0	100	9.0 (±2.0)

(1) Tests in accordance with BS EN ISO 10319 : 2015; the values given are the mean and tolerance values in accordance with BS EN 13251 : 2016.

2 Manufacture

2.1 Fortrac T and R-T Geogrids are manufactured from yarn woven or knitted into grids and coated with a protective layer of protective black polymer.

2.2 As part of the assessment and ongoing surveillance of product quality, the BBA has:

- agreed with the manufacturer the quality control procedures and product testing to be undertaken
- assessed and agreed the quality control operated over batches of incoming materials
- monitored the production process and verified that it is in accordance with the documented process
- evaluated the process for management of nonconformities
- checked that equipment has been properly tested and calibrated
- undertaken to carry out the above measures on a regular basis through a surveillance process, to verify that the specifications and quality control being operated by the manufacturer are being maintained.

2.3 The management system of Huesker Synthetic GmbH has been assessed and registered as meeting the requirements of BS EN ISO 9001 : 2015 by SGS TÜV Saar GmbH, Germany (Certificate DE18/819943759).

3 Delivery and site handling

3.1 The products are delivered to site in rolls, stacked and strapped to timber pallets. The rolls are 5.0 m wide and between 0.5 and 0.9 m in diameter, dependent on the product grade and roll length (see Table 1).

3.2 Each roll is wrapped for transit and site protection in black polythene film and labelled with the geogrid grade and identification (see Figure 2).

Figure 2 Label

3.3 The ends of the rolls are sprayed with colour-coded paint to assist identification of a particular grade of geogrid on site (see Table 1), in accordance with BS EN ISO 10320 : 2019.

3.4 Rolls should be stored in clean, dry conditions and protected from mechanical or chemical damage, exposure to direct sunlight and extreme temperatures. When laid horizontally, the rolls may be stacked up to five high. No other loads should be stored on top of the stack. The packaging should not be removed until immediately prior to installation.

3.5 Toxic fumes are given off if the geogrids catch fire and therefore the necessary precautions should be taken following the instructions of the material safety data sheet for the products.

Assessment and Technical Investigations

The following is a summary of the assessment and technical investigations carried out on Fortrac T and R-T Geogrids.

Design Considerations

4 General

4.1 When designed and installed in accordance with this Certificate, Fortrac T and R-T Geogrids are satisfactory for the reinforcement of soil embankments with maximum slope angles of 70°.

4.2 Structural stability is achieved through the frictional interaction of soil particles and the geogrids and the tensile strength of the geogrids.

4.3 The fill specification and method of placement and compaction, design strength of the reinforcement and length of reinforcement embedded within the compacted fill are the key design factors.

4.4 Prior to the commencement of work, the designer must satisfy the design approval and certification procedures of the relevant Highway Authority.

4.5 Particular attention should be paid in design to the following issues:

- site preparation and embankment construction
- fill material properties
- drainage
- protection of the product against damage from site traffic and installation equipment
- the stability of existing structures in close proximity
- design of the embankment facing.

4.6 The working drawings should show the correct orientation of the geogrids. Each layer of reinforcement must be continuous in the direction of load, ie without overlaps.

5 Practicability of installation

The products are designed to be installed by trained contractors in accordance with the specifications and construction drawings (see the *Installation* part of this Certificate).

6 Design

Design methodology

6.1 Reinforced soil embankments constructed using Fortrac T and R-T Geogrids should be designed in accordance with BS 8006-1 : 2010 and the *Manual of Contract Documents for Highway Works* (MCHW), Volume 1 *Specification for Highway Works.*

6.2 The typical service life given in BS 8006-1 : 2010, Table 7, for reinforced soil embankments is 60 years.

Geogrid reinforcement

6.3 In accordance with the methodology set out in BS 8006-1 : 2010, Annex 3, the design strength of the reinforcement (T_D) is calculated as:

$T_D = T_{CR}/f_m$

where:

T_{CR}	is the long-term tensile creep rupture strength of the reinforcement at the specified design life and design temperature
f_m	is the material safety factor to allow for the strength-reducing effects of installation damage, weathering (including exposure to sunlight), chemical and other environmental effects and to allow for the extrapolation of data required to establish the above reduction factors.

6.4 The long-term tensile creep rupture strength (T_{CR}) for each grade of geogrid is calculated using the formula:

$T_{CR} = T_{char}/RF_{CR}$

where:

T_{char}	is the characteristic short-term strength of the geogrid taken from Table 2
RF_{CR}	is the reduction factor for creep (see Section 7).

6.5 The material safety factor (f_m) is calculated as:

$f_m = RF_{ID} \times RF_W \times RF_{CH} \times f_S$

where:

RF_{ID}	is the reduction factor for installation damage
RF_W	is the reduction factor for weathering, including exposure to ultraviolet light

RF_{CH} is the reduction factor for chemical/environmental effects
f_S is the factor of safety for the extrapolation of data.

6.6 Recommended values for RF_{CR}, RF_{ID}, RF_W, RF_{CH} and f_S are given in sections 7 to 9. Conditions of use outside the scope for which the reduction factors are defined, are not covered by this Certificate, and advice should be sought from the Certificate holder.

Soil/geogrid interaction

6.7 There are two limiting modes of interaction between the soil and the reinforcement that need to be considered, and for which the length of reinforcement necessary to maintain equilibrium needs to be determined:

- direct sliding — in which the soil slides over the layer of reinforcement
- pull-out — in which the layer of reinforcement pulls out of the soil after it has mobilised the maximum available bond stress.

6.8 CIRIA SP123 : 1996, Sections 4.5 and 4.6, describes the following methods for determining resistance to direct sliding and maximum available bond, to which the appropriate partial factors should be applied in accordance with BS 8006-1 : 2010.

Direct sliding

6.9 The theoretical expression for the coefficient for resistance to direct sliding is:

$f_{ds} \times \tan \phi'$

where:

f_{ds} is the coefficient of direct sliding
ϕ' is the angle of shearing resistance of the soil (in terms of effective stress).

6.10 The direct sliding coefficient f_{ds} is calculated as:

$f_{ds} = \alpha_s \times (\tan \delta / \tan \phi') + (1 - \alpha_s)$

where:

α_s is the proportion of plane sliding area that is solid
δ is the angle of skin friction, soil on planar reinforcement surface
$\tan \delta / \tan \phi'$ is the coefficient of skin friction between the soil and geogrid material (in terms of effective stress).

6.11 For initial design purposes, the coefficient of skin friction ($\tan \delta / \tan \phi'$) for determining the resistance to direct sliding for the products when buried in compacted frictional fill may be conservatively assumed to be 0.6. Values for the proportion of plane sliding area that is solid (α_s) are given in Table 3.

Table 3 Soil geogrid interaction parameters for T and R-T Fortrac Geogrids

Grade	α_s (1)	Ratio of bearing (2) surface to plan area α_b x B/2S
35T	0.28	0.009
55T	0.31	0.009
65T	0.34	0.009
80T	0.34	0.009
110T	0.37	0.008
150T	0.39	0.008
200T	0.41	0.008
R300/50-30T	0.47	0.013
R400/50-30T	0.49	0.012
R600/50-30T	0.55	0.011
R800/100-30T	0.61	0.020
R1000/100-30T	0.87	0.007

(1) α_s is the proportion of the plane sliding area that is solid and is required for the calculation of the bond coefficient (f_b) and the direct sliding coefficient (f_{ds}) (see sections 6.10 and 6.13).

(2) The ratio is required to calculate the bond coefficient in accordance with CIRIA SP123 : 1996 (see section 6.13):
α_b is the proportion of the grid width available for bearing
B is the thickness of a transverse member of a grid taking bearing
S is the spacing between transverse members taking bearing.

6.12 For detailed design, the resistance to direct sliding should be determined from soil and geogrid specific shear box testing.

Bond

6.13 The theoretical expression for the coefficient for bond shearing resistance is:

$f_b \times \tan \phi'$

where:

f_b	is the bond coefficient
ϕ'	is the angle of shearing resistance of the soil in terms of effective stress.
$\tan \phi'$	is the shearing resistance of the soil (in terms of effective stress).

6.14 The bond coefficient may be calculated as:

$f_b = \alpha_s \times (\tan \delta / \tan \phi') + (\sigma'_b / \sigma'_n) \times ((\alpha_b \times B/2S) \times (1 / \tan \phi'))$

where:

α_s	is the proportion of plane sliding area that is solid
$\tan \delta / \tan \phi'$	is the coefficient of skin friction between the soil and geogrid material
σ'_b / σ'_n	is the bearing stress ratio
$\alpha_b \times B/2S$	is the ratio of bearing surface to plan area
ϕ'	is the angle of shearing resistance of the soil in terms of effective stress
δ	is the angle of skin friction, soil on planar reinforcement surface
σ'_b	is the effective bearing stress on the reinforcement
σ'_n	is the normal effective stress.

6.15 For initial design purposes, the coefficient of skin friction ($\tan \delta / \tan \phi'$) for the products when buried in frictional fill may be conservatively assumed to be 0.6. Values for the ratio of bearing surface to plan area (α_b x B/2S) are given in Table 3. Typical values for the bearing stress ratio (σ'_b / σ'_n) are given in CIRIA SP123 : 1996, Table 4.1.

6.16 The BBA recommends that site-specific pull-out tests are carried out to confirm the value of bond coefficient (f_b) used in the final design.

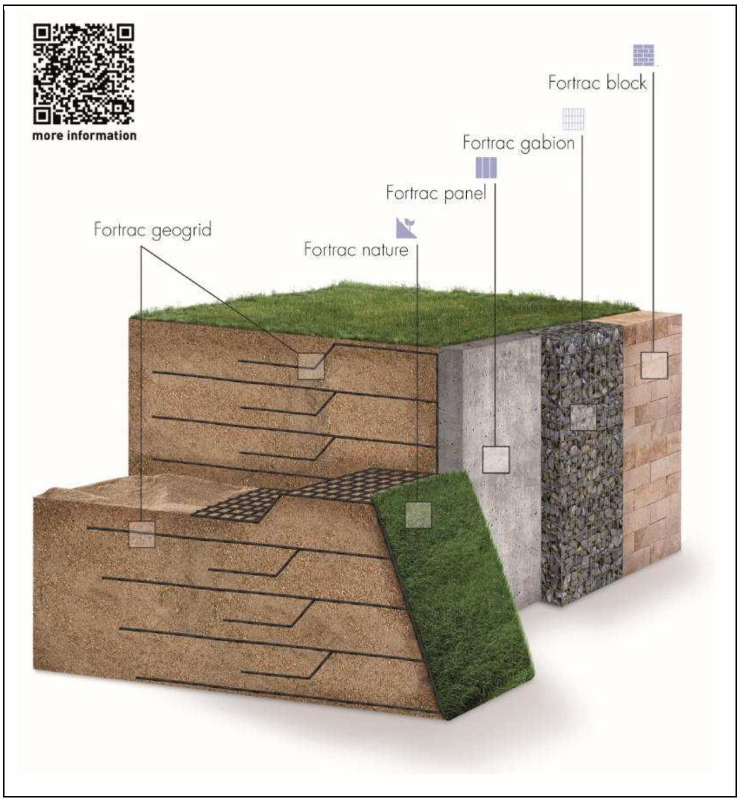
Fill material

6.17 The designer should specify the relevant properties of fill material deemed acceptable for the purpose of the design. Acceptable materials should satisfy the requirements of BS 8006-1 : 2010 and the MCHW, Volume 1.

Facing

6.18 A typical wraparound facing detail formed using the geogrid is shown in Figure 3. Where the geogrids are used to form the facing, natural or artificial protection must be provided to the grids and fill material to protect the products against damage from ultraviolet light (UV), fire and vandalism, and to protect the fill material from erosion.

Figure 3 Facing



6.19 Other types of facing including preformed panels, gabions/gabion sacks and other proprietary systems may be used but are outside the scope of this Certificate. Further guidance is given in BS 8006-1 : 2010.

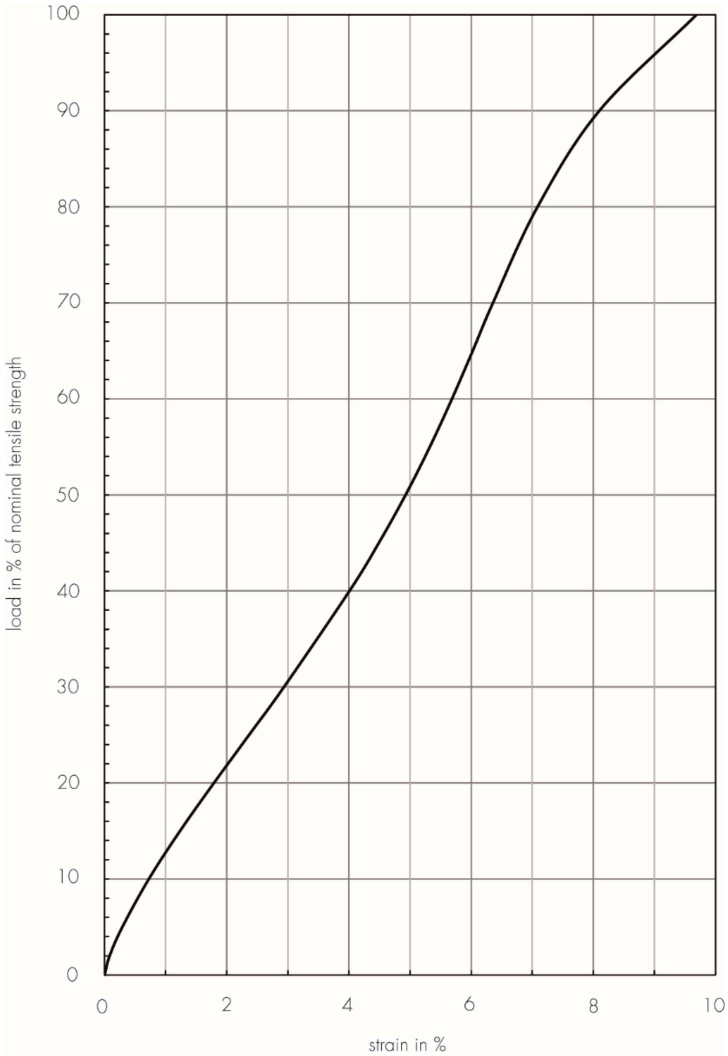
7 Mechanical properties

Tensile strength — short-term

7.1 Characteristic short-term tensile strength (T_{char}) and strain at maximum strength for the product range are given in Table 2.

7.2 A typical short-term stress/strain curve is shown in Figure 4.

Figure 4 Typical short-term stress/strain curve



Tensile strength — long-term

7.3 The long-term creep performance of the geogrids has been determined in accordance with the principles of ISO/TR 20432 : 2007 using conventional and stepped isothermal method (SIM) creep rupture test data. The resultant creep rupture diagram is shown in Figure 6.

7.4 Long-term tensile strength (T_{CR}) values for the products can be derived using the formula given in section 6, with the long-term creep reduction factors (RF_{CR}) shown in Table 4.

Table 4 Long-term creep reduction factors (RF_{CR})

Design Soil Temperature (°C)	Service life (years)	Reduction factor RF_{CR}
15	10	1.42
	60	1.47
	120	1.49
20	10	1.45
	60	1.50
	120	1.52
25	10	1.48
	60	1.53
	120	1.55
30	10	1.50
	60	1.56
	120	1.58
35	10	1.53
	60	1.59
	120	1.61

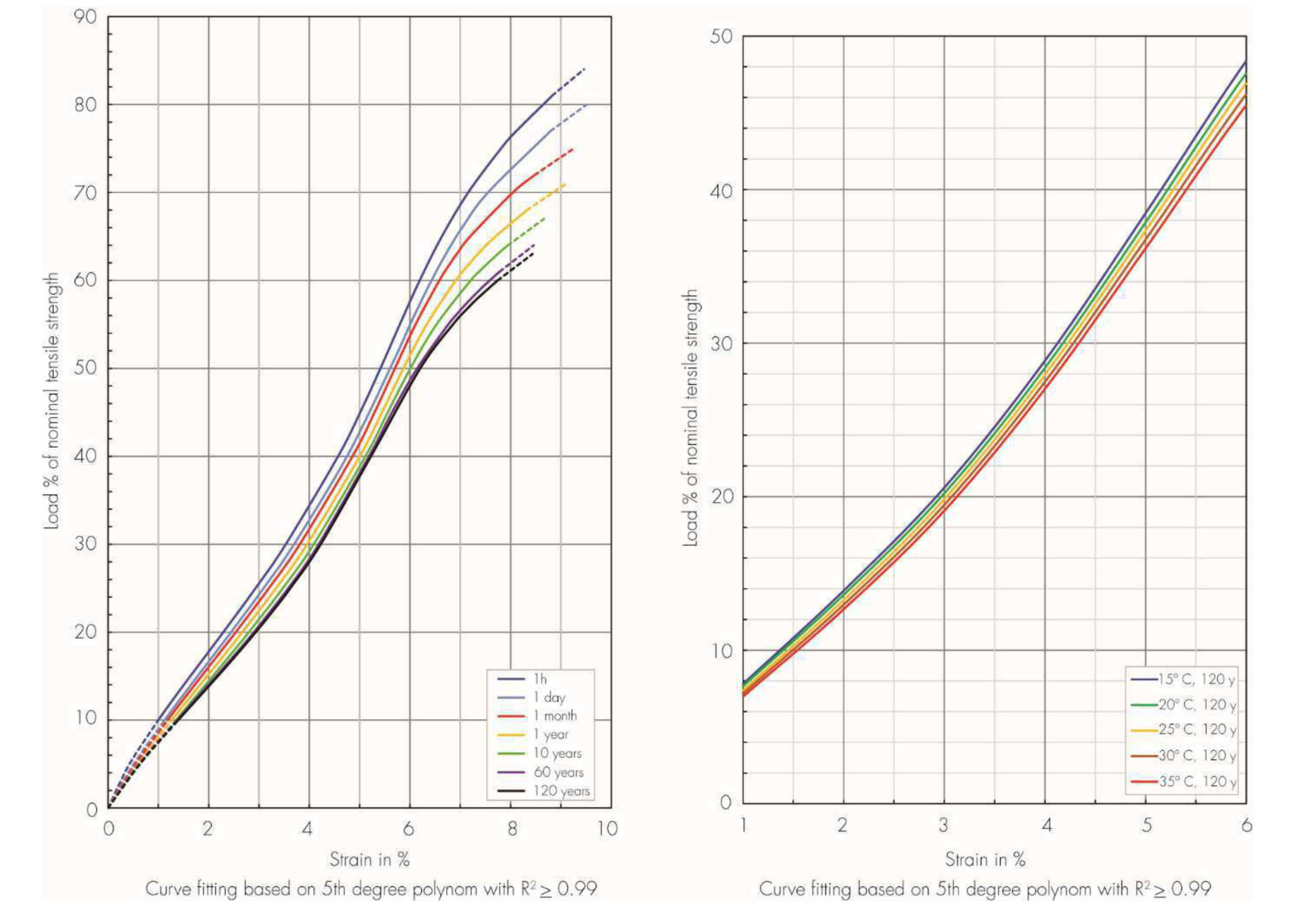
7.5 For a 60-year service life and design temperature of 20°C, the long-term tensile strength (T_{CR}) of Fortrac T and R-T Geogrids is 66.8% of the characteristic short-term tensile strength (T_{char}), giving a long-term creep reduction factor (RF_{CR}) of 1.50.

7.6 For a 120-year service life and design temperature of 20°C, the long-term tensile strength (T_{CR}) of Fortrac T and R-T Geogrids is 66.0% of the characteristic short-term tensile strength (T_{char}), giving a long-term creep reduction factor (RF_{CR}) of 1.52.

Serviceability limit strain

7.7 The isochronous curves for the product range covered by this Certificate are given in Figure 5 for a design temperature of 20°C and may be used to determine the maximum allowable tensile load T_{CS} for a given service life and limiting strain value (ε_{max}). Similarly, the second isochronous curves in Figure 5 represent the variation between design temperatures for a service life of 120 years and may be used to establish allowable tensile load T_{CS}.

Figure 5 Isochronous curves



Installation damage

7.8 To allow for loss of strength due to mechanical damage that may be sustained during installation, the appropriate value for RF_{ID} should be selected from Table 5. These reduction factors have been established from full-scale installation damage tests using a range of materials whose gradings can be seen in Figure 7. For fills not covered by Table 5, appropriate values of RF_{ID} may be determined from site-specific trials or the engineer may exercise engineering judgment to interpolate between the values given.

Figure 6 Creep rupture diagram —regression line for the expectancy at constant stress defined by % of characteristic short-term strength at 20°C

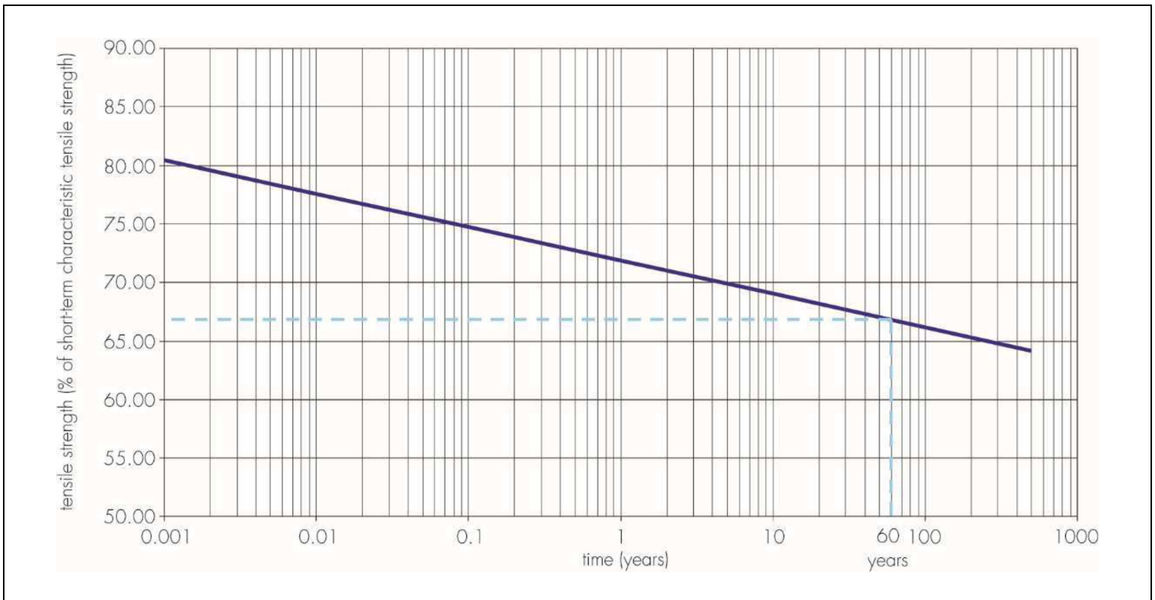


Figure 7 Particle size distributions of fills used in installation damage testing

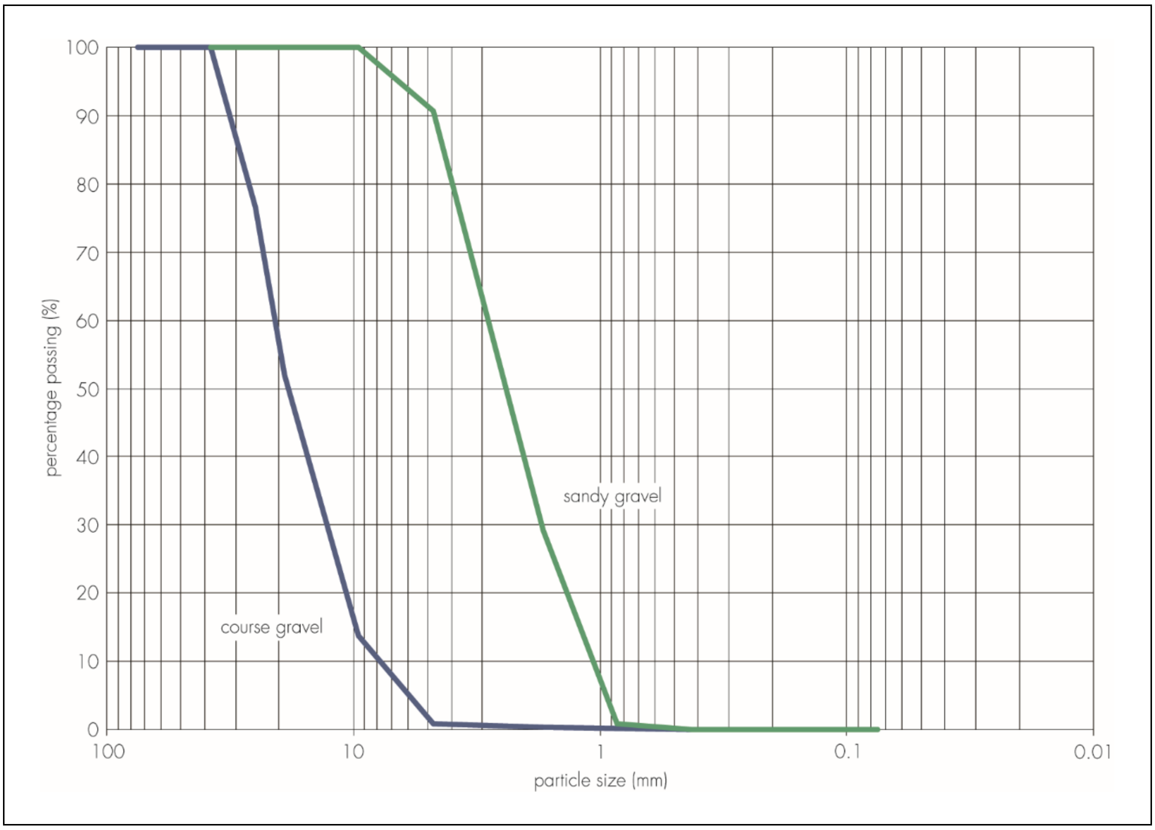


Table 5 Partial safety factor — installation damage (RF_{ID})

Soil type[1]	D_{90} particle size[2] (mm)	Grade	RF_{ID}
Sandy gravel	≤10	35T	1.15
		55T	1.15
		65T	1.15
		80T	1.15
		110T	1.10
		150T	1.10
		200T	1.10
		R300/50-30T	1.10
		R400/50-30T	1.10
		R600/50-30T	1.05
		R800/100-30T	1.05
		R1000/100-30T	1.05
Coarse gravel	≤35	35T	1.20
		55T	1.20
		65T	1.20
		80T	1.15
		110T	1.10
		150T	1.10
		200T	1.10
		R300/50-30T	1.10
		R400/50-30T	1.05
		R600/50-30T	1.05
		R800/100-30T	1.05
		R1000/100-30T	1.05

(1) Compacted soil thickness: 200 mm, weight of vibrating roll: 4550 kg.
(2) Detained particle size distributions are shown in Figure 5.

8 Effects of environmental conditions

Weathering (including exposure to UV light)

8.1 The geogrids have adequate resistance to weathering and exposure to sunlight, when protected from exposure in accordance with the recommendations of this Certificate. A reduction factor (RF_W) of 1.12 may be used for design provided the periods of exposure are limited to a maximum of one month. A reduction Factor (RF_w) of 1.00 may be used where the product is covered within one day.

Chemical/environmental effects

8.2 Within a soil environment where pH ranges from 4.0 to 9.0, the geogrids have adequate resistance to hydrolysis for applications where sustained soil temperatures are up to 25°C.

8.3 The geogrids are highly resistant to microbiological attack.

8.4 When designed and installed in accordance with the requirements of BS 8006-1 : 2010, BS EN 14475 : 2006 and this Certificate, the geogrids are suitable for use in soils at temperatures normally encountered in reinforced soil embankments in the UK. Long-term resistance to chemical and microbiological attack at temperatures greater than 25°C or lower than 0°C are outside the scope of this Certificate. Where geogrids may be exposed to temperatures outside this range, the advice of the Certificate holder should be sought.

8.5 For a service life of up to 120 years, a design temperature between 15 and 35°C and soil environments with pH values between 4.0 and 9.0, the reduction factors given in Table 6 may be used to take account of chemical/ environmental effects (including hydrolysis, resistance to acids and alkaline liquids and biological/microbial attack),.

Table 6 Reduction factors for chemical/environmental effects (RF_{CH})

Design soil temperature (°C)	Service life (years)	Reduction factor RF_{CH}
15	10	1.00
	60	1.01
	120	1.01
20	10	1.00
	60	1.01
	120	1.03
25	10	1.01
	60	1.03
	120	1.07
30	10	1.01
	60	1.07
	120	1.16
35	10	1.02
	60	1.16
	120	1.38

9 Factor of safety for the extrapolation of data (f_s)

9.1 The factors of safety for the extrapolation of data (fs) for a service life of up to 120 years and design temperatures between 15°C and 35°C, have been determined in accordance with PD ISO/TR 20432 : 2007, clause 20.1, and are shown in Table 7.

9.2 The extrapolation of creep rupture (R1) and extrapolation of chemical effect (R2) components used for determination of fs are shown in Table 7.

Table 7 R1 and R2 components and factor of safety for extrapolation of data (fs)

Design soil temperature (°C)	Service life (years)	R_1	R_2	f_s
15	10	1.0	1.00	1.00
	60	1.0	1.00	1.00
	120	1.0	1.01	1.01
20	10	1.0	1.00	1.00
	60	1.0	1.01	1.01
	120	1.0	1.02	1.02
25	10	1.0	1.00	1.00
	60	1.0	1.02	1.02
	120	1.0	1.03	1.03
30	10	1.0	1.00	1.00
	60	1.0	1.03	1.03
	120	1.0	1.07	1.07
35	10	1.0	1.01	1.01
	60	1.0	1.07	1.07
	120	1.0	1.17	1.17

10 Maintenance

As the products are confined within the soil and have suitable durability, maintenance is not required.

11 Durability

The geogrids will have adequate durability for a service life of up to 120 years when used and installed in accordance with this Certificate.

Installation

12 General

12.1 The construction of reinforced soil embankments incorporating the geogrids should be in accordance with the Certificate holder's Installation instructions, BS EN 14475 : 2006 and the MCHW, Volume 1.

12.2 Care should be exercised to ensure Fortrac T and R-T Geogrids are laid with the warp (longitudinal) direction parallel to the direction of principal stress. Design drawings should indicate geogrid orientation (see section 4.6).

13 Procedure

13.1 The geogrid is laid by unrolling the grid to the length required and cutting with a sharp knife or scissors. The unrolling of the grid may be carried out manually or mechanically.

13.2 The grids should be laid flat without folds, parallel and with widths in contact with each other. Each reinforcing layer must be continuous in the direction of loading and there should be no overlapping of the grids. Strip misalignment must not exceed 50 mm over a distance of 5 m. Pins or a stretching device may be used to control alignment and also to induce a small prestressing load prior to filling.

13.3 Particular care should be taken to ensure that the grids are adequately covered before compaction or trafficking. Construction traffic will damage unprotected geogrids.

13.4 Fill materials and the thickness and compaction of the fill should be in accordance with the requirements of the MCHW, Volume 1, and in line with those conditions used to determine the installation damage partial safety factors in the design (see section 7.5).

13.5 Facings are positioned as detailed on the engineer's design drawing. Where the geogrids are used as part of the facing, the geogrid must be wrapped around and anchored back into the fill and must be protected from exposure to ultraviolet (UV) light as detailed in sections 6.18 and 8.1. Formwork is used to assist in maintaining the shape of the facing. Facings, prefabricated or otherwise, are beyond the scope of this Certificate. A typical example is shown in Figure 3.

Technical Investigations

14 Tests

14.1 The manufacturing was evaluated, including the methods adopted for quality control, and details were obtained of the quality and composition of the materials used.

14.2 An examination was made of data relating to:

- evaluation of long- and short-term tensile properties
- chemical degradation
- resistance to hydrolysis
- resistance to biological attack
- resistance to weathering
- effects of temperature
- site damage trials and resistance to mechanical damage
- coefficients of interaction between the geogrids and the soil fill
- installation procedures and typical details.

14.3 Calculations were made to establish the plane sliding area that is solid and the ratio of bearing surface to plane area.

14.4 The practicability and ease of handling and installation were assessed.

Bibliography

BS 8006-1 : 2010 + A1 : 2016 *Code of practice for strengthened/reinforced soils and other fills*

BS EN 13251 : 2016 Geotextiles *and geotextile-related products — Characteristics required for use in earthworks, foundations and retaining structures*

BS EN 14475 : 2006 *Execution of special geotechnical works — Reinforced fill*

BS EN ISO 9001 : 2015 *Quality Management systems — Requirements*

BS EN ISO 9864 : 2005 *Geosynthetics — Test method for the determination of mass per unit area of geotextiles and geotextile-related products*

BS EN ISO 10319 : 2015 *Geotextiles — Wide-width tensile test*

BS EN ISO 10320 : 2019 *Geotextiles and geotextile-related products— Identification on site*

CIRIA SP123 : 1996 *Soil Reinforcement with Geotextiles: Jewel R A*

ISO/TR 20432 : 2007 *Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement*

Manual of Contract Documents for Highway Works, Volume 1 *Specification for Highway Works*

Conditions of Certification

15 Conditions

15.1 This Certificate:

- relates only to the product/system that is named and described on the front page
- is issued only to the company, firm, organisation or person named on the front page – no other company, firm, organisation or person may hold or claim that this Certificate has been issued to them
- is valid only within the UK
- has to be read, considered and used as a whole document – it may be misleading and will be incomplete to be selective
- is copyright of the BBA
- is subject to English Law.

15.2 Publications, documents, specifications, legislation, regulations, standards and the like referenced in this Certificate are those that were current and/or deemed relevant by the BBA at the date of issue or reissue of this Certificate.

15.3 This Certificate will remain valid for an unlimited period provided that the product/system and its manufacture and/or fabrication, including all related and relevant parts and processes thereof:

- are maintained at or above the levels which have been assessed and found to be satisfactory by the BBA
- continue to be checked as and when deemed appropriate by the BBA under arrangements that it will determine
- are reviewed by the BBA as and when it considers appropriate.

15.4 The BBA has used due skill, care and diligence in preparing this Certificate, but no warranty is provided.

15.5 In issuing this Certificate the BBA is not responsible and is excluded from any liability to any company, firm, organisation or person, for any matters arising directly or indirectly from:

- the presence or absence of any patent, intellectual property or similar rights subsisting in the product/system or any other product/system
- the right of the Certificate holder to manufacture, supply, install, maintain or market the product/system
- actual installations of the product/system, including their nature, design, methods, performance, workmanship and maintenance
- any works and constructions in which the product/system is installed, including their nature, design, methods, performance, workmanship and maintenance
- any loss or damage, including personal injury, howsoever caused by the product/system, including its manufacture, supply, installation, use, maintenance and removal
- any claims by the manufacturer relating to CE marking.

15.6 Any information relating to the manufacture, supply, installation, use, maintenance and removal of this product/system which is contained or referred to in this Certificate is the minimum required to be met when the product/system is manufactured, supplied, installed, used, maintained and removed. It does not purport in any way to restate the requirements of the Health and Safety at Work etc. Act 1974, or of any other statutory, common law or other duty which may exist at the date of issue or reissue of this Certificate; nor is conformity with such information to be taken as satisfying the requirements of the 1974 Act or of any statutory, common law or other duty of care.

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TECHNICAL SPECIFICATION

ISO/TS 13434

First edition
2008-11-01

Geosynthetics — Guidelines for the assessment of durability

Géosynthétiques — Lignes directrices concernant la durabilité

Reference number
ISO/TS 13434:2008(E)

Contents

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 13434 was prepared by Technical Committee ISO/TC 221, *Geosynthetics*.

This first edition cancels and replaces ISO/TR 13434:1998, which has been technically revised.

Geosynthetics — Guidelines for the assessment of durability

1 Scope

This Technical Specification provides guidelines for the assessment of the durability of geosynthetics, the object of which is to provide the design engineer with the necessary information, generally defined as changes in material properties or as partial safety factors, to ensure that the expected design life of a geosynthetic can be achieved with confidence.

This Technical Specification is not applicable to products designed to survive for only a limited time, such as erosion-control fabric based on natural fibres, or geotextiles for asphalt reinforcement.

This Technical Specification is applicable to the durability of the geosynthetics and not to the durability of the geotechnical structure as a whole.

NOTE The calculation of reduction factors for soil reinforcement applications is described in ISO/TR 20432.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10318, *Geosynthetics — Terms and definitions*

ISO 13431, *Geotextiles and geotextile-related products — Determination of tensile creep and creep rupture behaviour*

ISO 13438:2004, *Geotextiles and geotextile-related products — Screening test method for determining the resistance to oxidation*

ISO/TR 20432:2007, *Guidelines for the determination of long-term strength of geosynthetics for soil reinforcement*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10318 apply.

3.2 Symbols

A rate of degradation

A_0 constant in Arrhenius equation

d_{50} 50 % soil gradation

E activation energy

M_n number-averaged molecular weight

M_w weight-averaged molecular weight

R universal gas constant (8,314 J/mol·K)

t_g glass transition temperature

T absolute temperature

3.3 Abbreviated items

CMD cross-machine direction

CPE chlorinated polyethylene

CSPE chlorosulfonated polyethylene

DMTA dynamic mechanical thermal analysis

DSC differential scanning calorimetry

EIA ethylene interpolymer alloy

ENB ethylidene norbornene

EPDM ethylene propylene diene monomer

EPS expanded polystyrene

ESC environmental stress cracking

fPP flexible polypropylene

GBR-B bituminous geosynthetic barrier

GBR-C geosynthetic clay barrier

GBR-P polymeric geosynthetic barrier

GRI Geosynthetic Research Institute

HALS hindered amine light stabilizers

HDPE high-density polyethylene

HP-OIT high-pressure oxidation induction time

KEE ketone ethylene ester

LLDPE linear low-density polyethylene

MB modified bitumen

MD machine direction

OIT	oxidation induction time
PA	polyamide
PCR	post-consumer resin
PE	polyethylene
PEN	polyethylene naphthalate
PET	polyethylene terephthalate
PIR	post-industrial resin
PP	polypropylene
PS	polystyrene
PVA	polyvinyl alcohol
PVC	polyvinyl chloride
RPP	reinforced polypropylene
RR	rework resins
SBS	styrene-butadiene-styrene
S-OIT	oxidation induction time measured by standard method
XPS	extruded polystyrene
UV	ultraviolet

4 Generalized procedure

4.1 Introduction

When a geosynthetic is used in a civil engineering structure, it is intended to perform a particular function for a minimum expected time, called the design life. A geosynthetic is a generic term describing a product, where at least one of the components is made from a synthetic or natural polymer, in the form of a sheet, a strip or a three-dimensional structure, used in contact with soil and/or other materials in geotechnical and civil engineering applications. Geosynthetic products comprise geotextiles, geosynthetic barriers (polymeric, bituminous and geosynthetic clay liners), geogrids, geonets, geocells, geostrips, geomats and geospacers. The seven functions defined in ISO 10318 are barrier function, drainage, filtration, protection, reinforcement, separation, and surface erosion control. Each function uses one or more properties of the geosynthetic, such as tensile strength or water permeability for a geotextile and impermeability to liquids for a geosynthetic barrier. These are referred to as functional properties.

Assessment of the durability of structures using geosynthetics requires a study of the effects of time on the functional properties. The physical structure of the geosynthetic, the nature of the polymer used, the manufacturing process, the physical and chemical environment, the conditions of storage and installation, and the load supported by the geosynthetic are all parameters which govern the durability. The main task is to understand and assess the evolution of the functional properties over the entire design life. This problem is quite complex due to the combination and interaction of numerous parameters present in the soil environment, and to the lack of well-documented experience.

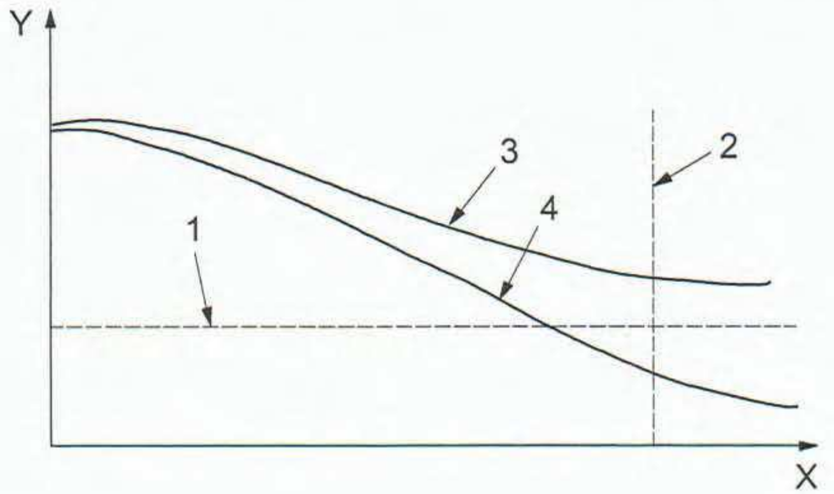
The majority of geosynthetics, when correctly processed and stabilized, are comparatively resistant to chemical and microbiological attack encountered in normal soil environments and for normal design lives. For such applications, only a minimum number of screening or index tests may be necessary. For applications in more severe environments, such as soil treated with lime or cement, landfills or industrial-waste containments, or for applications with particularly long design lives, special tests including "performance" tests with site-specific parameters may be required.

4.2 Available and required properties

4.2.1 Condition of acceptability

A geosynthetic will have one or more functional properties critical to its intended function, for example tensile strength or permeability. It is then necessary to differentiate between the available and required values of this functional property. The available property is that provided by the geosynthetic. The required property is the minimum level necessary for the geosynthetic to perform its intended function.

The available property is expected to change with time due to degradation of the material, as shown in Figure 1. The necessary condition is that, at the design lifetime (Item 2 in Figure 1), the available property exceeds the required property, which is shown for simplicity as remaining constant in time (Item 1). This condition is satisfied under the first set of conditions (Item 3) and is not satisfied under the second set of conditions (Item 4). These are therefore deemed to be acceptable and not acceptable, respectively.



Key

X time

Y property of a geosynthetic, expressed as a percentage of its original value

1 minimum acceptable level of required property

2 design lifetime

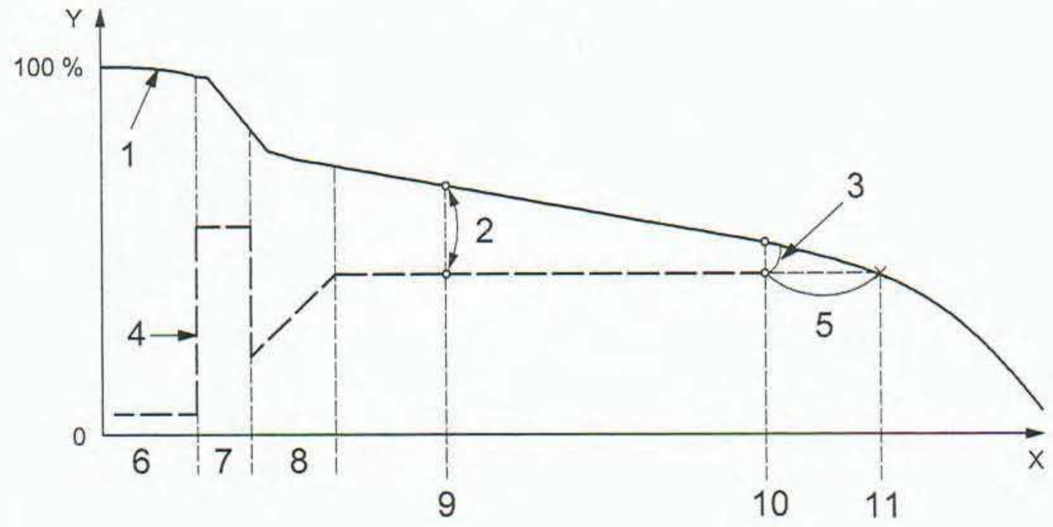
3 available property under first set of conditions (acceptable)

4 available property under second set of conditions (not acceptable)

Figure 1 — Available and required properties as a function of time under two different sets of conditions, the first acceptable and the second not acceptable

4.2.2 Development of the required and available properties with time

In practice, both the available property and the required property can vary with the successive events that occur between manufacture of the product and the design life. Figure 2 shows a schematic example.



Key

X time

Y property of a geosynthetic, expressed as a percentage of its original value

1 available property

2 margin between required and available property at intermediate time

3 margin of safety at design life

4 required property

5 margin of safety between design life and time to failure

6 duration prior to installation (storage and transportation)

7 duration of installation

8 duration of further construction

9 intermediate time during normal use

10 design life

11 time to failure

Figure 2 — Available and required properties of a geosynthetic during storage and transportation, construction, backfilling and use

A new geosynthetic exhibits an initial or short-term available property as defined by a set measurement standard. Depending on the level of quality control and quality assurance, a reduction factor may be applied to cover variations in the initial property.

The available property is shown as line 1 in Figure 2. During storage and transportation (period 6 in Figure 2), this property may change due to weathering, while during installation (period 7) and further construction (period 8), it may suffer from mechanical damage. The extent of the mechanical damage incurred during installation depends on the geosynthetic, the nature of the materials in contact with the geosynthetic, the equipment used and the care provided by the handling team (see 6.4.4). For polymeric geosynthetic barriers, the manufacturing process and the welding parameters during installation may not lead to immediate degradation, but can induce residual stresses in the material which lead to a stress-crack phenomenon and more rapid subsequent degradation.

After backfilling (period 8), the operating life of the material starts. During the operating life, the geosynthetic is subjected to chemical, biological or physical actions due to the soil, its constituents, and its air, water and organic content, resulting in a gradual reduction in the available property until the design life (Item 10 in Figure 2) is reached. The available property will diminish further if the geosynthetic remains in place beyond its design life.

The required property is shown as line 4 in Figure 2. During storage and transportation (period 6 in Figure 2), a minimum required property, generally strength, is needed to resist handling loads. Installation and compaction (period 7) may require a strength higher than that required for the remainder of the design life. During further construction (period 8), the load will increase from a lower level, increasing the required strength. When finally in use, the required property will remain constant.

It should be noted that the available property can diminish due to the level of constraints or the applied load: the greater the applied stress, the shorter the time to failure. This is a particularly important phenomenon that is described in 6.4, particularly in 6.4.1. Thus, there can be an interaction between the required property and the available property. There is no absolute available property curve as shown schematically in the graph by the presence of the two curves.

It should also be noted that there may be more than one functional property. For example, a filter or separator will have a minimum required strength to survive installation and construction, while in operation the required property will be the permeability or opening size. The above analysis should be performed for both properties.

The testing techniques and the assessment methods for estimating the property curves is presented and discussed in later subclauses. Index test methods are intended to ensure a minimum level of durability and do not constitute a comprehensive assessment procedure. Where this is needed, it will be necessary to carry out further performance tests more closely related to service conditions. These tests may also include investigations on samples extracted from sites where the same product has been used for several years in a similar environment. Procedures have been developed, such as those described in ISO 13437. As in other fields of engineering, confidence in the durability of geosynthetics is developing as the technology matures and the results of long-term service experience accumulate. Examples of experience to date are described in Clause 6.

4.3 Design life

The design life is specified on the time axis (Item 2 in Figure 1, Item 10 in Figure 2). It is set by the client (or a design code) and is decided at the design stage. Codes generally propose several fixed durations, according to whether the structure is meant for short-term use (typically a few years and not exceeding five years), temporary use (generally less than 25 years) or permanent use (over 25 years, and generally 50 to >100 years). The nature of the structure, the environmental risk involved and the consequences of failure may influence this duration (example: 70 years for a wall, 100 years for an abutment and beyond 100 years for landfills). Many geosynthetics have a temporary function although the structure is permanent; for example, an embankment over a weak soil may require a geotextile or geogrid reinforcement until the embankment has settled.

4.4 Margin of safety

At the end of the anticipated design life, the designer has to ensure a certain margin of safety (generally also indicated by codes), such that failure (Item 11 in Figure 2) is predicted to be well beyond the design life (Item 10). Item 3, the difference between the predicted available property and the predicted required property, represents the margin of safety for that component. This can be expressed as a ratio. The ratio can also be expressed in terms of the time to reach the end of life if the geosynthetic were to be left in service after the end of its design life (Item 5). These two representations of safety, the ratio of required and available property at the design life, and the ratio of the predicted end of life to design life, should be considered together because, in combination, they give a better idea of the real level of safety that exists.

The calculation of reduction factors for soil reinforcement applications is described in ISO/TR 20432.

4.5 End of life (function)

The end of life is the point on the time axis where the available property curve meets the required property curve (Item 11 in Figure 2). At this point, the product is predicted not to fulfil its function. Residual service may remain either if the expected loads are overestimated, or if they imply a combination of degradation mechanisms that may not all have reached their maximum values. Whatever the case, beyond that point on the graph, the possibility of end of function or failure is high.

4.6 Durability study

The design and durability assessment of a structure using a geosynthetic can be summarized as follows:

— defining the function(s) of the geosynthetic;

— making the inventory of the constraints imposed by the application (environmental, physical, chemical);

— defining the design life of the geosynthetic;

— quantifying the required properties of the geosynthetic (e.g. strength, permeability, impermeability, seam integrity);

— defining the geosynthetic properties;

— making sure that the estimated available properties at the end of the design life are greater than the required properties.

5 Constituents of geosynthetics

5.1 Types of geosynthetic

5.1.1 Polymeric durability considerations

The durability of a polymeric geosynthetic depends upon the formulation from which it is made, on any additives and fillers compounded with it, on the polymer microstructure, the fibre geometry and fabric layout for geotextiles, the thickness of geosynthetic barriers, and the quality of joints in geosynthetic barriers, geogrids and geocells. The geosynthetic should be chemically and biologically resistant if it is to be suitable for long-term applications.

The polymers used to manufacture geosynthetics are generally thermoplastic materials which may be amorphous or semi-crystalline. An amorphous polymer has a randomly coiled structure which, at the glass transition temperature, t_g, undergoes significant change from a stiff, glassy, brittle response to loads below the glass transition temperature to a more ductile, rubbery response above t_g. Most polymers used in geotextiles are semi-crystalline, that is they contain small, more or less oriented crystallites, alternating with amorphous material. Since the change in behaviour only affects the amorphous regions, the glass transition is less marked for a semi-crystalline polymer. At a higher temperature, however, the crystallites melt, which produces an abrupt change in properties. Values of t_g and melting temperature are given in Table 1 for the polymers most commonly used in geosynthetics. In civil engineering applications, polyesters are used below their t_g while polypropylene and polyethylene are used above t_g. Any acceleration of laboratory tests crossing a transition, such as t_g, should be avoided or, if this is not possible, an appropriate factor of safety should be applied.

Mechanical drawing of polymers, e.g. for forming tapes, fibres or filaments, leads to increased orientation that results in higher tensile properties, improved durability and reduction of the changes in properties at the glass transition temperature. As the molecules become more oriented, the fibres become stronger. The crystallites are retained and the ratio of crystalline regions and amorphous regions should be properly balanced to produce the physical properties necessary for fibres used in geotextiles, or for the ribs of extruded geogrids (see 5.1.5). The increased orientation and associated higher density leads to higher environmental resistance. The durability assessment should consider whether any change in this morphology is likely during the service life of the product, and whether such a change will lead to a significant change in properties. Thermal analysis techniques have proved useful in measuring such changes.

Any polymer, whether amorphous or semi-crystalline, consists of long-chain molecules (macromolecules), each containing many chemical units. Each unit may be composed of one or more monomers, the number of which determines the length of the polymeric chain and resulting molecular weight. The nature and the number of the monomer distribution determine the length and structure of the polymeric chain. These factors can affect physical properties such as the tensile strength and modulus, impact strength, flexibility and heat resistance, as well as the durability properties. The mechanical and physical properties of the plastics are also influenced by the bonds within and between chains, chain branching, and the degree of crystallinity.

Crystallinity has a strong effect on polymer properties, especially the mechanical properties, because the tightly packed molecules within the crystallites result in dense regions with high intermolecular cohesion and higher resistance to penetration by chemicals. An increase in the degree of crystallinity leads directly to an increase in rigidity and yield or tensile strength, hardness and softening point, and to a decrease in liquid permeability and gas diffusion.

Durability of all geosynthetics is influenced by fibre or rib diameter or surface-to-volume ratio. Resistance to oxidation and UV exposure is generally dependent on fibre or rib diameter or thickness since the rate of oxidative/photo-oxidative reactions is often limited by the rate of diffusion of oxygen, especially at elevated testing temperatures. Evaporation and extraction of additives is also inversely related to surface-to-volume ratio. These factors should be taken into account in the design of suitable testing procedures and in considering the results of established tests. The choice of test method should ensure that oxygen availability has been simulated correctly. Changes of polymer morphology caused by testing at too high temperatures should be avoided.

Durability is further influenced by the nature and quality of the additives and fillers used.

5.1.2 Geotextiles

A geotextile is a planar, permeable, polymeric (synthetic or natural) textile material, which may be woven, knitted or non-woven. The principal materials used are polypropylene (PP), polyester (PET) and polyethylene (PE).

5.1.3 Geosynthetic barriers or polymeric and bituminous geosynthetic barriers

A geosynthetic barrier is a planar, relatively impermeable, polymeric (synthetic or natural) (GBR-P) or bituminous (GBR-B) sheet. The polymers used to manufacture the geosynthetic barriers are generally thermoplastic materials, elastomeric materials and modified bituminous materials. The materials used are high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), polyvinyl chloride (PVC), flexible polypropylene (fPP), ethylene propylene diene monomer (EPDM), ethylene interpolymer alloy (EIA), chlorinated polyethylene (CPE), chlorosulfonated polyethylene (CSPE) and other elastomeric materials.

5.1.4 GSB-C

A geosynthetic clay barrier or liner (GBR-C) is a factory-manufactured geosynthetic hydraulic barrier consisting of clay, bentonite or other very low-permeability material supported by geotextiles, geosynthetic barriers, or a combination thereof, and held together by needle punching, stitching, chemical adhesives or other methods. Its durability is governed by the durability of the geosynthetics, the needle-punching fibres, the stitch-bonding filaments/yarns, the glues, and also the ion exchange between the material and the liquid retained or contained, and also desiccation.

For a formal definition, see ISO 10318.

5.1.5 Geogrids

A geogrid is a geosynthetic formed by a regular open network of integrally connected elements with apertures greater than 6,35 mm (1,4 in) to allow interlocking with surrounding soil, rock, earth, and other surrounding materials to function primarily as reinforcement. The elements in the machine and cross-directions may be integral or may be linked by bonding or interlacing. The manufacturing techniques vary widely. Currently weaving, knitting, and welding are used, making use of fibres of polyethylene (PE), polypropylene (PP), polyester (PET), polyvinyl alcohol (PVA) and aramid. Coating materials include acrylic polymers, polyvinyl chloride (PVC), and polyethylene (PE). In addition, PE and PP geogrids are made by the stretching of punched sheet.

5.1.6 Geonets

A geonet is an open planar, polymeric structure consisting of a regular dense network, whose constituent elements are linked by knots or extrusions and whose openings are larger than the constituents. The polymers used to manufacture the geonet are generally thermoplastic materials, such as high-density polyethylene (HDPE).

5.1.7 Geocells

A geocell is a three-dimensional, permeable, natural, or synthetic polymeric honeycomb or web structure, made of linked strips of geotextiles, geogrids, perforated sheets or geosynthetic barriers.

5.1.8 Geomats

A geomat is a three-dimensional, permeable, natural, or synthetic polymeric structure, made of bonded filaments, used to reinforce roots of grass and small plants and extend the erosion-control limits of vegetation for permanent erosion-control applications. The polymers used to manufacture the geomats are generally thermoplastic materials, such as PA, PE, PET and PP.

5.1.9 Geocomposites

A geocomposite is a manufactured or assembled material using at least two geosynthetic products among its components.

5.1.10 Geofoam

A geofoam is a block or a planar section of rigid cellular-foam polymeric material used in geotechnical engineering applications. Geofoam is commonly used as a lightweight fill to take up differential thermal expansion and for use in frozen ground.

5.2 Individual polymer types

5.2.1 General

The polymers used in geosynthetics are described below and three of their most important physical properties are listed in Table 1. The general remarks in 5.1.1 apply.

5.2.2 Polypropylene (PP)

Polypropylene is a thermoplastic polymer. PP is normally used in the isotactic stereoregular form, in which propylene monomers are attached in head-to-tail fashion and the methyl groups are aligned on the same side of the polymer backbone. PP has a semi-crystalline structure which gives it high stiffness, good tensile properties and resistance to acids, alkalis and most solvents. The tertiary carbon is sensitive to oxidation, so that stabilizers are added to prevent oxidation during manufacture, as well as to improve long-term durability and UV stability.

5.2.3 Flexible polypropylene (fPP)

Flexible polypropylene is a copolymer of propylene and ethylene. It is different from other PP-based olefinic polymers in that it is not a blend, but a reactor product using a proprietary catalyst. Its characteristics are quite different from the homopolymer PP and can be modified over a wide range by adjustment of the type, quantity and position of the second monomer in the molecular chain. In addition to the significantly higher degree of flexibility, it has a broad melting transition, which allows it to be thermally seamed over a wide range of seaming equipment. fPP maintains the inherent characteristics of polypropylene but is highly amorphous, so that greater attention needs to be paid to oxidation and UV stabilization.

5.2.4 Polyethylene (PE)

Polyethylene as used in geotextiles, geogrids and geosynthetic barriers is an alpha-olefin copolymer. It is used as high-density polyethylene (HDPE), which is known for its good chemical resistance, or in its linear low-density form (LLDPE), which is known for its excellent pliability, ease of processing and good physical properties, but which is less chemically resistant. PE requires to be stabilized to increase its resistance to weathering and oxidation. Certain grades of HDPE can be susceptible to environmental stress cracking.

5.2.5 Polyesters (i.e. PET, PEN)

Polyesters are a group of polymers. The type used most frequently in geotextiles is polyethylene terephthalate (PET) which is a condensation polymer of a dibasic acid and a di-alcohol. Since it is used below its t_g and in a highly oriented form, PET offers good mechanical properties, including a low creep-strain rate, and good chemical resistance to most acids and many solvents. The ester group, the important polymeric link, hydrolyses slowly in presence of water and throughout the fibre ("internal hydrolysis"). Under highly alkaline conditions there is an additional, more rapid surface reaction ("external hydrolysis") which is particularly serious for fine fibres with a large surface-to-volume ratio, except when the fibres are coated. Polyethylene naphthalate (PEN) is less prone to hydrolysis than PET, but more sensitive to weathering.

5.2.6 Polyvinyl chloride (PVC)

Polyvinyl chloride is the most significant commercial member of the family of vinyl-based resins. PVC is a very versatile plastic because its blending capability with plasticizers and other additives allows it to take up a great variety of forms. Plasticizers and fillers are used in quantities of up to 35 % to create more flexible compounds, the choice of plasticizer being dictated by the properties desired. Conversely, PVC absorbs certain organic liquids which have a similar plasticizing effect. PVC also tends to become brittle and darken when exposed to ultraviolet light or heat-induced degradation through plasticizer depletion. Many PVC formulations, with quite different durability characteristics, are available on the market to suit specific applications. UV and oxidation stability can be adjusted to the application by the addition of suitable stabilizers.

5.2.7 Polyamides (PA)

Polyamides (PA, PA 6 and PA 6,6) are melt processable thermoplastics that contain an amide group as a recurring part of the chain. PA offers a combination of properties including ductility, wear and abrasion resistance, low frictional properties, low permeability by gases and hydrocarbons, and good chemical resistance. Its limitations include a tendency to absorb moisture, with resulting changes in dimensional and mechanical properties, and limited resistance to acids, oxidation and weathering. The PA fibres used in geotextiles have a t_g of 40 °C to 60 °C which is lowered through moisture absorption. UV and oxidation stability can be adjusted to the application by the addition of suitable stabilizers.

5.2.8 Ethylene propylene diene monomer (EPDM)

Ethylene propylene diene monomer is an elastomer composed principally of saturated polymeric chains constituted of ethylene and propylene molecules. This polymeric material presents a structure increasing resistance to ozone and ageing. The presence of a third monomer, ethylidene norbornene (ENB), is efficient at providing chemically active cure sites for vulcanization. Carbon black is added to the formulation to increase the UV resistance and also resistance to tear. Stabilizers are also added to the formulation prior to the vulcanization process to improve oxidation resistance.

5.2.9 Ethylene interpolymer alloy (EIA)

Ethylene interpolymer alloy describes a compound which derives its performance from the ketone ethylene ester (KEE) resin. The KEE resin typically makes up approximately 50 % of the polymer content of the EIA compound. Along with the ethylene backbone, two monomers are polymerized together: an ester such as vinyl acetate or *n*-butyl acrylate; and a ketone or a carboxyl group. UV and oxidation stability can be adjusted to the application by the addition of suitable stabilizers.

5.2.10 Chlorinated polyethylene (CPE)

Chlorinated polyethylene is a product one step away from PE. On the CPE molecule, chlorine atoms have been introduced along the side of the PE backbone, replacing hydrogen atoms. The much bulkier chlorine atoms tend to disrupt the formation of any crystallinity. The amount of chlorine that is introduced, and the randomness of their attachment, will determine the extent to which the resulting resin will be non-crystalline, or amorphous. Therefore, CPE will tend to be a more flexible material than polyethylene. UV and oxidation stability can be adjusted to application by addition of suitable stabilizers.

5.2.11 Chlorosulfonated polyethylene (CSPE)

Chlorosulfonated polyethylene is a family of synthetic rubber materials. It was introduced in the early 1950s as a synthetic rubber material with better ageing characteristics than the natural and styrene-butadiene rubbers. This improved rubber material is cross-linked to provide elasticity (which improves over time) and contains a minimum level of crystallinity to provide flexibility while maintaining strength. The basic polymer backbone is the same as polyethylene and, because there are no double bonds, the long polymer chains are relatively impervious to attack from degrading agents, such as oxygen, ozone or energy in the form of UV light. Chlorine atoms are introduced along the side of the PE backbone, together with a certain number of sulfonyl chloride groups. Since the sulfonyl chloride groups are larger than the chlorine atom, they are more efficient at breaking up the crystallinity and provide chemically active cure sites. Repair or extension is problematic due to its cross-linked nature. UV and oxidation stability can be adjusted to application by addition of suitable stabilizers.

5.2.12 Bitumen (MB)

Bitumen comprises modified bitumen (MB) and oxidized bitumen.

Modified bitumen is a modification of bitumen with a synthetic elastomer such as styrene-butadiene-styrene (SBS). These styrenic block copolymers are produced by a sequential operation of successive polymerization. The polymers comprise long chains of monomer building blocks that are large enough to have their own separate identity. Their content does not generally exceed 25 %. The effect is a lowering of the softening point and viscosity of the blend. The polymers present in a formulation increase the elasticity, fatigue resistance and ageing of the bitumen. Sensitivity to UV and oxidation can be adjusted by suitable additives.

Oxidized bitumen has different ageing properties to those of modified bitumen.

5.2.13 Aramid

Aramid is a synthetic fibre, in which the fibre-forming substance is a long-chain synthetic polyamide, in which at least 85 % of the amide linkages are attached directly to two aromatic rings. The links are formed by strong hydrogen bonds.

Aramid offers a high strength-to-weight ratio and exhibits low elongation and low creep deformation. It is typically stable between pH 4 and 9,5.

Aramid is generally sensitive to UV radiation. The amide bonds can be hydrolized especially in more acid media. The material absorbs moisture and has a low abrasion resistance. Aramid has high glass transition and dissociation temperatures.

5.2.14 Polyvinyl alcohol (PVA)

After synthesis, polyvinyl alcohol is obtained in the form of a white precipitate, which is then refined and washed to produce the powdered commercial product. The water insoluble PVA used in geosynthetics is generally formed into fibres by means of three successive operations: dissolution, spinning and finishing. The resulting fibres exhibit a very high tenacity, high modulus and low elongation (typically < 6 %). PVA is unaffected by animal, vegetable and mineral oils and exhibits a high degree of resistance to acids and alkalis. It is typically stable between pH 4 and 13.

5.2.15 Polystyrene (PS)

Polystyrene is mainly used in extruded form (XPS) or as an expanded foam (EPS). UV and oxidation stability can be adjusted according to the application by the addition of suitable stabilizers.

Table 1 — Typical physical properties of polymeric geosynthetics

Polymer	Density of blended polymer g/cm^3	Melting temperature [a] °C	Glass transition temperature [a] °C
PP	0,900 to 0,910	170	< –10
fPP	0,89	150	< –20
HDPE	0,940 to 0,960	130	< –80
LLDPE	0,910 to 0,925	120	< –80
PET	1,38 to 1,40	250	80
PVC	1,3 to 1,5	N/A	–25 to 100
PA.6	1,2	220	50
EPDM	1,40	NA	–60
CPE	1,2	170	< –50
CSPE	1,47	NA	–55
MB	1,2 to 1,3	NA	< –50
aramid	1,44	550	300
PVA	1,2 to 1,3	228	85
PS	1,05 (solid material)	230	100

[a] Approximate temperatures are given. Specific temperatures are dependent on polymer properties, such as molecular weight, percentage crystallinity and formulation ingredients such as additives and fillers. The values of t_g are derived from DSC measurements. The values of t_g for the very slow processes relevant for durability are generally markedly lower than those measured using DSC, example values of t_g lower than 60 °C have been observed while DSC gives 80 °C. For the purposes of durability assessment, values of t_g measured by DTMA are preferred, if available.

5.3 Manufacturing process

5.3.1 General

Geosynthetics are manufactured using several different processes which are described in this subclause.

5.3.2 Geotextiles

5.3.2.1 General

Geotextiles include non-woven, woven and knitted products. All are made of polymers drawn into fibres, yarns or films. The different manufacturing processes lead to geotextile products with a wide range of properties.

The drawing process is very important in the production of the different types of polymeric fibres, filaments and tapes. During this process, the polymeric chains become aligned along the filament or tape length and their crystallinity, mechanical properties and durability all increase. The mechanical properties of the product depend upon the details of the manufacturing process.

The structure of the fabric and the fibre diameter will contribute to the durability properties; for example, large diameter fibres and thick tapes are less susceptible to weathering. The stabilization systems applied to improve the properties are therefore adjusted to suit either a non-woven geotextile of finer fibres, a woven geotextile or a geogrid.

5.3.2.2 Non-woven geotextiles

For the production of non-woven geotextiles, continuous filaments (spunbonded) or staple fibres (cut fibres) are used. Woven and knitted geotextiles are produced using different types of yarn, such as spun yarns, multifilament yarns, monofilaments and film tapes or split film yarns.

The types of fibres, multifilaments, monofilaments and tapes used in the manufacture of such geotextiles are produced mainly by a melt spinning process. To produce fibres, multifilaments and monofilaments the molten polymer is extruded through orifices of a die, cooled, drawn by stretching and, according to the end use,

a) laid on a screen to form a planar structure (continuous filament or spunbonded non-woven),

b) processed to staple fibres by crimping and staple cutting, or

c) processed to multifilaments or monofilaments, winding the filaments after drawing and annealing directly on to spools. In the case of multifilament production, this technique is known as spin-drawing.

Spunbonded non-wovens (continuous filament non-wovens) are manufactured in a continuous process starting with the polymer and proceeding through filament production, geotextile formation and filament bonding in the same line, finishing with the roll of non-woven.

Staple fibre non-wovens are manufactured in a two-stage process: the first stage consists of fibre production (extrusion and cutting) and the second stage consists of the formation of the geotextile, bonding and production of the finished roll.

Bonding of non-woven geotextiles formed from either continuous filaments or from staple fibres is done mechanically by needle punching with felting needles, by thermal (cohesive) bonding using heat with or without pressure (calendering), by chemical (adhesive) bonding, or by a combination of these processes.

The physical structure and properties of the non-woven products are often related to the bonding system. More specifically, heat-bonded wovens and non-wovens (tape-film wovens) are thin products, in which the fibres are oriented in a two-dimensional structure. Needle-punched non-wovens have a three-dimensional structure, the configuration of which may be fixed by a final thermal bonding stage.

5.3.2.3 Woven and knitted geotextiles

Woven geotextiles are also produced in a discontinuous process with at least two stages. The first stage is the production of the yarn, monofilament or multifilament. The second stage is the weaving either to flat wovens (or simply wovens) or knitted wovens (knits).

Weaving involves the interlacing of two sets of yarns at right angles to each other: the machine (MD) and cross-machine direction (CMD). The MD threads are held under tension and in distance by means of a loom. The loom is equipped with MD threads passing through heddles on two or more shafts. The MD threads are moved up or down, depending on the design by the shafts, creating a space called the shed. The CMD yarn is brought into the shed, perpendicular to the MD yarn. The raising/lowering sequence of MD threads gives rise to many possible weave structures. The number of threads per unit width and their individual strength lead to final product strength.

In the knitting process, yarn bundles are tensioned parallel in the machine direction (MD) and perpendicular yarns are placed in the cross-machine direction (CMD). An extra thread is used to link these together and to form a stable integral mesh. Usually a coating is applied in order to provide protection.

Film tapes and split yarns are normally only produced from polypropylene and polyethylene. These products are made by extruding a film, cutting the film into individual tapes and stretching them by a uniaxial drawing process followed by thermal fixation. Coarse film tapes may be too stiff for further handling in beaming and weaving, and are therefore fibrillated after the drawing process and before winding and twisting. These types of yarn are then called split film yarns. Nevertheless, large volumes of geosynthetics are woven directly from film tapes.

5.3.3 Geosynthetic barriers

Geosynthetic barrier sheets are normally produced from thermoplastic polymers. These products are made by extruding a sheet or by blown film processes or by calendering.

The manufacturing begins with the production of the raw materials which include the polymer resin, various additives, fillers and lubricants. The formulations are then processed into a geosynthetic barrier sheet of various width and thickness by one of two extrusion methods. In the first process, called flat die, the polymer formulation is forced between two horizontal die lips. The second process, called blown film, uses a circular die which forces the polymer formulation between two concentric die lips oriented vertically. The polymer exits the die and extends upward in the form of a cylinder. At the top of the system, two counter-rotating rollers draw the cylinder upward and, after passing over the rollers, the sheet is longitudinally cut, unfolded to its full width, and rolled onto a roll.

The mechanical and durability properties of the product are related to the details of the manufacturing process as well as to the bonding of the sheets.

Bonding of geosynthetic barrier sheets is done mechanically by thermal (cohesive) bonding using heat with or without pressure, by fusion using heating elements (hot wedges) with pressure, by chemical (adhesive) bonding, or by a combination of these processes.

The continuous process used to produce bituminous geosynthetic barriers is quite different. A geotextile is unrolled and dipped into consecutive baths containing a modified styrene-butadiene-styrene (SBS) bituminous formulation to obtain a bitumen-impregnated geotextile product.

All flexible and scrim-reinforced geosynthetic barriers made from PVC and CSPE are manufactured by a calendering method. The polymer formulation is fed to a mixer from which the material exits, moves on a conveyer to a roll mill and passes through a set of counter-rotating rollers (calender) to form a final sheet. This type of manufacturing gives rise to multiple plies of laminated geosynthetic barriers with an open-weave fabric (called scrim) between the individual plies.

5.3.4 Geogrids

5.3.4.1 Polyethylene (uniaxial)

Geogrids manufactured from polyethylene start with the extrusion of a sheet. This is perforated either during extrusion or, subsequently, in a separate operation, forming a regular arrangement of apertures. The perforated sheet is then stretched in a uniaxial direction under controlled conditions, inducing a high degree of molecular orientation to achieve a higher level of tensile strength, creep resistance and durability.

An alternative method of manufacture is to make coated fibre strips which are cross laid. The joints are then welded, for example by microwave or ultrasonic techniques.

5.3.4.2 Polypropylene (biaxial)

Polypropylene geogrids are manufactured in the same way as those made from polyethylene (5.3.4.1), except that stretching is biaxial rather than uniaxial.

5.3.4.3 Coated fibre

Woven and knitted geogrids are made by the same processes as described for woven and knitted geotextiles (5.3.2.3), but with apertures left between individual yarn bundles. The woven or knitted structure is subsequently coated. For the materials, see 5.1.5.

5.3.5 Geonets

Geonets are typically manufactured by an extrusion process, in which a minimum of two sets of strands (filaments) are overlaid to yield a three-dimensional product. The openings between the strands permit an in-plane flow of liquids, such as water or landfill leachate, and gases.

5.3.6 Geocomposites

Geocomposites are composed of at least two different geosynthetics joined together by a process such as bonding, gluing, welding, weaving, knitting or sewing.

5.3.7 Geocells

Geocells are three-dimensional geosynthetics used for soil confinement in erosion-control applications. They are manufactured either by extrusion, HDPE strip welding or geotextile strip welding.

5.3.8 GBR-C

A clay geosynthetic barrier (GBR-C) is a factory-manufactured geosynthetic hydraulic barrier consisting of clay supported by geotextiles, geosynthetic barriers, or a combination thereof, that are held together by needle punching, stitching, chemical adhesives or other methods.

5.4 Recycled and reworked materials

In the industry, three expressions are used to identify recycling of processed materials:

- rework resin (RR) (or regrind);
- post-consumer resin (PCR);
- post-industrial resin (PIR).

It is common practice within the plastics industry to recycle the processed material (in-house rework resin), since it can be considered comparable to virgin material as long as it is used in small percentages (less than 10 % for polymeric geosynthetic barriers). Some producers manufacture geotextiles using 100 % PCR, for example reground PET bottles. PIR is the recycling of industrial resin originating from another process or client.

Recycled materials may originate from various stages of processing following their original formulation, or from subsequent processes such as weaving for geotextiles. The materials may have been used in service, whether in the form of textiles or as other products such as packaging. The level of control over the quality of the material, and thus its durability, decreases with the number of stages and processes it has gone through after leaving the original manufacturer's plant.

The use of PCR or PIR may compromise the durability of geosynthetics. It is advisable not to use these materials without proof of their long-term durability. The composition of the blended polymer should be assured. For example, for HDPE geosynthetic barriers, the percentage of reworked resin should be limited. According to GRI GM13 (revision 4, Dec 2000), items 4.3 and 4.4: "The resin shall be virgin with no more than 10 % rework. If rework is used, it must be a similar HDPE as the parent material. No post-consumer resin of any type shall be added to the formulation." Also, no post-industrial recycled polymer shall be added to the geosynthetic barrier formulation.

5.5 Additives, stabilizers, fillers and reinforcement scrims

5.5.1 General

Additives play a major role in polymer stabilization. Typical additives used in the production of geosynthetics are antioxidants, acid scavengers, metal ion deactivators, UV stabilizers, lubricants, plasticizers, lubricants, mineral fillers and scrims.

5.5.2 Antioxidants

Antioxidants prevent deterioration of the appearance and of the physical properties of polymers caused by the oxidative degradation of polymer bonds. Stabilization is achieved by either providing alternative opportunities for termination reactions, or by preventing the formation of free radicals and thus interrupting the chain of reaction. With some stabilizers, the oxidation of the polymer starts only after an induction (or incubation) period has elapsed. During this time, the stabilizer is consumed causing a strong inhibition of polymer oxidation. With other antioxidants, no induction period but a reduced velocity of oxidation is achieved. Both types of action may be combined by mixtures of different antioxidants or by certain single antioxidants.

Oxidation is accelerated by the heat generated during the manufacturing process. These antioxidants, designed to work during the manufacturing process (high temperatures), are referred to as processing antioxidants. The main groups are hindered phenols and organic phosphites.

Antioxidants intended to protect the geosynthetic during its subsequent exposure to the environment (low temperatures) are referred to as long-term antioxidants. The main groups are aromatic amines, thioesters, hindered phenols and hindered amines.

5.5.3 Acid scavengers

Acid scavengers provide protection of the polymer to acids resulting from catalyser residues or oxidation/hydrolysing processes in the polymer. They are considered to be a part of the stabilizer package along with primary antioxidants and phosphites. They are mainly soluble or dispersible bases, e.g. metallic stearates, lactates, hydrotalcites or zinc oxides.

5.5.4 Metal ion deactivators

Heavy metal ions, including transition metal ions, catalyse the decomposition of peroxides, leading to the formation of reactive radicals which accelerate autoxidation. Ion deactivators form stable inert complexes with such ions, and thus may contribute considerably to stabilization.

5.5.5 UV stabilizers

UV stabilizers provide ultraviolet light stabilization to polymers by several mechanisms that interfere with the physical and chemical processes of light-induced degradation in the presence of oxygen (photo-oxidation):

— absorbing the range of critical wavelengths by UV-absorbing chemical compounds (e.g. hydroxybenzophenones) or pigments (e.g. carbon black or titanium dioxide);

— quenching of energized photochemical states by certain quenchers (e.g. certain nickel compounds);

— trapping of free radicals by certain antioxidants [e.g. hindered amine light stabilizers (HALS)].

Often a combination of different stabilizers provides the best protection.

5.5.6 Plasticizers

In order to make a flexible compound from a rigid resin, such as PVC, plasticizers must be added. They come in a variety of chemical compositions and molecular weights. The plasticizing additives, such as those containing residual fatty acids (glycerol esters, laureates, oleates, phthalates and stearates), have to be resistant to migration and leaching and may have to be protected with other additives since they are susceptible to attack by micro-organisms.

5.5.7 Lubricants

Process aids can include materials, such as waxes, stearates or low-molecular-weight polyethylenes. These materials assist in the production of a calendered sheet material, and subsequent handling of a geosynthetic. These products provide improved mill and calender roll release at production temperatures, and improved anti-blocking properties of the geosynthetics.

5.5.8 Mineral fillers

Mineral fillers, such as clay and calcium carbonate, are usually added to the formulation for economic considerations. They can provide some internal reinforcement for the compound, while increasing the compound strength.

5.5.9 Scrims

A scrim is usually an open-weave polyester fabric inserted between the individual plies of a geosynthetic barrier. It is used to reinforce a flexible product. Generally, scrims are made of 1 000 dtex filaments spaced at 0,1 mm (specified as 10 × 10, 1 000 dtex).

6 Environmental factors that may lead to degradation

6.1 The environment above ground

Ageing of exposed geosynthetics is mainly initiated by the ultraviolet (UV) component of solar radiation, heat and oxygen, with contributions from other climatic factors, such as humidity, rain, oxides of nitrogen and sulfur, ozone, deposits from polluted air and pollens, and contained liquids.

The energy of ultraviolet radiation is sufficient to initiate rupture of the bonds within the polymer leading to subsequent recombination with, for example, oxygen in the air, or initiating more complex chain reactions. This is a general property of polymers and is not restricted to geosynthetics. Additives increase resistance to ultraviolet radiation in a variety of ways as described in 5.5.

The resistance to ultraviolet radiation is affected both by the surface temperature of the sample and by precipitation, for which reason accelerated weathering tests include control of temperature and an intermittent spray cycle. Since natural weathering is both seasonal and variable, artificial tests have the advantage not only of being able to increase the intensity of the radiation, but also of ensuring that the radiation is constant, controlled and lasts up to 24 h a day. The performance following accelerated testing is related to the duration of exposure on site as described in 8.3.1.

In most applications, geosynthetics are exposed to UV light for only a limited time during storage, transport and installation and are subsequently protected by a layer of soil. On the other hand, exposed geosynthetic barriers, mainly installed at the top of slopes of reservoirs, ponds and channels, must resist for a longer time. The need for either short- or long-term resistance to weathering therefore depends on the application.

Exposure to UV has been shown to reduce the subsequent chemical resistance of thin textiles but this has not been observed in geotextiles. In addition, atmospheric pollution and acid rain may enhance UV degradation, particularly of PA, for longer exposures above ground. Attacks by birds and animals have been observed during deliberate exposure of specimens during outdoor weathering tests and in applications.

6.2 The environment below ground

Below ground the main factors affecting the durability of geosynthetics are as follows. They apply especially to the soil particles, soil suspension and soil water in direct contact with the geosynthetic:

— particle size distribution and angularity;

— acidity/alkalinity (pH);

— metal ions present;

— presence of oxygen;

— moisture content;

— organic content (e.g. phenols, organic acids);

— temperature;

— micro-organisms.

Adequate specification of the soil is thus essential for proper consideration of the durability of the geosynthetic.

Soils as encountered in the world should be divided into topsoil (0,20 m to 1,00 m) and underlying sediments. Their nature depends primarily on the underlying rock and on the local climate, including the mean temperature and the drainage conditions. Topsoil is a mix of weathered sediments and humus produced by decaying organic material. The conditions of decay can be aerobic, with oxygen present, or anaerobic.

Sediments are deposits of minerals and lack organic material. They are generally formed by the physical and chemical weathering of rocks. Silt, sand and gravel (particle size 0,002 mm to 60 mm) are formed by physical weathering, while clays (particle size < 0,002 mm) are formed by chemical weathering. Fills and backfills originate from sediments, where particle size and angularity is determined not only by the manner in which the sediment was formed but also by any subsequent industrial processing such as crushing. The range of particle sizes of a soil is measured by sieving and is depicted by a graph of particle size against percentage by weight. Mechanical damage increases with particle size, and with the angularity of the particles. This is described further in 6.4.4. Sharp-edged particles in underdrain and drainage layers can cause considerable mechanical damage to geosynthetics; in fact the exhumation of specimens after a number of years and leak detection surveys on covered geosynthetic barriers often shows that puncture is the only form of degradation that can be identified with certainty.

The topsoil or sediments can be fully saturated, partially saturated or dry, or intermittently wet and dry. In wetter climates, the drainage is principally downwards, drawing soluble materials to lower levels, while in drier climates, moisture is removed by evaporation at the surface and the resultant upward movement of the water draws these soluble fractions upwards and deposits them at the surface. The water content of an unsaturated soil is described by the local relative humidity.

The temperature of the soil is constant (to within ± 0,5 °C) only at a depth of 10 m or more. Its value is then equal to the annual average atmospheric temperature at the surface. Daily and seasonal variations occur with decreasing intensity as the distance from the surface increases. For example, the daily variation in atmospheric temperature and solar radiation is felt to a depth of 0,5 m (Segrestin and Jailloux, 1988) and even more in Nordic regions (1,2 m to 1,5 m). Since higher temperatures increase the rates of ageing and creep of polymers disproportionately, their effect on geosynthetic behaviour may need to be considered for material installed close to the surface.

Similarly, very cold temperatures increase the brittleness of the polymeric material. Special considerations apply to frozen ground or permafrost, where the combined effect of frozen soil and geosynthetic should be taken into account.

Topsoil generally has a pH of 5,5 to 7, but anaerobic peats or soils which have been affected by acid rain may have a pH of approximately 4. Atmospheric carbon dioxide leads to generally increased acidity at the surface. Limestone or chalk soils may have a pH of 8 to 8,5. Geological deposits have a wide range of pH, as shown in Table 2, with values between 2 and 10 having been recorded.

Table 2 — Some typical minerals and fills and their pH values

Mineral	Formula	Maximum pH
Feldspar		
Albite	$NaAlSi_3O_8$	9 to 10
Anorthite	$CaAl_2Si_2O_8$	8
Orthoclase	$KAlSi_3O_8$	8 to 9
Sand		
Quartz	SiO_2	7
Muscovite	$KAl_2(AlSiO_3)O_{10}(OH)_2$	7 to 8
Clays		
Kaolinite	$Al_2SiO_2O_5(OH)_4$	5 to 7
Carbonates		
Dolomite	$CaMg(CO_3)_2$	9 to 10
Calcite	$CaCO_3$	8 to 9

The use of bentonite and other clays in civil engineering construction, such as diaphragm wall construction, grouting processes, sealing layers in landfill and tunnelling, causes local alkaline areas of pH values of 8,5 to 10. If the soil is treated with lime (calcium hydroxide), then the possible pH can be as high as 11. Concrete substrates can also exhibit high alkalinity (pH 11 and higher).

6.3 Chemical and biological effects on a geosynthetic

6.3.1 General

Chemical attack is most serious when the polymer chain backbone is broken, leading directly to a loss of mechanical properties and, frequently, to a loss of hydraulic properties. Chemical degradation of polymers occurs by a variety of processes including oxidation and hydrolysis, depending on the type of polymer and on the acidity or alkalinity of the soil. Acidity and alkalinity are expressed as pH, a scale with neutral soil having a pH of 7, lower values implying acid soils and higher values alkaline soils.

All chemical reactions occur more rapidly at higher temperatures, as described by Arrhenius' Law (see 8.5.4.4).

6.3.2 Hydrolysis of PET and PA

Polyesters and polyamides are susceptible to hydrolysis, which in polyester materials takes two forms. The first, alkaline or external hydrolysis, occurs in alkaline soils above pH 9,0, particularly in the presence of calcium, and takes the form of surface attack or etching. Caution should be applied in the use of polyesters for long periods above pH 9. The second, internal hydrolysis, occurs in aqueous solutions or humid soil at all values of pH. It takes place throughout the cross-section of the material. The rate of hydrolysis is slow, such that the process has little effect at mean soil temperatures of 15 °C or below in neutral soils, although it can be accelerated in acids. The rate of internal hydrolysis in a partially saturated soil depends upon the local relative humidity. Sensitivity to hydrolysis can be reduced by selecting a polyester of sufficiently high molecular weight [i.e. high intrinsic viscosity (IV)]. It is recommended that the number-averaged molecular weight, M_n, should be greater than 25 000 and the carboxyl-end-group count less than 30 µeq/g.

6.3.3 Oxidation of PE and PP

Polypropylene and polyethylene are susceptible to oxidation, as are most other polymers. This is accelerated by the catalytic effects of transition metal ions in a chemically activated state at levels as low as 100 ppm (parts per million). Of these the ferric (Fe^{3+}) ion is the most common, but copper and manganese have also been shown to be important. However, the sensitivity to oxidation is dramatically reduced by the inclusion of antioxidant stabilizers or additives (see 5.5), and is retarded by the high level of orientation in polymer fibres or ribs as are found in most geotextiles and geogrids.

For UV radiation and oxidation with limited oxygen diffusion, the rates of degradation depend strongly on surface-to-volume ratio, as do the rates of extraction and evaporation of additives.

6.3.4 Biochemical attack

Biochemical attack occurs generally by means of oxido-reduction, depending on the type of polymer and on the biomass growth. The conditions of decay can be aerobic, with oxygen present, or anaerobic.

In the past 25 years, there have been no reports of microbial attack on synthetic geotextiles either in testing or in the ground. Only geotextiles containing vegetable fibres (most of which are deliberately designed to degrade once natural vegetation has become established) and containing fibreglass scrims are likely to be affected. However, in topsoil, micro-organisms, such as bacteria and fungi, might attack geotextiles if they contain components that provide nutrition and if the micro-organisms can penetrate the remaining polymer. The long-chain molecules of thermoplastics used in geotextiles are generally resistant to microbial attack. Also, low molecular components and certain additives could be susceptible to biodegradation, but this can be countered by biostabilizers. Micro-organisms could, in theory, produce degradation products that attack geotextiles chemically. Soil burial tests (EN 12225 and ASTM D3083) endeavour to provide a soil of maximum biological activity to encourage any reaction that can occur, but it is not possible to accelerate the test further.

Geotextiles in soil also come into contact with animals such as rodents and with the roots of plants. Rodents can locally destroy a geotextile, while roots can penetrate and clog it. No specific tests have been proposed to simulate attack by rodents, while CEN/TS 14416 tests the susceptibility to penetration by roots.

6.3.5 Chemical effects on other geosynthetic barriers

PVC geosynthetic barriers have a high chemical resistance to the majority of acids, bases, salts and alcohols, but the plasticizers can be affected by benzene, trichloroethylene and toluene. The PVC structure can be attacked by ketones, such as methyl-ethyl-ketone, tetrahydrofuran and acetone. The effect is more critical in amorphous polymers such as PVC, where very small fractions of a chemical, often a subsidiary additive to a compound liquid, have been known to cause critical failures.

fPP geosynthetic barriers can be affected by oxygen (see 5.2.3) and by halogenated aliphatic hydrocarbons, aromatics and aliphatic hydrocarbons. Care must be ensured when in long-term contact with the following chemicals: organic acids, volatile organics, oils and waxes and strong oxidants.

CSPE and EPDM geosynthetic barriers can be affected by industrial-waste liquids containing high concentrations of aromatic and chlorinated organic hydrocarbons (see 5.2.8 and 5.2.11).

Modified SBS bituminous geosynthetic barriers should not be contact with nonpolar solvents, aromatic solvents, aliphatics or halogenics for long periods of time, nor with very strong acidic and basic solutions ($pH < 2$ and $pH > 9$).

The sensitivity of geosynthetic barriers to microbiological attack is the same as for geotextiles.

EN 14414 describes a test for resistance of geosynthetic barriers to chemical attack in landfills, using both specified chemicals and synthetic leachates, while EN 14415 describes a test for the leaching of additives by chemicals, leaving the remaining polymer vulnerable to oxidative attack.

Table 3 lists the principal test methods for geosynthetic barriers.

Table 3 — Geosynthetic barrier durability tests

Description	Standards	PVC	EPDM CSPE	fPP	PE	MB	GBR-C
Carbon black dispersion	ISO 18553				*		
Carbon black content	ISO 6964			*	*		
Stress-cracking resistance	ASTM D5397			*	*		
Oxidative induction time (DSC)	ASTM D5885		*	*	*		
	ISO 11357-6	*	*	*	*		
Resistance to weathering (UV)	ASTM D4355					*	
	ISO 4892-2	*	*	*	*	*	*
	ASTM G151		*				
	ASTM G154			*	*		
	ASTM G155			*	*		
	EN 1297-1	*	*	*	*	*	
Chemical resistance to liquids	ASTM D5747	*	*	*	*	*	
	ISO 175	*	*	*	*		
	EN 14030	*	*	*	*	*	*
	EN 14414	*	*	*	*	*	*
	EN 14415	*	*	*	*	*	*
Chemical immersion procedures	ASTM D5322	*	*	*	*	*	*
	ASTM D5496	*	*	*	*	*	*
Resistance to micro-organisms	EN 12225	*	*	*	*	*	*
	ASTM G160	*	*	*	*	*	*
Oxidation	ASTM D5721			*	*	*	
	ISO 13438	*	*	*	*		
	EN 14575	*	*	*	*	*	
Water absorption	ASTM D1239			*			
	ISO 62	*	*	*	*		
Plasticizer content and molecular weight	ASTM D2124						
Melt flow index	ISO 1133			*	*		
Softening point (ring and ball)	ASTM D36					*	
	EN 1427					*	
Loss of volatiles	ASTM D1203	*		*			
Swell index of clay	ASTM D5890						*
Evaluation of aged geosynthetic	EN 12226	*	*	*	*		

6.4 Effects of load and mechanical damage

6.4.1 Tensile load: creep and creep-rupture

A major difference between polymers and metals is that, at normal operating temperatures and tensile loads, polymers extend with time, that is they creep. This is particularly important in the design of reinforced soil structures.

At high loads, creep leads ultimately to creep-rupture, also known as stress-rupture or static fatigue. The higher the applied load, the shorter the lifetime. The highest load which, if applied continuously over the lifetime of the product, is predicted to lead to creep-rupture on the day following the design life is defined as the unfactored design load. Of equal importance is definition of the creep strain, which even at low loads can cause a reinforced soil structure to reach a serviceability limit by movement or sagging without leading to total collapse. This can be predicted from isochronous curves (see ISO/TR 20432).

At the microscopic level, when a load is applied to a polymer it will cause the long-chain molecules to stretch or rearrange themselves. While the crystalline areas remain relatively stable under load, rearrangement takes place in the amorphous regions, and it is noticeable that in polymers, such as polyethylene and polypropylene used above t_g, where the amorphous regions are in a rubbery rather than a glassy state, creep takes place more rapidly and is more sensitive to temperature than those, such as polyester, used below t_g. In oriented polymers, an important part is played by the "tie" molecules which link one crystallite with another across the amorphous regions. For example, in polyester molecules, the load can cause these highly stressed molecules to change the arrangement of their side branches, resulting in a temporary reduction in secant modulus and in the characteristic S-shaped stress-strain curve. These processes of rearrangement continue under the combined effects of load and thermal activation.

Tensile creep for a geotextile is measured in accordance with ISO 13431, in which a specimen generally 200 mm wide is placed under a constant load for a set time, typically 1 000 h (six weeks) or 10 000 (1,14 years), and the elongation monitored. Such tests can be performed over a range of loads and, if required, at various temperatures (see ISO/TR 20432). In a reinforced soil structure, part of the load can in fact be transferred to the soil so that the creep measured in air represents a maximum or conservative value.

Creep-strain effects in polymeric geosynthetic barriers are not generally considered in design. Installation stresses in geosynthetic barriers can, however, diminish with time thanks to stress relaxation, the time-dependent reduction in stress at a constant strain, which is the counterpart of creep and which depends on the same parameters of strain and temperature. Creep-rupture, however, can be significant, because, in unoriented polymers such as polyethylene, the high energy, ductile failure that occurs at short times under high loads is preceded at lower loads by a low energy, "brittle" form of failure. Although this effect is well understood, it means that short-term tests cannot be used to predict long-term lifetimes, and leads to a "knee" in the creep-rupture characteristic. The susceptibility to creep-rupture can be reduced by the use of high molecular weight polymer, copolymerization and orientation. Long-term tests under load at high temperatures can be used as a proof test to ensure sufficient resistance to creep-rupture.

6.4.2 Synergy of tensile load with environmental effects (environmental stress cracking)

Environmental effects generally have little effect on creep strain but can reduce the creep-rupture lifetime. If the combined effect of load and environmental effect is greater than the addition of their individual effects, then there is said to be synergy between them.

Environmental stress cracking is the acceleration of low energy, "brittle" creep-rupture in unoriented polymers by fluids, particularly those which dissolve in and swell the polymer, enabling the molecules to untangle and separate. Semi-crystalline polymers such as polyethylene are susceptible to ESC, while oriented fibres and the ribs of drawn geogrids are resistant to it (Wrigley 1987).

Environmental stress cracking of geosynthetic barriers has been studied widely. Some fluids are chosen to accelerate crack growth deliberately in testing. Although modern grades of polyethylene can be very resistant to environmental stress cracking, it is equally necessary to control the presence of residual stresses in a geosynthetic barrier introduced during production, installation or welding, and to select material suited to the expected content of the leachate.

Susceptibility to stress cracking can be measured by immersing notched samples under load in a bath of liquid and can be accelerated by raising the load, liquid concentration or temperature (EN 14576; ASTM D5397). This provides a screening test for the selection of suitably resistant materials.

6.4.3 Effect of mechanical load on weathering and oxidation

Mechanical stress can have a significant effect on the rate of photo-oxidation and thermal oxidation of HDPE and PP, particularly in geosynthetic barriers.

6.4.4 Loading during installation: mechanical damage

Mechanical damage is caused by direct contact between the soil fill or granular drainage layer and the geosynthetic under pressure. Light damage consists of scuffing, scratches on the surfaces and abrasion of the fibres, while more severe damage may include cuts, tears and perforations in the fabric or sheet. For geotextiles, sheaths or coatings may be cut away to reveal the fibres they protect. The surface of geogrids and geosynthetic barriers may be abraded, and oriented polymers may split along the direction of orientation. The susceptibility of some geosynthetics to mechanical damage during installation can increase under frost conditions. The severity of the damage increases with the coarseness and angularity of the granular material and with the applied compactive effort of equipment, and decreases with the thickness of the geosynthetic. Clays and sands ($d_{50} < 2$ mm) generally produce little mechanical damage.

Severe damage can be caused when backfill is dropped from a height onto a geosynthetic, particularly when large rocks or cement blocks are used for erosion control. More detail is given in Watn and Chew (2002). This damage may reduce the mechanical strength of the geosynthetic. When perforations are present, it will affect the hydraulic properties.

In general, the method of installation should preclude damage to the goesynthetic or provide a method for detection and remediation (e.g. leaks). Damage can be restricted by the choice of a suitable material or by inclusion of a protective layer. If, however, some damage is unavoidable, tests should be carried out if there is a risk that it could affect the performance of the geosynthetic. These tests should be carried out as performance tests, using the actual soil and equipment in accordance with accepted practice (ASTM D5818, for general guidance ISO 13437). ISO 10722 is an index test that should only be used for comparison of materials.

For reinforcement applications, a reduction factor should be applied to take into account the reduction in strength caused by the damage. More details are given in ISO/TR 20432.

6.4.5 Normal pressure: compressive creep and penetration

Normal pressure can induce long-term deformation of geosythetics and can also force a material, such as a geogrid, to embody into a soft material, such as a geosynthetic barrier, and reduce the distance of separation, restricting the drainage flow. Compressive creep strain and, if necessary, the time to collapse should be measured using EN 1897.

6.4.6 Abrasion and dynamic loading

Geosynthetics used under roads, railways or in coastal erosion protection may be subject to dynamic loading which will lead to mechanical damage to the geosynthetic in a manner similar to mechanical damage on the installation. While fibres and bulk thermoplastics are susceptible to mechanical fatigue, the principal cause of degradation is abrasion and frictional rubbing. The test for mechanical abrasion is given in ISO 13427 but there is no test for mechanical fatigue. Geosynthetics intended to operate under severe dynamic loading on the coarse backfill should therefore be subjected to performance tests which simulate or accentuate the site conditions. In railway applications, dynamic loading may apply only intermittently, giving a possibility of simulating a long service life.

7 Evidence of the durability of geosynthetics

7.1 Historical development

Large quantities of geotextiles made from man-made fibres were used in the Netherlands after the catastrophic flooding of 1953 which inundated 150 000 hectares and killed 2 000 people. To stop the flooding and reconstruct the sea barriers many million square metres of woven synthetic fabric were used, partly because at that time Europe had run out of jute for sandbags and willow fascines for seabed protection.

In the 1960s, a range of non-woven fabrics was manufactured for use as foundation, separation, and filter layers between granular fills and weak subsoils. In the 1970s, different grades of reinforcing materials, such as heavy wovens and extruded geogrids, were developed specially for such applications. The first applications of HDPE geogrids, in retaining walls in the UK, were probably in the late 1970s. Flexible polyester-based woven geogrids were developed starting in 1984 and the first application was in mid-1985 in a highway in Malaysia. While the incentive to develop geotextiles may have originated from a shortage of natural fibres, now geotextiles and geogrids are produced worldwide for their cost-effectiveness in replacing natural materials and for facilitating structures that otherwise would be difficult or impossible to build.

Studies of geosynthetic barriers as "lower-cost canal liners" commenced in the USA in 1945, with the first experimental installation of a PVC liner in 1957 and the first installation under construction specifications in 1968. Previously hot spray-applied asphalt had been used. The first HDPE geosynthetic barriers were manufactured and installed in Germany in the early 1970s with production increasing rapidly in the early 1980s as geosynthetic barrier lining systems became a regulated requirement in American landfills. The first prefabricated bituminous geosynthetic barrier was installed in 1974 as a barrier/separator under the ballast of a French railroad. While the incentive to develop geosynthetic barriers may have originated due to a shortage of natural clayey soils, they are now used worldwide.

Geosynthetic clay liners were introduced as an alternative, or as an assist, to natural clay in the USA in the early 1980s, with the first solid-waste landfill composite liner application being in 1986.

7.2 Empirical evidence of durability from geosynthetics extracted from the soil

7.2.1 Geotextiles

Will geotextiles last for 50 years, 100 years, or longer? To answer this question, we should start by investigating empirically what has been established over the past 45 years. Some examples giving clear evidence of durability are given below. These observations can then be compared with the results of accelerated and other laboratory tests.

In the early period, Sotton et al. (1982) reported on samples of non-woven polyester and polypropylene geotextiles retrieved from 25 sites in France, ten to fifteen years after installation. These fabrics were still functioning as filters, separators and drainage layers. Losses in tensile strength of up to 30 % were observed, but, with laboratory analysis, no chemical or biological attack could be identified. It was concluded that the reduction in strength was due mainly to mechanical damage occurring principally during installation.

In the following decade (1980-1990), Leflaive (1988) reported on a 5 m high vertical wall in Poitiers, France, which had been constructed in 1970. In this case, 5 m long polyester straps had been embedded in the concrete facing elements and anchored in the backfill, which had a pH of 8,5. Testing of the straps after 17 years showed a 2 % reduction in tensile strength within the backfill but up to 40 % reduction at the point where the straps entered the concrete facing units. Here the pH value was believed to have reached 13 to 14 at a temperature of 30 °C for some time. Subsequent analysis showed that this degradation could be explained by alkaline surface attack (25 %), internal hydrolysis (5 % to 10 %) and mechanical damage, again probably during installation.

In 1990, Wisse et al. reported on samples of 1 000 g/m^2 woven polypropylene, part of a quantity of four million square metres that had been laid as the backing of block mattresses on the sea bed of the Oosterschelde in 1978 to prevent scouring. The geotextile had been in sea water at 10 °C for nine years with a local partial pressure of 3 % oxygen. The permanent load was only 10 % of the tensile strength. The design life was expected to be determined by the time to embrittlement of the polypropylene due to oxidation. After visual examination and analysis to determine the remaining antioxidant content, the samples were subjected to accelerated oven ageing and compared with unexposed samples from the original source of material. Subsequently, the estimated time to embrittlement in sea water at 10 °C was calculated to be 80 to 120 years.

In 1994, Troost et al. reported on the condition of large quantities of woven polyester fabric retrieved from a soil-retaining structure. A multi-layered geotextile-reinforced wall, 4 m high, with slopes of 2:1 and 4:1, was constructed in the Netherlands to study possible degradation of the woven polyester fabric with time. Thirteen years later, the wall was carefully dismantled and the mechanical and chemical properties of the yarns investigated. The 50 m long embankment was oriented from east to west to provide slopes facing north and south. These slopes were partially covered with bitumen and vegetation to prevent ultraviolet attack. After the retrieved fabric had been tested, no hydrolysis could be detected on material either from the interior of the embankment or from the protected slopes, i.e. the mechanical properties, molecular weight (M_w = 33 000), and carboxyl-end-group count (23) had not changed. On the unprotected north and south slopes, reductions of 15 % to 50 % in tensile strength were observed, which were concluded to be due mainly to ultraviolet radiation and not to hydrolysis.

In 2006, Harney and Holtz investigated the degradation of a woven polyester geotextile exhumed from the embankments of the first pile-supported bridge approach in which geotextiles were used. The 100 g/m^2 multifilament woven polyester fabric was installed in 1972 in Sweden. Samples were removed in 2001 and tested together with some original archive material that had fortunately been retained. Too often, archive material is not available and aged material results are simply compared to published original material specifications. When these specifications are found to be exceeded, the material is considered "acceptable", implying no degradation. Only when aged material parameters can be directly compared to actual measured reference (archive) material can a true picture of degradation, or lack of it, be obtained.

Although there were a few tears in the exhumed sample (possibly installation damage), microscopy of the fibre surfaces showed no obvious general degradation damage. However, there was a 50 % reduction in mean yield tensile strength, a reduction of 30 % in mean elongation at rupture, a reduction of 33 % in mean offset tensile modulus, and a 13 % reduction in mean 10 % secant modulus. But, since no installation damage measurements had previously been made, the relative amounts of installation damage and mechanical degradation could not be identified.

Harney and Holtz did note that the reduction in mean yield strength was consistent with typical reduction factors used for installation damage (1,05 to approximately 3,0) and durability (1,1 to approximately 2,0) such as presented by Elias (2000).

7.2.2 Geosynthetic barriers

While PVC geosynthetic barriers (geomembranes) had been used as canal liners since the mid-1950s, the widespread acceptance of geosynthetic barriers started with the use of HDPE to construct liners in geotechnical hydraulic applications in the early 1970s. They became extensively used in landfill applications in the 1980s. During the last 10 years, many samples have been recovered, principally from landfills, to assess their functional durability. It is interesting to report a few of these findings; Hsuan et al. (1991), Dullmann et al. (1993), Brady et al. (1994), Rollin et al. (1994) and Rowe (1998).

Hsuan et al. (1991) recovered high-density polyethylene geosynthetic barrier samples from a leachate pond in service for seven years. The HDPE geosynthetic barrier was exposed at the top sections of the pond slopes and immersed in leachate at the pond bottom. The macroscopic analysis of the recovered samples from many locations in the pond indicated no detectable changes in the geosynthetic barrier. Only minor variations in the microscopic properties were identified and no stress cracking could be measured in the collected samples.

Dullmann et al. (1993) could not observe any variation in the mechanical and chemical properties of an HDPE geosynthetic barrier recovered from a landfill cell in operation for 8 to 10 years. Brady et al. (1994) also analysed HDPE geosynthetic barrier samples collected from many landfills. No detectable variation of their density and water adsorption could be detected. A 50 % reduction in the impact resistance for 30 year old samples and a negligible decrease for 15,5 year old samples was observed. The HDPE samples were found to be more rigid and to have a lower elongation at break.

Rollin et al. (1994) analysed HDPE geosynthetic barrier samples recovered from top, slope, and bottom sections of a seven-year-old landfill cell. A minor increase in the yield strength and a decrease in the elongation at break were noted. The ageing of the samples collected from the cell bottom (in contact with the leachate) was slightly more advanced than for the samples collected on, and at the top of, the slopes.

More recently, Rowe (1998) recovered HDPE geosynthetic barrier samples from a leachate pond in service for 14 years. For exposed geosynthetic barrier decreases in elongation, in the stress-cracking resistance, and in S-OIT (standard oxidation induction time) were observed. On the other hand, no S-OIT variation could be detected in samples immersed in the leachate.

These results and others are some examples giving clear evidence of durability of HDPE geosynthetic barriers. The minor variations detected in the geosynthetic barrier properties did not affect their function during their service life.

The US Bureau of Reclamation has performed a detailed 10 year study on many different types of geosynthetic barriers installed in 34 test sections of irrigation canals in the northwest United States. A final report was issued in 2002 by Swihart and Haynes. Subgrades were described as "severe rocky". Four generic types of liners were assessed: fluid-applied, concrete alone, exposed geosynthetic barrier, and geosynthetic barrier with concrete cover. The durabilities of these four generic types in this very challenging environment were assessed as 10 to 15, 40 to 60, 10 to 25, and 40 to 60 years, respectively. Of the geosynthetic barriers, the following observations were made after 10 years of exposure.

— HDPE. Elongation down 90 %, OIT down 30 %, predicted service life 20 to 25 years.

— PVC/geotextile composite. Elongation down 70 %, predicted service life 10 to 15 years.

— Hypalon. Tear strength down 60 %, predicted life 10 to 15 years.

After 10 years of exposure.

— EPDM. Elongation down 30 %, predicted service life 15 to 20 years.

— LLDPE. Tear strength down 10 %, predicted service life 10 to 15 years.

It must be noted that subgrades were very rough, there was very little maintenance of the liners and they were continuously subject to vandalism and animal damage.

Breul (2006) reports that the bituminous liner installed directly under the ballast in the French railroad in 1974 was "still working well" in 1999.

One of the first HDPE liners in Germany was installed in 1974 to contain jarosite sludge. A second facility was lined in 1984. Tarnowski and Baldauf (2006) reported the results of testing performed in 2005 on samples removed from both ponds. After 31 years, they found little change in the uniaxial tensile yield stress and elongation or in the break strength. However, there was a reduction of 70 % (30 % retained) in the break elongation. The single-point notched constant tensile load stress-cracking resistance (SP-NCTL) was a very low 5 h, and S-OIT on a full thickness specimen was 5 min, indicating that some of the antioxidant additive package was still present. However, to further assess S-OIT, specimens were taken from the exposed surface layer and from the centre of the geosynthetic barrier. Geosynthetic barrier thickness was not identified but was probably 2,5 mm.

After 21 and 31 years, the surface layers of the 1974 liner had S-OIT values of 71 min and 0 min, respectively, while the centre sections had values of 8,8 min and 4 min, respectively. After 21 years, the 1984 material had 5 min on the surface and 65 min in the centre. As expected, the surface layers lose their protection and oxidize first. There is some truth to the old saying that "thicker is better".

That surface layers oxidize first means that, under any applied, induced, or residual stress, stress cracks will initiate first on the surface. Once initiated on the surface, they will propagate faster through the original core material than they would have done if the surface had not been oxidized. Thus, Tarnowski and Baldauf state that the use of retained standard OIT is a more sensitive way of assessing material durability after accelerated ageing than by using tensile properties. They also state that initial OIT, retained OIT after thermo- and photo-oxidation, and stress-cracking resistance "are the [durability] properties to be well defined in every [HDPE] geosynthetic barrier specification".

A 0,5 mm thick PVC geosynthetic barrier installed in an aquaculture pond in 1971 was tested by Newman et al. (2001) after samples from above and below the water level were removed in 2000. Samples were properly conditioned for laboratory testing. All properties met the NSF 54 standard first introduced in 1983. However, it was noticed that when conditioned, the samples from below the water level were somewhat stiffer than just after they had been removed, as had been observed is other similar situations. It is concluded that the chemicals that could be responsible for the extraction of plasticizer during service themselves act as plasticizer, provided the solution remains in contact with the liner. However, when the PVC is removed from the solution, the chemicals volatilize out of the PVC leaving it stiffer because of the reduced amount of original plasticizer. Therefore, it should not be assumed that a PVC geosynthetic barrier at the time of testing is in the same condition as it is under a liquid.

Thick PVC geosynthetic barriers plasticized with solid rather than liquid polymers have performed excellent exposed service for about 20 years on the upstream faces of dams high in the Alps, without any evidence of surface degradation.

Polypropylene geosynthetic barriers introduced in the early 1990s, both unreinforced (fPP) and reinforced (RPP), have had mixed performances. Some RPP test samples for exposed landfill caps have worked well for 14 years and a full-scale-exposed cap has performed well for over 9 years (Congdon et al., 1998). Other pond liners have worked well for over 15 years. However, there have been some stress-cracking problems in exposed liners, tank liners, and floating covers (Peggs, 2006) as a result of loss of additive protection. Research on this wide-ranging behaviour and on the best way to specify a durable PP geosynthetic barrier is ongoing.

7.2.3 Geogrids

Due to their relatively short times in service, geogrid performance has not been investigated to the same extent that geotextile and geosynthetic barrier performances have been evaluated. In general, Allen and Bathurst (2002) have observed that, in reinforced walls, the actual loads on the reinforcement elements are well below values required to cause creep-rupture over the design life of the structure and in some cases creep appears to have stopped completely. Thus, mechanical durability is implied to be adequate.

Good performance over an 8 to 9 year service period has been reported by Bright et al. (1994) for HDPE geogrid soil-reinforcing elements in a concrete-faced mechanically stabilized retaining wall in Arizona, USA. In comparison with archive samples, they found "no significant change" in ultimate strength and strain, 1 000 h creep response, melt rheology, melt temperature range, crystallinity, and S-OIT.

After 10 years of service in the aggregate under railroad tracks on top of a retaining wall at the entrance to Karlsruhe's main station, Jenner and Nimmesgern (2006) found that the tensile break strength of the HDPE geogrid still met the original material specifications but that break elongation was a little lower. Direct comparisons with archive material were planned but were not reported. Oxidative-induction-time measurements were also planned but not completed. The geogrid, the top layer of wall reinforcement, was covered by 70 cm of aggregate below one rail and 50 cm below another rail. There was some mechanical abrasion damage on the surface of the geogrid in the latter location, but not in the former. In the latter case, there were also a few cracks running along the oriented ribs (completely through the thickness of the rib) and sometimes across the transverse bars from rib to rib. In the deeper aggregate area, there were only a few surface cracks in the ribs. No distinction was made between installation damage and damage incurred during service.

Probably the most comprehensive exhumation study of geogrids was performed by Elias et al. (2000) for the US Federal Highways Administration. A total of 24 geosynthetic samples, both geogrid and high-strength geotextiles, including HDPE. PP and PET were exhumed from 12 sites after being in service for up to 20 years. A comprehensive testing programme was performed on the materials, including S-OIT on HDPE and carboxyl-end-group count and viscosity on PET. Again, no installation damage had been previously identified so separation of installation damage and in-service mechanical damage was not possible. Elias et al. stated this is an essential component of durability studies as is full polymer characterization of the actual material, either at the time of installation or via archived and properly stored material. There appeared to be a small amount of hydrolytic degradation on the PET and no measurable OIT loss in either the HDPE or PP, implying no microstructural degradation. They felt that such degradation would only become evident after about 30 years in service.

7.3 Summary

In general, the durabilities of geosynthetics are proving to be very good, but a 30 year practical history is still not very long considering that some facility owners are looking for 1 000 year or more service lifetimes for the containment of such items as low-level radioactive wastes. Nevertheless, where it has been done, the rate of mechanical degradation appears to be within quasi-theoretical calculations, using established reduction and safety factors. For potential field durability studies, it is important to define the amount of installation damage, to fully characterize the polymers and to retain properly stored archive samples. The archive samples are extremely important since, in such a young technology, tests are modified with time to focus on new parameters that may not have been used at the time of installation. For instance, consider the use of OIT to assess PP and HDPE degradation rather than mechanical properties, and now the trend toward HP-OIT as opposed to S-OIT. Also as we are discovering, it is important to note that basic polymers, copolymers, and UV/thermal additive formulations, change with and within manufacturers, so data generated on one grade of material may not apply to another.

8 Procedure for assessment of durability

8.1 Introduction

8.1.1 Need for testing

Many civil engineering structures are designed for long lifetimes, typically 100 years or more. Established materials, such as masonry and steel, have been used for centuries and, with appropriate maintenance, have proved durable over that time. As described in Clause 6, geosynthetics have only been in existence since the 1960s and the plastics and polymer fibres from which they are made were invented in the 1930s or later. A durability of 100 years cannot therefore be demonstrated from experience alone.

Much is now known, however, about the manner in which plastics degrade, the rate at which this occurs, and how it can be prevented. Based on this knowledge, simple tests have been established from which a minimum durability of 25 years can be predicted with reasonable certainty for the commonest geosynthetics.

With current knowledge, it is not possible to define a complete set of index tests for a lifetime greater than 25 years, for any such tests would be of too long a duration for measurements to be made in advance of construction. Prediction of durability for such lifetimes has to be made on the basis of a mixture of extrapolation from experience and accelerated testing.

8.1.2 Scope of durability assessment

Clause 8 describes the procedures to be followed in the assessment of durability of geosynthetics on the basis of existing practice. It is important to consider all the chemical and physical processes that could, potentially, affect the properties of his geosynthetic over its service lifetime. The assessment relates solely to the geosynthetic and not to the soil structure in which it is used. It is not possible to predict mechanisms which depend on both soil and geosynthetic, for example clogging or frost, without detailed information on the soil and on the hydraulic properties of the site.

Satisfactory durability depends heavily on the quality of both design and installation, particularly for geosynthetic containments such as landfills and reservoirs. Most failures that have occurred to date have been due to faulty design, incorrect choice of material, and poor or uncontrolled installation practices. Reliable assurance of durability of a geosynthetic has to assume that it has been correctly installed on site. Joints and welds made on site are therefore excluded.

The procedure for assessing long-term durability is described in 8.5. Reference is made to the following subclauses:

— material (8.2.1);

— function and application (8.2.2);

— environment (8.2.3);

— mechanism of degradation (8.2.4);

— design life (8.2.5);

— "end-of-life" criterion (8.2.6).

8.2 Procedure

8.2.1 Material

The material should be defined in terms of the following, further details being given in Clause 5:

— the generic chemical nature of the polymer and other components, such as additives and coatings;

— the physical structure of the geosynthetic, e.g. thick or thin fibres forming a woven or non-woven fabric, extruded grid, coated fibrous strip, geosynthetic clay barrier, continuous sheet;

— joints forming part of the structure of the geosynthetic.

8.2.2 Function and application

The functions of the geosynthetic should be defined, as described in ISO 10318, as barrier function, drainage, filtration, protection, reinforcement, separation and surface erosion control. Not all these functions require a lifetime of 100 years. Some applications, such as construction roadways (separation) or prevention of slip failure during settlement (reinforcement), are temporary by design; in others, it may be easy to repair or replace the geosynthetic. Soil reinforcement, drainage and barriers for landfill and tunnels, however, are typical examples of where a long lifetime is required and repair or replacement are possible only at great expense.

8.2.3 Environment

The environment should be defined as in 6.1 (above ground) and 6.2 (below ground), including the design temperature for the application in hand. In the absence of a specific design temperature, 20 °C should be used as the default value for applications below ground, noting the comments on extreme situations given in 6.2.

8.2.4 Mechanism of degradation

Each aspect of the environment, and its potential degrading effect, should be considered for each application, as defined in 8.2.2, and placed in order of significance. Some aspects may be considered as not significant. Others may be significant only when considered in combination (e.g. pH and temperature). Types of degradation that should be considered include the following (for guidance see 6.3 and 6.4):

— mechanical damage due to coarse soils, leading to a reduction in strength, or to perforations;

— oxidation (e.g. of PP and PE), leading to a reduction in strength or surface cracking, retarded by the inclusion of antioxidant stabilizers;

— photo-oxidation due to ultraviolet light, general weathering;

— hydrolysis (e.g. of PET and PA) in aqueous solutions, leading to a reduction in strength;

— alkaline attack (e.g. on PET and on additives in PP and PE), leading to a reduction in cross-section and strength;

— acid attack (e.g. on PA and on additives in PP and PE) under aerobic conditions, leading to a reduction in strength;

— the effect of solvents, which may swell polymers, leach out additives or cause environmental stress cracking under load;

— the effects of waste effluents and leachates;

— compressive or tensile creep;

— freeze-thawing, wet-dry cycles and ion exchange (principally of GBR-C).

8.2.5 Design life

The design life should be defined as described in 4.3.

8.2.6 The "end-of-life" criterion

The end of life should be defined. This is the point when the geosynthetic can no longer function satisfactorily. It should be related to the application and function and, where possible, defined quantitatively (see 4.5). Examples of end-of-life criteria are

— percentage reduction in strength and/or elongation (e.g. 30 %),

— percentage reduction in drainage cross-section (e.g. 50 %),

— observed rupture,

— increase in permeability (e.g. 25 %), and

— residual antioxidant stabilizers in PP or PE (e.g. 10 %), preceding mechanical degradation.

8.3 Degradation during storage and installation

8.3.1 Weathering

The effect of weathering should be defined. Many geosynthetics are exposed to light during storage and on the construction site but are covered in service. Degradation during exposure to light is due to the ultraviolet component of solar radiation, whether direct sunlight or diffuse light, aided by heat and moisture. Some weathering effects are due to the alternation of day and night or of wet and dry periods.

It is therefore recommended that all geosynthetics should be tested for their resistance to weathering, using an accelerated test which provides a high level of radiation coupled with cycles of temperature and moisture, such as ASTM D4355 and EN 12224.

EN 12224 is based on the 50 MJ/m^2 radiant exposure (quantity of incident ultraviolet radiation), corresponding to one month's exposure in Southern Europe in summer. The strength retained by a geotextile at the end of the test, together with the specific application of the product, will define the length of time during which the material may be exposed on site, as shown in Table 4:

Table 4 — Installation exposure period for geotextiles

Application	Retained strength after testing according to EN 12224	Maximum exposure time (uncovered) during installation
Reinforcement or applications where long-term strength is a significant parameter	>80 %	1 month [a]
	60 % to 80 %	2 weeks
	<60 %	cover on day of installation
Other applications	>60 %	1 to 4 months [a]
	20 % to 60 %	2 weeks
	<20 %	cover on day of installation

[a] Exposure of up to four months may be acceptable, depending on the season and location.

In the case of geosynthetic barriers, no testing is considered necessary if the exposure time on site is less than three days and the barrier remains shielded from light throughout its lifetime. If the exposure time is to be up to 1 year, then the material should retain 75 % of its initial strength and elongation after a radiant exposure of 350 MJ/m^2, based on a test irradiance of 40 W/m^2 and water sprays of 1 h in 6 h.

Extended artificial weathering tests using methods similar to those in EN 12224 are required for materials which are to be exposed for longer durations. If the radiation is increased too much, the temperature of the geosynthetic rises to a point where the accelerated test is no longer representative of the performance in service. This limits the degree of acceleration to about a factor of three, with the result that many years' testing may be required to simulate the service life of a geosynthetic exposed permanently to light.

8.3.2 Mechanical damage

For geotextiles, the effect of damage during installation should be determined (see 6.4.4). For geosynthetic barriers damage during installation is limited by strict control of the materials in contact supported by a geophysical survey of the complete installation. In the case of poor installation procedures, defects will be introduced which are likely to lead to premature failure. Testing for the effects of damage may not be relevant.

8.4 Short- and medium-term applications of up to 25 years

For applications where the geosynthetic has a design life of less than five years in natural soils and the consequences of failure are low, only tests for weathering and, if relevant, mechanical damage are necessary. In some such applications, the soil structure itself may have a longer design life, but the geosynthetic no longer plays an essential part.

For applications with design lives up to 25 years in natural soils, with pH values between 4 and 9, and at temperatures less than 25 °C and for PE, PP and PA 6 and 6,6, durability can be assured on the basis of screening tests. These index tests, ISO 13438, EN 14030, EN 12447, ASTM D5819, ASTM D6213, ASTM D6388 and ASTM D6389, are designed to exclude materials where there is any doubt concerning their durability. Table 3 lists corresponding tests for geosynthetic barriers. These are based on the methods of accelerated testing but are not intended for the purposes of life prediction. The conditions in the tests are generally too extreme, necessitated by the short duration required, for the test to simulate the conditions in service. For EN 12447, however, which covers the hydrolysis of polyester fibre products, there is sufficient confidence to state a minimum strength retention after 25 years on the basis of the index test, implying an activation energy of 105 kJ/mol.

It is emphasized that these tests are intended to ensure a minimum level of durability only and that the actual lifetime may be greatly in excess of 25 years.

Screening tests are not intended to be regular quality-control tests, nor do they provide sufficient information for the prediction of time to failure, since the degree of acceleration varies from one polymer type to another.

8.5 Assessment of long-term durability

8.5.1 General

For all situations other than those described in 8.3 and 8.4, make an assessment of long-term durability. Such situations include

— all applications with design lifetimes exceeding 25 years,

— all applications of polyester in highly alkaline environments with pH >10,0, particularly in the presence of lime, cement or concrete, or for long design lives with pH >9,

— applications of polyamide in aerobic acid environments, landfill sites or contaminated ground,

— applications in which the geosynthetic is likely to be exposed to temperatures greater than 25 °C or less than 0 °C for a significant period,

— recycled materials, for which manufacturers are expected to maintain sufficient control over the uniformity of their feedstock.

Consider all those items listed in 8.2.4 and in addition:

— past experience, noting the conditions of that experience;

— results of tests, whether index or performance tests: in performance tests the general method for testing and evaluation is defined; certain parameters are site-specific, such as the choice of backfill or landfill leachate;

— sites on which the geosynthetic is currently being monitored;

— the confidence in the data and the relation between the duration of testing and the design life.

8.5.2 Index test for long-term durability of polyester geosynthetics

It is as yet premature to define simple index tests for ensuring lifetimes exceeding 25 years. Current opinion, however, is that if a geosynthetic based on polyester multifilament yarns has a number-averaged molecular weight, M_n, measured to ASTM D2857 exceeding 25 000 and a carboxyl-end-group count no greater than 30, then it should be durable for 100 years in saturated natural soil with $4 \leqslant \text{pH} \leqslant 9$. This is based on a limited though increasing body of evidence.

8.5.3 Evidence from service

Consider any relevant evidence from geosynthetics which have been in service.

Measurements of the degradation in real service environments are the most authoritative evidence for durability. Since geosynthetics have only been used since the 1960s, however, the evidence for long-term durability is limited and frequently incomplete, or relates to conditions that differ from those for which the assessment is being made. Some examples are given in Clause 7. Where such information is available, the following should be noted.

— As much information as possible should be obtained on the material itself, as described in Clause 5. If possible, archive material produced at the same time should be made available for comparison. Unfortunately, the value of data from archive material can be limited because the storage conditions have not been controlled or defined sufficiently. Thus, the importance of well-defined analytical data increases.

— The environment should be defined in as much detail as possible, as described in 6.1 and 6.2.

— The duration over which the material was in service.

— All observed changes.

The effects of mechanical damage and of exposure to light during installation, whether correctly or incorrectly performed, should be identified so that they can be separated from long-term degradation. It may be possible to find areas of material which have not been damaged or exposed to light for comparison.

The rate of change should be determined, noting that it may vary with time. It should relate to the mechanism degradation believed to be dominant for the geosynthetic, and should be statistically significant. Statements that nothing has changed serve only to help provide an assurance of durability for comparable lifetimes. The environmental conditions experienced in the past should be related to the future design conditions, which are frequently more severe than those actually experienced. When accelerated tests have been performed, it may be possible to use the parameters of Arrhenius' formula to convert from one temperature to another.

Frequently, the material used in the past will differ from that for which an assessment is to be made in the future. Products change with time and it will be necessary to make a subjective judgement on the level of similarity.

Failures at joints should not be taken as typical of the bulk material while, if joint failure is the end of life, then the prediction should be based on this alone.

The rate of change, adjusted to future design conditions, should be extrapolated to the service life to establish whether the "end-of-life" criterion will have been reached. Extrapolation should use a formula based on the degradation mechanism if one is available. If not, the simplest formula that fits the measurements should be used (Occam's principle). Power law relations are recommended; polynomials are not. Computer-assisted fits and predictions should be regarded with caution unless the basis for the calculation and its limitations are understood. Particular care should be taken in using logarithmic scales which condense long periods of real future time into conveniently short distances on a diagram. Current practice is to extrapolate by durations of up to ten times without penalty; extrapolation by larger amounts should incur a precautionary factor unless supported by other data — see, for example, ISO 20432:2007, Clause 10. The user should never forget how long a hundred years really is. Ultimately, he is the judge of what is acceptable.

8.5.4 Accelerated testing

8.5.4.1 General

Perform appropriate accelerated tests.

In accelerated testing, the rate of degradation is increased by increasing the frequency of the degrading agent, by increasing the severity of the agent causing degradation, or most commonly by changing the temperature. For stabilized materials, further acceleration is possible by intensifying the leaching process (e.g. evaporation, extraction, migration).

8.5.4.2 Increasing frequency

Increasing the frequency of the degrading agent is only possible when the agent is intermittent. The method is widely used in industry, for example automobile design. For geosynthetics, this method is only relevant in cases such as traffic loading and tidal surges, where the duration under actual load can be condensed into a period short enough for testing to be performed under conditions that are otherwise equivalent to those anticipated in service.

8.5.4.3 Increasing severity

Increasing the severity of the agent of degradation includes methods such as raising the chemical concentration, the availability of oxygen, the intensity of UV radiation (see 8.3.1) or the mechanical load. If the relation between the rate of degradation and the severity (or concentration) is known, then it may be possible to define a single test. If not, multiple tests should be performed in order to determine both the rate of degradation and its dependence on the intensity of the agent. In creep-rupture, for example, a range of high loads is applied to different specimens and the times to rupture monitored. A graph of load against time, or more commonly the logarithm of time, defines the time to rupture (the inverse of the rate of degradation) and how this time depends on load. The graph can then be extrapolated from the short lifetimes and high loads used in testing for the long lifetimes and lower loads applied in service, with the object of defining a design load corresponding to the service lifetime. For further details, see ISO/TR 20432.

8.5.4.4 Increasing temperature

Temperature is very widely used to accelerate both chemical and physical processes. Prediction of long-term degradation from accelerated tests is only valid if the mechanisms of degradation and failure are the same at all the test temperatures and the service temperature.

Extrapolation makes use of the Arrhenius formula,

$$A = A_0 \exp\left[-E/(R \cdot T)\right]$$

where

A is the rate of degradation;

A_0 is a constant;

E is the activation energy of the process, in J/mol;

R is the universal gas constant (8,314 J/mol·K);

T is the absolute temperature, in K (temperature in °C + 273,15).

Tests are set up at different temperatures and the rate of degradation, A, measured in each case. This "rate" may, for example, be a rate of diffusion, the inverse of the time to failure or the inverse of the time to halve the strength. The natural logarithm of the rate of degradation ($\ln A$) is then plotted against the inverse of the absolute temperature ($1/T$). If the points lie on a straight line, the line can be extrapolated to derive the rate of degradation at the service temperature. The gradient of the line is $-E/R$.

In planning Arrhenius tests, the maximum temperature is likely to be limited by a transition such as the melting point and the minimum temperature by the predicted duration of the test. Temperature steps should be no greater than 10 °C. When measurements are to be made at set time intervals, these should be spaced logarithmically. Reserve specimens should be installed in case the durations have to be extended. Planning Arrhenius tests is simpler if the answer can be estimated in advance.

It is generally recommended that the lowest test temperature should be not more that 20 °C above the design temperature, and that extrapolation over time should be by no more than a factor of ten. If this is not possible, generally because the duration of testing would be too long, then a safety factor should be applied to the predicted available property.

Temperature and load can be used simultaneously to predict creep-rupture, while time-temperature shifting is traditionally used to extrapolate creep curves. Details are given in ISO/TR 20432. Oxygen concentration and temperature can be used simultaneously to accelerate oxidation (ISO 13438:2004, Methods C1 and C2).

To confirm that the mechanisms of degradation are the same, any visible signs of degradation, such as failure surfaces, should appear identical. Cracking of the surface, for example, may represent an unacceptable change as the cracks increase the availability of oxygen; development of a barrier layer is likewise unacceptable for the opposite reason that it can restrict the flow of oxygen. There should be no kink in the graph used for extrapolation. There should be no phase transition, such as a glass transition temperature, between the service temperature and the maximum test temperature, unless it can be shown that the transition has no effect on the degradation (see 5.1.1). Antioxidants intended to protect a polymer during processing will be effective at higher temperatures, while others may extend the long-term durability at lower temperatures. For this reason, the measurement of oxidation induction time at high temperatures is useful for quality control but should not generally be used in predicting long-term degradation.

Where the property measured (e.g. intrinsic viscosity of a polyester) differs from the required property of the geosynthetic (e.g. strength), it will be necessary to establish the relation between the two properties that is valid over the range of times and temperatures covered.

Where there are two sequential processes, for example a stage during which the antioxidant in a polyethylene geosynthetic barrier is progressively consumed followed by a stage during which the tensile strength progressively reduces, it may be necessary to determine separate Arrhenius curves for each stage. In the first stage, the loss of stabilizer is monitored and, in the second stage, the loss of strength. The period for each stage to occur is calculated for the service temperature, and finally the two periods are added.

8.5.4.5 Examples of chemical degradation and accelerated testing

8.5.4.5.1 Oxidation

ISO 13438, the index test method for resistance to oxidation, applying in the first instance to polyolefins such as polypropylene and polyethylene, includes two alternative types of method with equal priority. In the oven tests (Methods A and B) temperature is increased alone; in the pressurized oxygen test (Method C), the material is placed in an aqueous solution, and heated under 5 MPa of oxygen, increasing both severity and temperature simultaneously. The advantages and disadvantages of each method are set out in an annex to the standard. After exposure to the test, the retained strength should exceed 50 % of the tensile strength of the reference samples.

As index tests, these test methods are believed to ensure 25 years' durability to normal soils and temperatures. The methods themselves can, however, be used more widely, in particular for the prediction of longer lifetimes of polyolefins by means of an Arrhenius diagram, for the assessment of other polymers, and for assessment of stabilized polymers. Since there are two sequential processes, the procedure described in the last section should be adopted: the first stage should be monitored by measuring the reduction in stabilizer content by chemical analysis, OIT or HP-OIT, and the second by measuring the reduction in strength or elongation. This is followed by determining separate Arrhenius curves for each stage. The standard OIT test suffices for most geosynthetics, but those containing hindered amine stabilizers may require the use of the HP-OIT test.

If oxygen concentration and temperature are used simultaneously to accelerate oxidation (ISO 13438:2004, Methods C1 and C2), the degree of acceleration can be established by performing tests over a range of different temperatures and pressures. A three-dimensional relation between rate of oxidation, pressure and temperature is then generated numerically and used to predict the rate of oxidation at the design temperature and at atmospheric oxygen partial pressure (0,21 bars). For example, tests can be performed at three different temperatures (e.g. 80 °C, 70 °C and 60 °C) at 50 bars of oxygen and two additional pressures (e.g. 10 bars and 20 bars of oxygen) at a single temperature. The time-dependent change in reference property should be determined by at least five different exposure durations for each set of conditions (total 25 tests). The composition (pH, ion content) of the aqueous medium used can be adjusted to the soil conditions of the application and environment considered and to the stabilizer system of the product used.

Extrapolation to the design temperature and pressure is performed by a modified Arrhenius plot using 3D regression analysis.

The state of degradation of the product tested during exposure can be characterized additionally, e.g. by determination of the carbonyl index, the peroxide content or the melt flow index. The state and content of the stabilizer can be determined by OIT, HP-OIT or chemical analysis.

8.5.4.5.2 Internal hydrolysis

Polyester fibres are susceptible to hydrolysis. This can be predicted by exposing the yarns to hot water and establishing an Arrhenius relation between time to a specific reduction in strength and temperature. The method described in EN 12447 can be extended to lower temperatures and longer times to yield an Arrhenius diagram (Schmidt et al. 1994).

If the yarns are coated in the final product, consideration should be given to testing the polyester yarns uncoated.

NOTE In soil that is not fully saturated, the rate of hydrolysis decreases approximately in proportion to the relative humidity.

8.5.4.5.3 Resistance to alkalis and acids under aerobic conditions

The methods described in EN 14030 for determining the acid and alkaline attack on geosynthetics can similarly be extended to lower temperatures and longer times to yield an Arrhenius diagram.

8.5.4.5.4 Resistance to biological effects

The high molecular weight synthetic polymers commonly used in geosynthetics are in general not affected by the action of fungi and bacteria (see 6.3.1). EN 12225 describes a test method which may be applied to determine whether a statistically significant loss of properties takes place over the duration of the test under conditions of maximum biological activity. The test does not set out to compare the rate of degradation under these maximum conditions with that on a specific site. The test is not required for virgin (not recycled) polyethylene, polypropylene, polyester (polyethylene terephthalate: PET) and polyamides 6 and 6.6, nor for other polymers whose biological resistance can be demonstrated. It may be applied to other materials including vegetable-based products, new materials, geocomposites, coated materials and any which are of doubtful quality.

A test should be performed for bituminous geosynthetic barriers. Studies have reported the aerobic degradation of oxidized bitumen by bacteria and moulds in soils by biological attack occurred under aerobic conditions and by biological degradation under different moisture conditions.

Resistance to burrowing animals requires the selection of a material of sufficient strength and toughness. It cannot be assessed by the methods appropriate to long-term durability.

8.6 Prediction of durability

8.6.1 Statement of the durability

The durability should be predicted for the material, its function and environmental conditions as defined in 8.1.2 and 8.2.1 to 8.2.6.

Examples of statements of durability are as follows. They relate to the available and required property or properties (see 4.2) corresponding to the function of the geosynthetic (see 8.2.2).

— No change in the available property is predicted at the end of the design life.

— A change in the available property is predicted at the end of the design life and the level is acceptable (see Figure 1).

— The ratio of the predicted available property to the predicted required property at the design life is acceptable (see Figure 2, Item 3).

— The margin between the design life and the predicted end of life is acceptable (see Figure 2, Item 5).

— The geosynthetic should be replaced after a stated number of years.

— A sample of geosynthetic should be extracted after a stated number of years to determine the level of degradation; a decision regarding replacement will depend on the result.

If results from both experience and accelerated testing are available and of similar quality, then the results of accelerated testing should be used to predict the rate of degradation for the known site conditions. This can then be compared with observation. If there is a discrepancy, the predictions from the accelerated tests should be adjusted to meet the observations on site. The results of experience should be given priority provided that they are defined with sufficient precision.

8.6.2 Level of confidence

State the confidence in the result. This should take into account the variability of the product as a whole; for example, a predicted strength should take into account the minimum strength acceptable to the manufacturer's quality assurance system. Estimates of statistical uncertainty based solely on the individual results measured may not be representative of production as a whole. Extrapolation should be restricted as described in 8.5.4.4.

If the level of confidence is low, for example when there is extended extrapolation or the results are of poor quality, then caution should be applied, for example by applying a higher safety factor in design or planning inspection intervals to check on the rate of degradation.

8.7 Planning for future inspection

If possible, install samples for future extraction and inspection.

Every prediction is an estimate. It can only take into account what is known about the material and its potential degradation. The methods above do not consider synergistic processes such as ESC. To provide for better information in the future, it is recommended that samples be installed with the deliberate intention of extracting them at set intervals in order to monitor the degradation. In doing so, reference should be made to ISO 13437 and the following should be noted.

— The properties to be monitored should be decided from the outset, as should the frequency of measurement, and the number and size of samples should be chosen accordingly. Where possible, the properties should be chosen so that they can be compared with the results of accelerated testing.

— The method of extraction should be planned from the start so as to minimize both disruption to the structure and damage to the samples.

— The influence of material variability should be controlled and minimized.

— The effect of mechanical damage on installation should be considered, for example by installing and then immediately extracting samples which will then have been subject to installation damage but not to long-term degradation.

— The location of samples should be clearly marked or set out on a plan.

— All records should be kept in a form such that they can be retrieved in many years' time.

— The environment should be monitored.

— Control material should be retained and stored in a suitable environment. In general, a cool and dark environment is recommended. Special environments may be considered for certain polymers.

In addition, it is possible to set up long-term laboratory tests on the material at temperatures that are elevated but require extensive time periods, for example 60 °C, 70 °C and 80 °C, and to monitor the rates of degradation. When these are established, the durability can be reassessed with a higher level of confidence.

Although the evidence from installed samples will not be available for many years, well-planned extractions will provide vital information in the future, particularly in warning of incipient loss of properties or of unexpected effects.

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TECHNICAL REPORT

ISO/TR 20432

First edition
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Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement

Lignes directrices pour la détermination de la résistance à long terme des géosynthétiques pour le renforcement du sol

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 20432 was prepared by Technical Committee ISO/TC 221, *Geosynthetics*.

Guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement

1 Scope

This Technical Report provides guidelines for the determination of the long-term strength of geosynthetics for soil reinforcement.

This Technical Report describes a method of deriving reduction factors for geosynthetic soil-reinforcement materials to account for creep and creep rupture, installation damage and weathering, and chemical and biological degradation. It is intended to provide a link between the test data and the codes for construction with reinforced soil.

The geosynthetics covered in this Technical Report include those whose primary purpose is reinforcement, such as geogrids, woven geotextiles and strips, where the reinforcing component is made from polyester (polyethylene terephthalate), polypropylene, high density polyethylene, polyvinyl alcohol, aramids and polyamides 6 and 6,6. This Technical Report does not cover the strength of joints or welds between geosynthetics, nor whether these might be more or less durable than the basic material. Nor does it apply to geomembranes, for example, in landfills. It does not cover the effects of dynamic loading. It does not consider any change in mechanical properties due to soil temperatures below 0 °C, nor the effect of frozen soil. The Technical Report does not cover uncertainty in the design of the reinforced soil structure, nor the human or economic consequences of failure.

Any prediction is not a complete assurance of durability.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 10318, *Geosynthetics — Terms and definitions*

3 Terms, definitions, abbreviated terms and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 10318 and the following apply.

3.1.1
long-term strength
load which, if applied continuously to the geosynthetic during the service lifetime, is predicted to lead to rupture at the end of that lifetime

3.1.2
long-term strain
total strain predicted in the geosynthetic during the service lifetime as a result of the applied load

3.1.3
reduction factor
factor (⩾ 1) by which the tensile strength is divided to take into account particular service conditions in order to derive the long-term strength

NOTE In Europe, the term 'partial factor' is used.

3.1.4
characteristic strength
95 % (two-sided) lower confidence limit for the tensile strength of the geosynthetic, approximately equal to the mean strength less two standard deviations

NOTE This should be assured by the manufacturer's own quality assurance scheme or by independent assessment.

3.1.5
block shifting
procedure by which a set of data relating applied load to the logarithm of time to rupture, all measured at a single temperature, are shifted along the log time axis by a single factor to coincide with a second set measured at a second temperature

3.1.6
product line
series of products manufactured using the same polymer, in which the polymer for all products in the line comes from the same source, the manufacturing process is the same for all products in the line, and the only difference is in the product mass per area or number of fibres contained in each reinforcement element

3.2 Abbreviated terms

CEG carboxyl end group

DSC differential scanning calorimetry

HALS hindered amine light stabilizers

HDPE high density polyethylene

HPOIT high pressure oxidation induction time

LCL lower confidence limit

MARV minimum average roll value

OIT oxidation induction time

PA polyamide

PET polyethylene terephthalate

PP polypropylene

PTFE polytetrafluorethylene

PVA polyvinyl alcohol

RF_{CH} reduction factor to allow for chemical and biological effects

RF_{CR} reduction factor to allow for the effect of sustained static load

RF_{ID} reduction factor to allow for the effect of mechanical damage

RF_{W} reduction factor to allow for weathering

SIM stepped isothermal method

TTS time-temperature shifting

3.3 Symbols

A_i	time-temperature shift factor
b_a	gradient of Arrhenius graph
d_{50}	mean granular size of fill
d_{90}	granular size of fill for 90 % pass (10 % retention)
f_s	factor of safety
G, H	parameters used in the validation of temperature shift linearity (see 7.4)
m	gradient of line fitted to creep rupture points (log time against load); inverse of gradient of conventional plot of load against log time.
M_n	number averaged molecular weight
n	number of creep rupture or Arrhenius points
P	applied load
R_1	ratio representing the uncertainty due to extrapolation
R_2	ratio representing the uncertainty in strength derived from Arrhenius testing
S_{sq}	sum of squares of difference of log (time to rupture) and straight line fit
S_{xx}, S_{xy}, S_{yy}	sums of squares as defined in derivation of regression lines in 9.4.3
σ_0	standard deviation used in calculation of LCL
t	time, expressed in hours
t_{90}	time to 90 % retained strength
t_D	design life
t_{deg}	degradation time during oxidation
t_{ind}	induction time during oxidation
t_{LCL}	LCL of time to a defined retained strength at the service temperature
t_{max}	longest observed time to creep rupture, expressed in hours
t_{n-2}	Student's t for $n - 2$ degrees of freedom and a stated probability
t_R	time to rupture, expressed in hours
t_s	time to a defined retained strength at the service temperature
T	load per width
T_B	batch tensile strength (per width)
T_{char}	characteristic strength (per width) (see 6.1)
T_x	unfactored long-term strength (see 9.4.3)

T_D	long-term strength per width (including factor of safety)
T_{DR}	residual strength
θ_j	temperature of accelerated creep test
θ_K	temperature
T_{LCL}	LCL of T_{char} due to chemical degradation
θ_s	service temperature
x	abscissa: on a creep rupture graph the logarithm of time, in hours
$\bar{x}$	mean value of x
x_i	abscissa of an individual creep rupture point
x_p	predicted time to rupture
y	ordinate: on a creep rupture graph, applied load expressed as a percentage of tensile strength, or a function of applied load
y_0	value of y at 1 h (log t = 0)
$\bar{y}$	mean value of y
y_i	ordinate of an individual creep rupture point
y_0	value of y at time 0, derived from the line fitted to creep rupture points

4 Design procedure

4.1 Introduction

The design of reinforced soil structures generally requires consideration of the following two issues:

a) the maximum strain in the reinforcement during the design lifetime;

b) the minimum strength of the reinforcement that could lead to rupture during the design lifetime.

In civil engineering design, these two issues are referred to as the serviceability and ultimate limit state respectively. Both factors depend on time and can be degraded by the environment to which the reinforcement is exposed.

4.2 Design lifetime

A design lifetime, t_D, is defined for the reinforced soil structure. For civil engineering structures this is typically 50 to 100 years. These durations are too long for direct measurements to be made in advance of construction. Reduction factors have therefore to be determined by extrapolation of short-term data aided, where necessary, by tests at elevated temperatures to accelerate the processes of creep or degradation.

4.3 Causes of degradation

Strain and strength may be changed due to the effects of the following:

- mechanical damage caused during installation;
- sustained static (or dynamic) load;
- elevated temperature;
- weathering while the material is exposed to light;
- chemical effects of natural or contaminated soil.

4.4 Design temperature

The design temperature should have been defined for the application in hand. In the absence of a defined temperature or of site specific in-soil temperature data, the design temperature should be taken as the temperature which is halfway between the average yearly air temperature and the normal daily air temperature for the hottest month at the site. If this information is not available, 20 °C should be used as the default value.

Many geosynthetic tests are performed at a standard temperature of (20 ± 2) °C. If the design temperature differs, appropriate adjustments should be made to the measured properties.

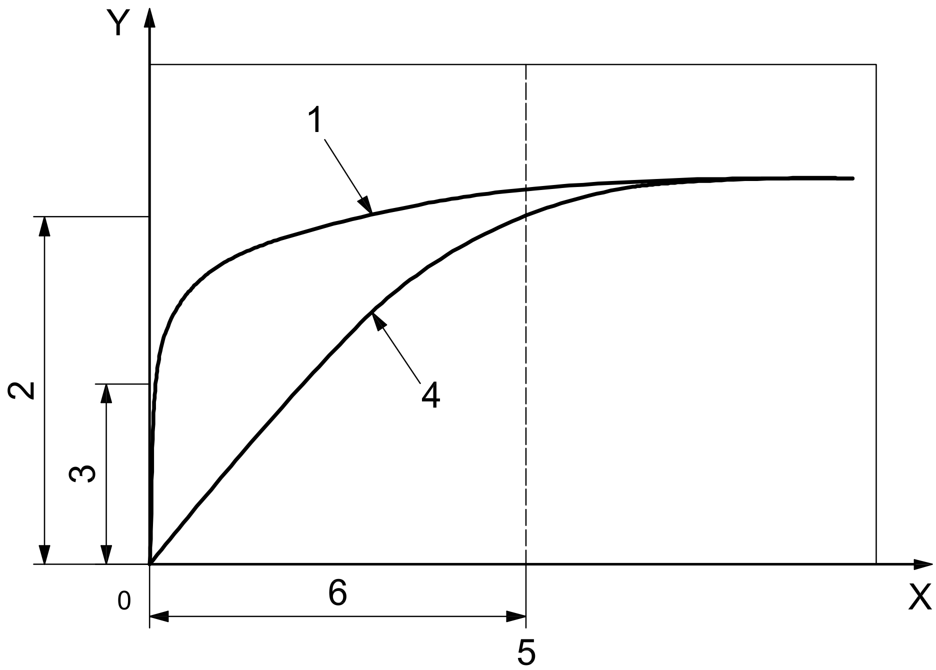
This Technical Report does not cover the effects of temperatures below 0 °C (see Clause 1).

5 Determination of long-term (creep) strain

5.1 Introduction

The design specification may set a limit on the total strain over the lifetime of the geosynthetic, or on the strain generated between the end of construction and the service lifetime. In the second case, the time at “end of construction” should be defined, as shown in Figure 1. When plotted against log t, even a one-year construction period should have negligible influence on the creep strain curve beyond 10 years.

Levels of creep strain encountered in the primary creep regime (creep rate decreasing with time) are thought not to adversely affect strength properties of geosynthetic reinforcement materials.



Key

1	Laboratory creep test	5	New time = 0 for post construction creep
2	Load ramp period on wall	6	Wall construction time
3	Load ramp period in creep test	X	Time
4	Loading and creep of reinforcement in wall	Y	Strain

Figure 1 — Conceptual illustration for comparing the creep measured in walls to laboratory creep data

5.2 Extrapolation

Creep strain should be measured according to ISO 13431 and plotted as strain against the log t. It may then be extrapolated to the design lifetime. Extrapolation may be by graphical or curve-fitting procedures, in which the formulae applied should be as simple as is necessary to provide a reasonable fit to the data, for example, power laws. The use of polynomial functions is discouraged since they can lead to unrealistic values when extrapolated.

5.3 Time-temperature superposition methods

Time-temperature superposition methods may be used to assist with extending the creep curves. Creep curves are measured under the same load at different temperatures, with intervals generally not exceeding 10 °C, and plotted on the same diagram as strain against log t. The lowest temperature is taken as the reference temperature. The creep curves at the higher temperatures are then shifted along the time axis until they form one continuous "master" curve, i.e. the predicted long-term creep curve for the reference temperature. The shift factors, i.e. the amounts (in units equivalent to log t) by which each curve is shifted, should be plotted against temperature where they should form a straight line or smooth curve. The cautions given in 7.6 should be noted.

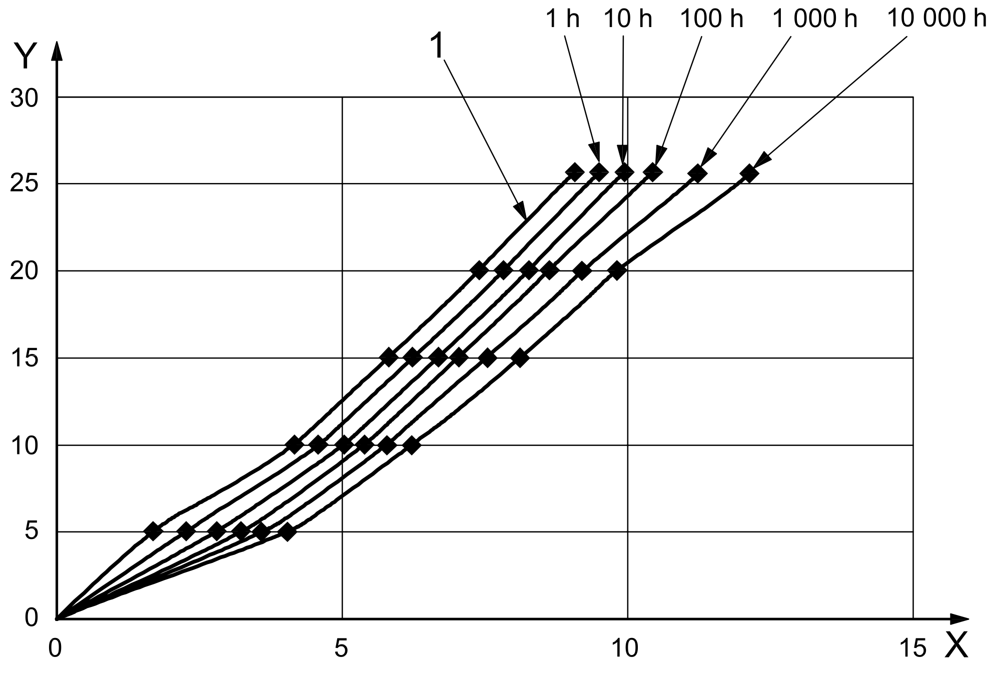
Experience has shown the strains on loading are variable. Since the increase in strain with time is small, this variability can lead to wide variability in time-temperature shifting (TTS). The stepped isothermal method (SIM) described in 7.5 avoids this problem by using a single specimen, increasing the temperature in steps, and then shifting the sections of creep curve measured at the various temperatures to form one continuous master curve.

If a more accurate measure of initial strain is required, five replicates are recommended at each load. Some of these can be of short duration, e.g. 1 000 s. At a series of loads, fewer replicates at each load will suffice if the data are pooled using regression techniques. One approach is to use regression analysis to develop an isochronous load versus strain curve at 0,1 h. The creep curve should then be shifted vertically to pass through the mean strain measured after 0,1 h.

If the lowest test temperature is below the design temperature, the shift factor corresponding to the design temperature should be read off the plot of shift factor against temperature. The time-scale of the master curve should then be adjusted by this factor.

5.4 Isochronous curves

From the creep curve corresponding to each load, read off the strains for specified durations, typically 1 h, 10 h, 100 h, etc., and including the design lifetime. Set up a diagram of load against strain. For each duration, plot the points of load against strain for the corresponding durations (see Figure 2). These are called isochronous curves. Where a maximum strain is permitted over the design lifetime, or between the end of construction (e.g. 100 h) and the design lifetime, it is possible to read off the corresponding loads from these curves. Where the strain is measured from zero, note that in geosynthetics strains are measured from a set preload (defined in ISO 10319 and ISO 13431 as 1 % of the tensile strength) and that some woven and particularly non-woven materials may exhibit considerable irreversible strains below this initial loading. See [2] in the Bibliography for additional details on creep strain characterization.



Key

X Strain

Y Load

Figure 2 — Isochronous diagram

5.5 Weathering, chemical and biological effects

Creep strain is generally insensitive to limited weathering, chemical and biological effects. In addition, creep strains are in general not affected by installation damage, unless the damage is severe, or unless the load level applied is very near the creep limit of the undamaged material. In most cases, the load level applied is well below the creep limit of the material. See [3] in the Bibliography for additional details on this issue. Thus, no further adjustment is generally required beyond the effect of temperature.

Note, however, that artificially contaminated soils may contain chemicals, such as organic fuels and solvents, which can affect the creep of geosynthetics. If necessary, perform a short-term creep test according to ISO 13431 on a sample of geosynthetic that is immersed in the chemical or has just been removed from it. If the creep strain is significantly different, do not use this geosynthetic in this soil.

6 Determination of long-term strength

6.1 Tensile strength

The characteristic strength, T_{char}, is taken as the basis for the long-term strength. T_{char} is typically a statistical value generated from the mean strength of production material less two standard deviations sometimes referred to as the minimum average roll value (MARV), unless otherwise defined.

6.2 Reduction factors

T_{char} can then be divided by the following four reduction factors, each of which represents a loss of strength determined in accordance with this Technical Report, to arrive at the long-term strength T_D:

— RF_{CR} is a reduction factor to allow for the effect of sustained static load at the service temperature;

NOTE The effect of dynamic loads is not included.

— RF_{ID} is a reduction factor to allow for the effect of mechanical damage;

— RF_W is a reduction factor to allow for weathering during exposure prior to installation or of permanently exposed material;

— RF_{CH} is a reduction factor to allow for reductions in strength due to chemical and biological effects at the design temperature (see 4.4).

In addition to the reduction factors, a factor of safety, f_s, takes into account the statistical variation in the reduction factors calculated (see 6.1). It does not consider the uncertainties related to the soil structure and the calculation of loads.

6.3 Modes of degradation

Degradation of strength can be divided into three Modes according to the manner in which they take place with time:

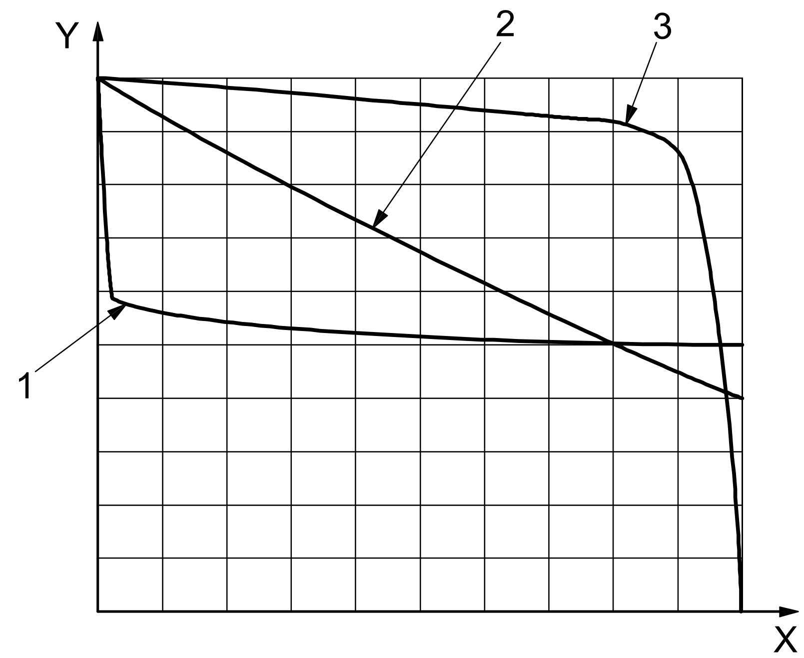
— Mode 1: Immediate reduction in strength, insignificant further reduction with time;

— Mode 2: Gradual, though not necessarily constant, reduction in strength;

— Mode 3: No reduction in strength for a long period; after a certain period, onset of rapid degradation.

For Mode 1, of which installation damage is an example, it is appropriate to reduce the tensile strength by an appropriate time-independent reduction factor. For Mode 2, where there is a progressive reduction in strength, the tensile strength will be reduced by a time-dependent reduction factor. For Mode 3, it is not appropriate to apply a reduction factor to the tensile strength but rather to restrict the service lifetime.

These Modes are depicted schematically in Figure 3.



Key

1 Mode 1

2 Mode 2

3 Mode 3

X Time

Y Retained strength

Figure 3 — Retained strength plotted against time for the three Modes of degradation

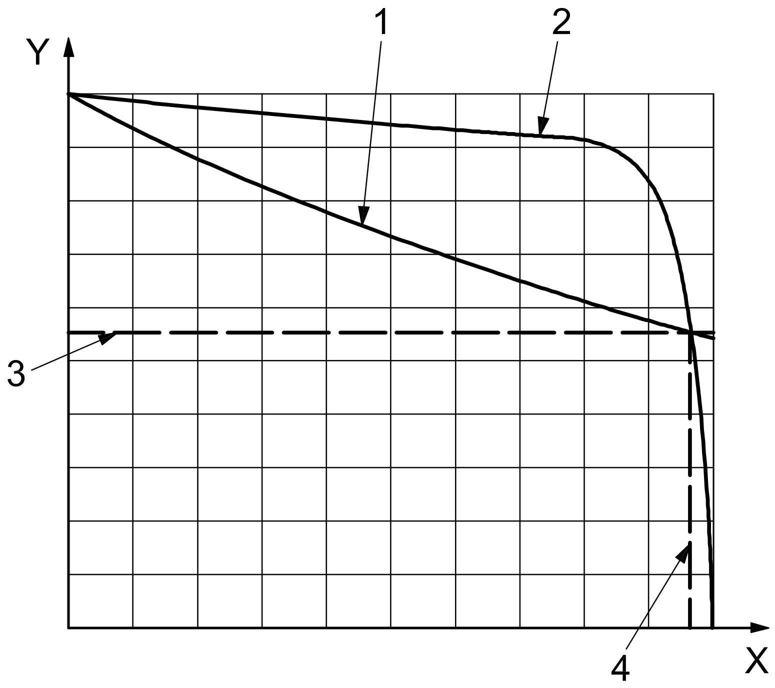
7 Creep rupture

7.1 Introduction

Creep rupture, or lifetime under sustained load, is determined by measuring times to rupture of up to at least 10 000 h. The results are extrapolated to predict longer lifetimes at lower loads and thereby the reduction factor RF_{CR}.

This procedure may be supported by measurements at higher temperatures. Conventional TTS of results obtained on multiple specimens at elevated temperatures provides an improved prediction of the long-term behaviour at ambient temperature. In the SIM, the temperature of a single specimen is increased in steps. The sections of creep strain curve measured at each temperature step are then combined to predict the long-term creep strain and rupture lifetime.

It should be noted that a creep rupture diagram depicts applied load plotted against time to rupture and is not a statement of the loss of strength under continuous load. It has been predicted on the basis of accelerated tests that many geosynthetics exposed to sustained load do not in fact significantly diminish in strength until close to the end of their predicted life. When the strength equals the applied load, the material ruptures (see Figure 4). Sustained load is therefore a Mode 3 form of degradation.



Key

1 Creep rupture

2 Residual strength

3 Applied load

4 Lifetime

X Time

Y Applied load, residual strength

Figure 4 — Creep rupture and residual strength as a function of time

The creep rupture curve shows the predicted lifetime corresponding to a particular applied load. During that lifetime, the strength of the geosynthetic follows the residual strength curve, falling to equal the applied load at the moment of rupture.

7.2 Measurement of creep rupture: conventional method

For limit state design, the creep rupture behaviour of the product should be measured according to ISO 13431 with a minimum of 12 measurements. As a guide, at least four of the test results should have rupture times between 100 h and 1 000 h, and at least four of the test results should have rupture times of 1 000 h to 10 000 h, with at least one additional test result having a rupture time of approximately 10 000 h (1,14 years) or more.

Specimens should be tested in the direction in which the load will be applied in use. The tensile strength of the same batch, T_B, of the material in the same direction should be determined according to ISO 10319 using grips similar to those used for creep rupture testing. Loads applied during the creep rupture tests should be expressed as a percentage of T_B. The nature of the failure should be observed and recorded.

It is recommended that creep strain is measured as well as time to rupture, since this can assist with conventional time-temperature strain shifting and in identifying any change in behaviour that could invalidate extrapolation of the results. This practice will also permit laboratory creep data collected at moderate differences (plus or minus 10 °C) in test temperature to be corrected to the desired reference temperature. Similar moderate changes in reference temperature will be facilitated under this practice as well.

The temperature should be as stated in ISO 13431 and ISO 10319; if a different temperature, for example, the design temperature, is used then it should be the same for both tensile and creep rupture measurements. Further tests at elevated temperature may be used for the purposes of TTS.

The creep rupture data for the product should be tabulated as:

— load per width T, as percentage of the batch tensile strength, T_B;

— time to rupture, t_R, in h;

— log t to rupture;

— observations on the failure, including the strain at failure or the strain at the point where the rate of creep starts to increase (tertiary creep) and, where visible, the nature of the fracture surface, e.g. ductile, semi-brittle or brittle and smooth;

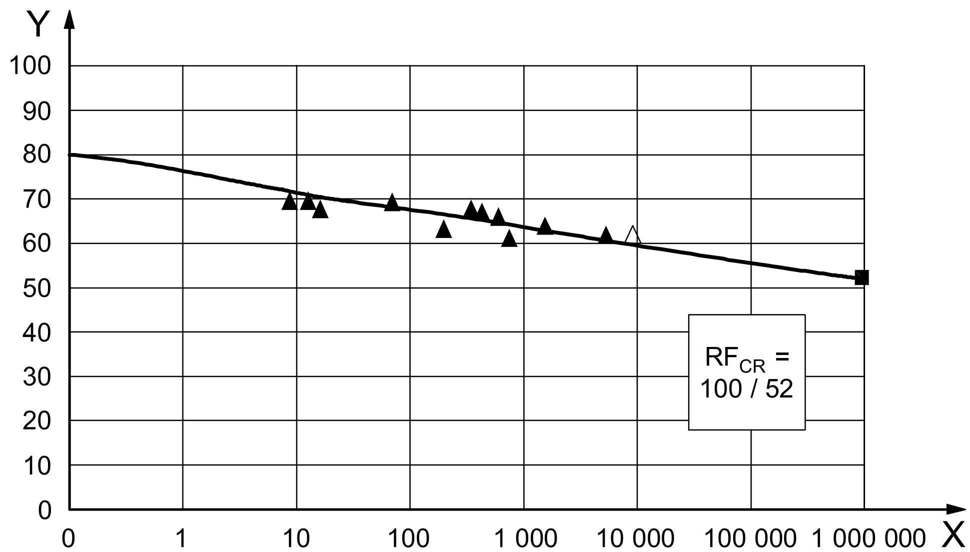
— creep strain data, if available, particularly if conventional time-temperature strain shifting is applied;

— whether the test was conventional (20 °C), time-temperature accelerated, SIM or was performed on a similar material as supporting data.

Incomplete tests may be included, with the test duration replacing the time to rupture, but should be listed as such. The procedure for handling incomplete tests is described in 7.3.

7.3 Curve fitting (conventional method)

The data, including any relevant supporting data, should be plotted as $y = T$ (expressed as a percentage of T_B) against $x = \log t_R$, which should yield a linear plot (see Figure 5). This is referred to as a semi-logarithmic plot and has been shown to apply to polyester reinforcements. If the plot is not linear, it may be necessary to plot the ordinate (y) as a function of applied load to achieve a linear plot. The use of the function $y = \log T$, resulting in a double logarithmic plot, has been shown to apply to polyethylene and polypropylene reinforcements. Where a function of T is used, it should preferably be based on a known physical model.



Key

X Time (h)

Y Load per width T, as % tensile strength

Figure 5 — Creep rupture diagram with straight line fit

Fit a straight line using statistical regression analysis. In the following, x equals log t_R and y equals T or a function of P. The creep rupture points, total number n, are denoted as (x_i, y_i). Note that in contrast to most scientific plots, the independent variable is plotted on the y axis and the dependent variable is plotted on the x axis. The formulae that follow therefore differ from those conventionally found by having x and y interchanged.

The straight line fit (regression line) is given by the formula:

$$x = \bar{x} + m(y - \bar{y})$$

where

$$\bar{x} = \frac{\sum x_i}{n} \quad \text{and} \quad \bar{y} = \frac{\sum y_i}{n}$$

summed over all points (x_i, y_i).

m is given by the formula:

$$m = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (y_i - \bar{y})^2}$$

Because of the interchange of x and y, the gradient of the graph is equal to $1/m$. For a semi-logarithmic diagram, this should be expressed as percentage tensile strength per decade of time. The gradient should be a negative value.

The intercept y_0 on the line x = 0 (i.e. at log t = 0; t = 1 h) is given by:

$$y_0 = \bar{y} - \bar{x} / m$$

The accepted practice for incomplete tests is as follows. The regression should first be performed with the incomplete tests excluded. The time to failure for an incomplete test should then be determined for the corresponding value of T. If the predicted time to failure is less than the duration of the incomplete test, the point may be added and the regression recalculated. If the predicted time to failure is greater than the duration of the incomplete test, the point should continue to be excluded. In Figure 5 the incomplete test shown by an open triangle is included since it lies to the right of the regression line.

Extend the regression line to the design lifetime, for example in Figure 5 where for a design lifetime of 1 000 000 h, T = 52 % of tensile strength. RF_{CR} = 1/52% = 100/52 = 1,92

Record the duration of the longest test that has ended in rupture, or the duration of the longest incomplete test whose duration has been included in the regression calculation: this duration is denoted as t_{max}.

7.4 Curve fitting for time-temperature block shifting of rupture curves

If data obtained at higher temperatures θ_i are to be included for the purposes of acceleration, tabulate the values of y_i and t_R as in 7.3 together with the temperatures θ_j. For each temperature θ_i, assign a nominal shift factor A_j. Assign nominal values to the constants y_0 and m. Include the test points derived at 20 °C for which A_i = 0. Then proceed as follows.

For each measured value of t_R, calculate the shifted log time x_i = log t_R + A_j.

For each value of y_i, calculate the logarithm of the predicted time to rupture $x_p = (y_i - y_0)m$.

For each pair of values, calculate the square of the difference $(x_i - x_p)^2$.

Derive the sum of squares $S_{sq} = \Sigma_i(x_i - x_p)^2$.

Using a spreadsheet optimization programme, minimize S_{sq} as a function of all A_j, y_0 and m.

Plot y_i against x_i and add the straight line fit as in 7.3.

Plot A_i against θ_i. Check that the line passes through the point (20 °C, 0) and is then straight or lightly curved, such that if the curve is approximated by the quadratic equation

$$A_j = G(\theta_i - 20) + H(\theta_i - 20)^2$$

then $-0{,}003 < G/H < 0{,}003$. If not, the validity of the tests should be reviewed.

For example in Figure 6, the regression creep rupture lines for 20 °C, 40 °C and 60 °C are assumed to be parallel. The 40 °C and 60 °C lines and associated points have been shifted to the right until they coincide with the 20 °C line to which they form an extension. Temperature steps $\leqslant$ 10 °C are recommended for PE and PP.

This procedure assumes that the creep rupture curves at all temperatures are linear and parallel, which has been found empirically to apply to polyester (semi-log plots) and polypropylene (log/log plots). It should be pointed out that the theory of Zhurkov [4] in the Bibliography, which assumes that the fracture process is activated thermally with the additional effect of applied stress, predicts that the creep rupture characteristics should be straight when plotted on a semi-logarithmic diagram, and that their gradients should be stress-dependent. This theory has not provided a better fit to experimental creep rupture data than the empirical method used here, but experience has shown that the shift factors can be stress-dependent and block shifting ignores this.

7.5 Strain shifting and the stepped isothermal method

Long-term rupture data can be obtained through the use of the classical TTS of creep strain data. Strain shifting as described in 5.2 can be applied to creep curves terminated in rupture. For example, a creep strain versus log t curve obtained under a given load at 60 °C and which terminates in rupture can be shifted to longer times. Needed to accomplish this are creep strain curves at, say, 20 °C and 40 °C under the same load. The lower temperature curves can be terminated before rupture provided that sufficient data are available to effect the TTS procedure properly. Because of the scatter in initial strains mentioned previously, the strain tests should be replicated.

In the SIM, which is a special case of TTS, the temperature of the creep test is raised in a series of steps. The sections of creep curve at the individual temperatures are then combined to form a continuous determination of the creep strain at the starting temperature. The time to rupture can also be determined. ASTM D 6992:2003 is recommended.

SIM can be considered for use in generating and extrapolating geosynthetic creep rupture data, provided that the predictions are consistent with those based on conventional testing or time-temperature block or strain shifting as described above. To this end, it is recommended that a minimum of 12 data points, time-shifted to the reference temperature, be obtained from accelerated (TTS and SIM) and conventional testing, with a minimum of

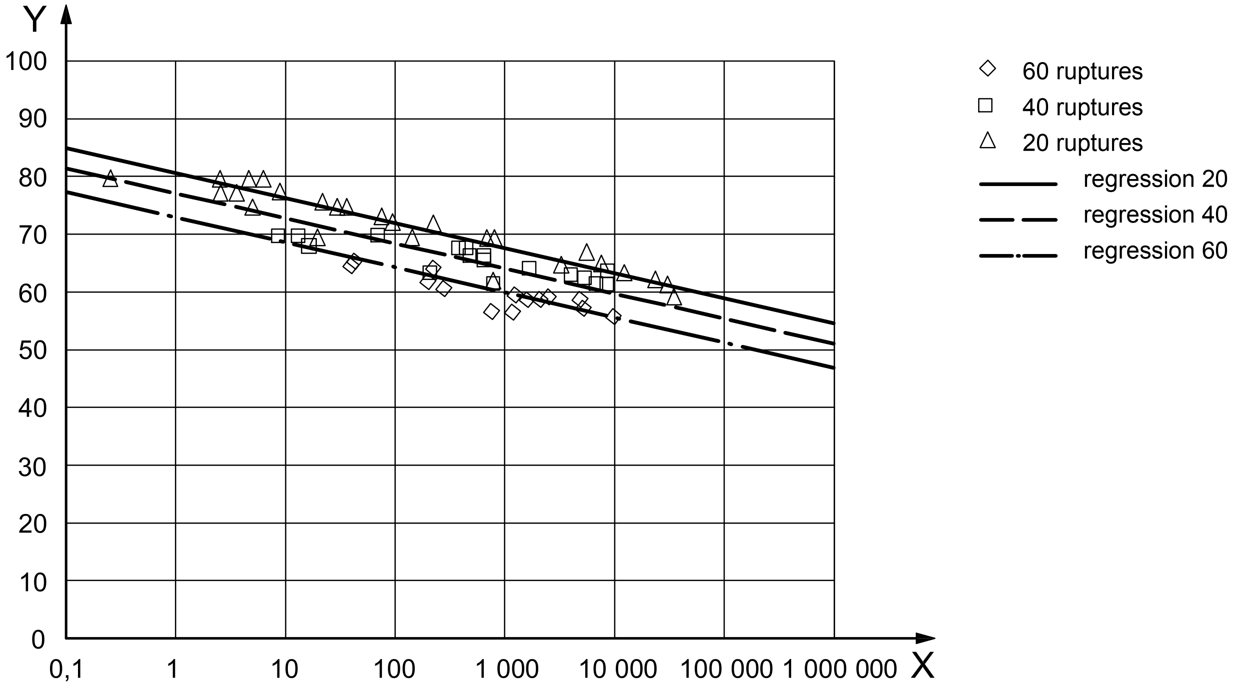
— three time-shifted durations between 1 000 and 100 000 h, and

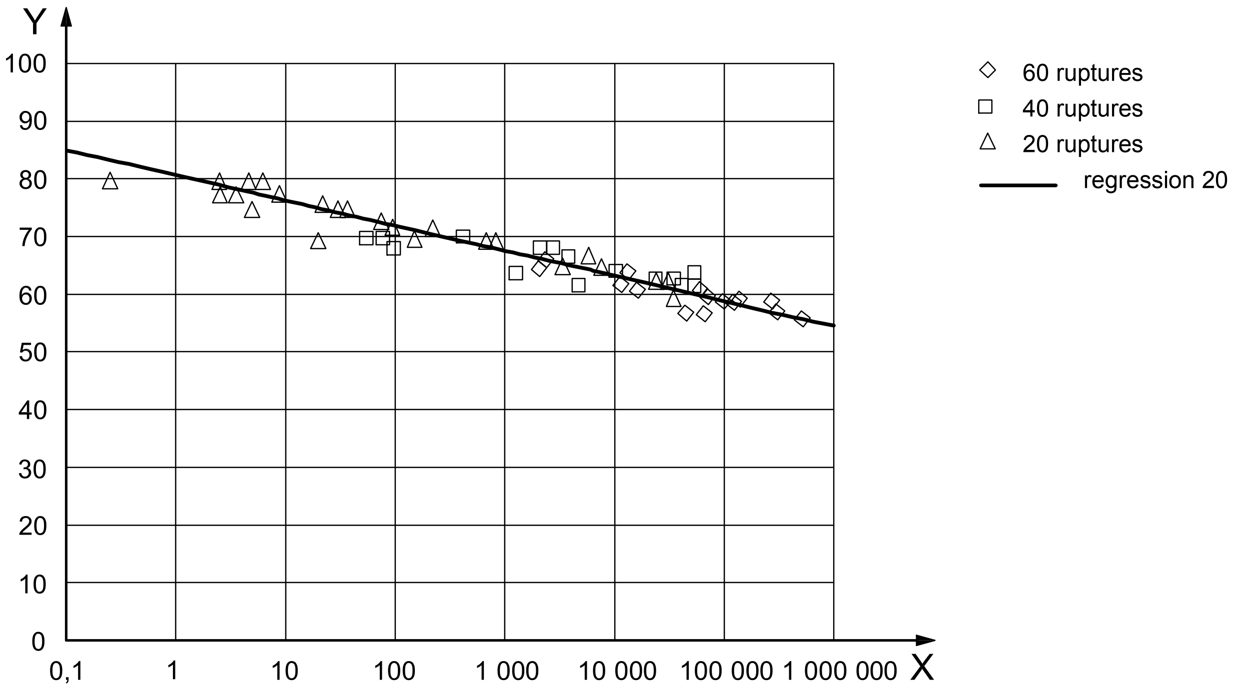
— three time-shifted durations between 100 000 and 10 000 000 h.

In addition, a limited programme of conventional creep rupture tests obtained at the reference temperature and therefore un-shifted (except as corrected per 7.2), should be performed in accordance with 7.2. It is recommended that there should be four conventional creep rupture data points between 100 h and 10 000 h and one data point at 10 000 h or more. (The last data point may be an incomplete test). This conventional creep rupture data envelope should then be compared to the envelope determined from the accelerated data.

Linear regression analysis should be performed separately for the conventional and accelerated data in accordance with 7.3 and 7.4. The value of RF_{CR} determined from the accelerated data at 2 000 h at the reference temperature should differ from the value of RF_{CR} determined from conventional data at 2 000 h at the reference temperature by no more than 0,15. Also the value of RF_{CR} determined from the accelerated data at 10 000 h at the reference temperature should differ from the value of RF_{CR} determined from conventional data at 10 000 h at the reference temperature by no more than 0,15. If both the conditions are fulfilled, the SIM data may be combined with the conventional data and used to determine RF_{CR}. If not, RF_{CR} should be determined from data from conventional testing alone (additional conventional data will be needed in this case).

The validity of SIM is supported by various publications [5-9] in the Bibliography.





Key

X Time (h)

Y Percentage tensile strength

Figure 6 — Block shifting

7.6 Extrapolation and definition of reduction factor or lifetime

Extrapolate the straight line fit to log t_D. Read off the corresponding percentage y from the formula $y = y_o - (\log t_D)/m$ (if y is a different function of load, derive the percentage accordingly).

Calculate $RF_{CR} = 100/y$. RF_{CR} should be greater than unity.

A condition of the extrapolation is that there is no evidence or reason to believe that the rupture behaviour will change over this duration. It should be checked that at long durations, and at elevated temperatures, if used:

— there is no abrupt change in the gradient of the creep rupture curve;

— there is no abrupt change in the strain to failure;

— there is no significant change in the appearance of the fracture surface.

Any evidence of such changes, particularly in accelerated tests, should invalidate the extrapolation unless it can be taken into account as described in the following example. Particular attention is drawn to the behaviour of unoriented thermoplastics under sustained load, where a transition in behaviour is observed in long-term creep rupture testing. The effect of this transition is that the gradient of the creep rupture curve steepens at the so-called “knee” such that long-term failures occur at much shorter lifetimes than would otherwise be predicted. The strain at failure is greatly reduced and the appearance of the fracture surface changes from ductile to semi-brittle. If this is observed, any extrapolation should assume that the “knee” will occur. For the method of extrapolation, reference should be made to ISO 9080:2003.

7.7 Residual strength

Creep rupture is Mode 3 degradation, resulting in little reduction in strength until the duration approaches the design life (see Figure 4). If the applied load is expected to be lower than T_{char}/RF_{CR}, it can be more appropriate to calculate the time to failure corresponding to the applied load and to check that this substantially exceeds t_D. On the basis of current measurements, it may then be assumed that the strength remains close to T_{char} over the design life. This is particularly relevant to seismic design and to other cases where a certain reserve strength has to be assured.

7.8 Reporting of results

The results should be reported as a graph of applied load (or a function of applied load) plotted against time to rupture in the manner of Figure 5.

The following should be stated:

— material;

— design lifetime;

— design temperature;

— T_{char};

— equation of the regression line $y = y_0 - x/m$;

— RF_{CR}.

7.9 Procedure in the absence of sufficient data

Long-term creep data obtained from tests performed on older product lines, or other products within the same product line, may be applied to new product lines, or a similar product within the same product line, if one of the following conditions is met.

- The materials and structure of the proposed product are similar to those of the tested product. Data should be provided which shows that the minor differences between the tested and the untested products will result in equal or greater creep resistance for the untested products.
- The results of a limited testing programme on the proposed product are not significantly different from those predicted from the data on the tested product. For creep evaluation, this limited testing programme should include creep tests taken to at least 1 000 h to 2 000 h in length.
- If SIM is accepted for the previously tested product, then SIM can be used exclusively on the proposed product or products. In this case, the SIM tests should be concentrated in the 100 000 h to 10 000 000 h time window for maximum statistical efficiency. Three SIM tests should be sufficient for each proposed product.

Similarity can be judged on the following.

- Equivalence of polymer structure, molecular weight, carboxyl end group count (CEG) cross-linking, crystallinity and draw ratio. It should be noted that per cent crystallinity is not a controlled property and there is presently no indication of what an acceptable value for percent crystallinity should be. For the method of determining CEG, see 9.4.5.2.
- Tensile strength per identifiable unit such as single rib or yarn. Tests performed on single ribs or yarns should, however, be shown to be representative of the material as a whole.
- Polymer additives used (i.e. type and quantity of antioxidants or other additives used).
- Textile (weave, style of non-woven, grid) and yarn structure, and fibre diameter.

NOTE Not all properties apply to all materials.

The data provided should show that the performance of the new or similar product is equal to or better than the performance of the product previously tested. If so, the results from the full testing programme on the older or similar product could be used for the new/similar product. If these conditions are not met, then a full testing and evaluation programme for the new product should be conducted.

Single ribs for geogrids or yarns for woven geotextiles may be used for creep testing for ultimate limit state design provided that it can be shown, for example, by a creep testing programme similar to the conventional creep tests defined in 7.5, that the rupture behaviour and envelope for the single ribs or yarns are the same as that for the full product.

If the procedures described in this section are applied, then this should be noted in the statement of the corresponding reduction factors.

8 Installation damage

8.1 General

Coarse backfills and heavy compaction loads can damage geosynthetics, causing an immediate reduction in strength. The effect is referred to as installation damage and the corresponding reduction factor as RF_{ID}.

Generally, the mechanical damage occurs on installation (Mode 1). If significant further damage is likely to occur in use, there will be an additional time-dependent contribution to this factor.

8.2 Data recommended

Measurement of the effect of installation damage on geosynthetic reinforcement strength and deformation should be determined from the results of installation damage tests. General guidance is given ISO 13437 and BS 8006,1995, Annex D. The installation damage tests should simulate the installation conditions (conditions of service) as closely as practicable to the installation conditions anticipated in the geosynthetic structure. The installation conditions to be simulated should include, as a minimum:

— the nature of the backfill both below and above the sample: particle size distribution, hardness and angularity;

— the depth at which the sample is installed;

— whether the material is driven over by vehicles before compaction;

— method and degree of compaction.

Test results from damaged specimens should be compared to tensile test results obtained from undamaged (i.e., not exposed to installation conditions) specimens taken from the same lot, and preferably the same roll, of material as the damaged specimens.

The specimens should be large enough to be used for wide-width tensile testing (ISO 10319). Consideration should be given to increasing the number of specimens to ensure that they are fully representative of the damaged material. It is desirable that multi-rib tests, with at least four ribs, should be used for installation damage evaluation. With single rib testing it can be difficult to assess the effect of severed ribs on the strength and modulus of damaged materials, and the effect of differences in degree of damage between ribs on the overall tensile strength of the product. Single ribs of geogrids are generally unsuitable for installation damage testing. If this cannot be avoided, for example, for very high strength materials, then it should be demonstrated that the strength of the single ribs is representative of the full product.

Further information is given in [10] in the Bibliography.

8.3 Calculation of reduction factor

The reduction factor to allow for the effect of mechanical damage for the site conditions used, RF_{ID}, should be expressed as the ratio of the mean tensile strength of the undamaged material to the mean tensile strength of the damaged material.

8.4 Procedure in the absence of direct data

8.4.1 General

In the absence of site-specific data obtained in accordance with 8.2, one of the approaches in 8.4.2, 8.4.3 or 8.4.4 can be taken.

8.4.2 Interpolation from measurements with different soils

If the RF_{ID} of the material under consideration is known for other soils with grain size both less than and greater than the soil to be used, then RF_{ID} should be determined by interpolation using the values of d_{50} or an alternative such as d_{90} for the respective soils to obtain RF_{ID} for the soil in question. It is recognized that this is only an approximation, particularly for soils with a broad particle distribution, and other soil gradation characteristics may be considered for interpolation purposes if it can be shown that they produce a more accurate correlation than the d_{50} size. An example of this interpolation procedure to obtain RF_{ID} at a different soil d_{50} is provided in Figure 7, which shows the interpolation of RF_{ID} for a soil with d_{50} equalling 2 mm from measurements made with soils with d_{50} equalling 0,02 mm, 0,5 mm and 10 mm.

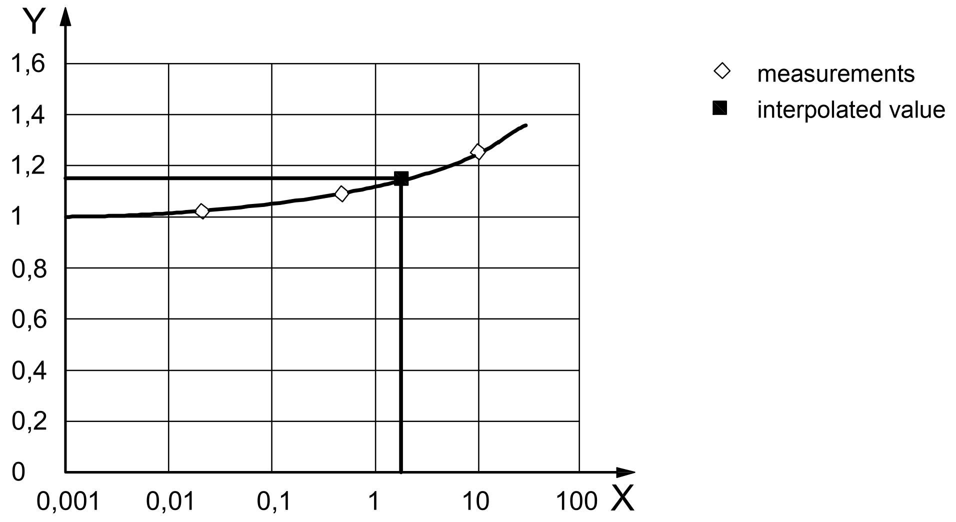
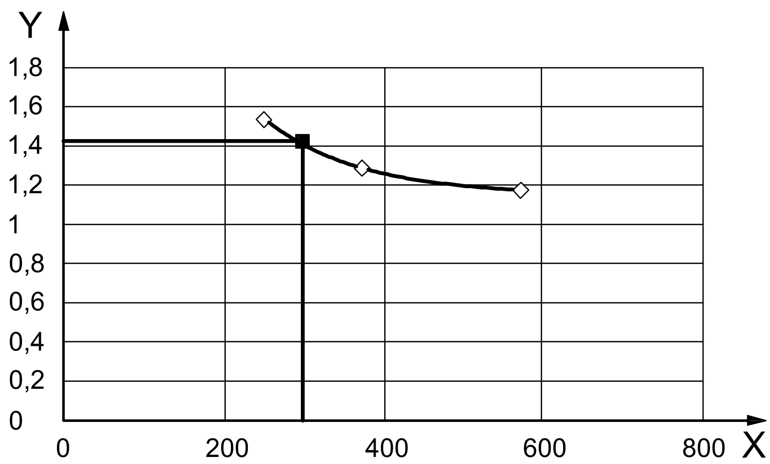


Figure 7 — Interpolation of RF_{ID}

8.4.3 Interpolation between products of the same product line

This interpolation may also be made for other products within the product line of the subject product, provided that a relationship can be established between the weight, tensile strength, etc. of the product and the RF_{ID} of the product as in Figure 8, and provided that data are available for products which are both lighter (weaker) and heavier (stronger) than the product in question. For products that are heavier (stronger) than the heaviest product tested, the RF_{ID} for the heaviest product tested may be used. For coated polyester geogrids, the coating thickness or coating mass per area relative to the mass per area of the product should be considered for the purpose of correlating RF_{ID} between products rather than product weight or tensile strength alone. In Figure 8 for a product of weight 300 g/m^2, RF_{ID} = 1,42.



Key

X Product weight, g/m^2

Y Reduction factor RF_{ID}

Figure 8 — Interpolation of RFID from damage measurements on products from the same line but with different weights

8.4.4 Laboratory damage tests

It should be noted that ISO 10722 is intended as an index test for comparative purposes and should not be used for the derivation of reduction factors for geosynthetic soil reinforcements.

9 Weathering, chemical and biological degradation

9.1 Introduction

Polymers are susceptible to environmental degradation due to weathering, including exposure to ultraviolet light, to chemical attack and to biological attack. All three effects are further influenced by temperature and, for some polymers, by moisture uptake. The durability of geosynthetic reinforcements is improved by their high degree of orientation and high molecular weights, while for polyolefins in particular the principal reason is the inclusion of special additives.

Environmental degradation can lead to degradation by Modes 1, 2 and 3. Weathering on site before a geotextile is covered can be regarded as Mode 1, while the weathering of geotextiles permanently exposed should be regarded as Mode 2. For chemical degradation, the preferred approach is to restrict the service lifetime to the period over which no significant reduction in strength is predicted. This is, however, not always possible, and for the hydrolysis of polyesters, which takes place continuously (Mode 2) a time-dependent reduction factor should be determined.

Two reduction factors are defined: RF_W for weathering and RF_{CH} for chemical and biological degradation. Allowances for statistical scatter and uncertainty are made by means of a separate factor of safety, f_s.

9.2 Data recommended for assessment

It is recommended that the following data be provided.

- Statement of principal polymers used.
- Evidence of the resistance of these polymers to weathering (for example EN 12224) and to chemical degradation, in particular to hydrolysis and oxidation in aqueous solutions with or without the presence of oxygen. For polyesters, a statement may be made of the number averaged molecular weight (M_n) and of the carboxyl end group count (CEG).
- A statement that post-consumer recycled material is not used.
- Predicted exposure to daylight: duration, location and season.
- Effective design soil temperature (see 4.4).
- Soil pH.
- A statement of any non-natural contaminants in the soil, e.g. industrial waste.
- Any unusual biological hazards such as termites.

9.3 Weathering

All polymers can degrade when exposed to ultraviolet light, although stabilizing additives will normally have been added to materials intended for outdoor use. In this Technical Report, “weathering” will be taken as applying solely to the effects of ultraviolet light, either alone or together with temperature and water spray.

The recommendations for weathering are related to the duration of exposure during storage and on site. If the geosynthetic is exposed to ultraviolet light for a maximum of 12 h, no reduction factor need be applied. If the exposure time is longer, then the geosynthetic should undergo an accelerated weathering index test such as

EN 12224. If the loss of strength is no greater than 5 % or is not statistically significant, no reduction factor is applicable. This is on condition that the installer covers the geosynthetic within one month.

Any geosynthetic reinforcement showing a greater loss of strength should not be exposed on site for longer than the duration shown in Table 1, and a reduction factor RF_W should be applied.

Table 1 — Installation exposure period

Retained strength after testing according to EN 12224	Maximum exposure time (uncovered) during installation	Reduction factor RF_W
> 80 %	1 month [a]	Ratio of tensile strength of unexposed material to that of exposed material
60 % to 80 %	2 weeks	1,25
< 60 %	1 day	1,00
Untested material	1 day	1,00

[a] Exposure of up to four months may be acceptable depending on the season and location.

For a range of products identical except for mass per area, it is sufficient to subject only the product with the lowest mass per area to the test. The results of the test may be applied for the other products in the range, unless they have been tested separately.

If the geosynthetic is to be exposed to light for longer than one month, then it should be tested according to EN 12224 or a similar method for a duration such that extrapolation of the radiant exposure to that expected in service can be justified. The radiant exposure (ultraviolet radiation) in EN 12224 is 50 MJ/m^2, corresponding to approximately one summer month’s exposure in southern European or central North American latitudes. The strength retained after the full radiant exposure should be predicted. RF_W should be set equal to the ratio of the strength of the unexposed material to that predicted for the exposed material.

9.4 Chemical degradation

9.4.1 Causes of chemical degradation

The principal causes of chemical degradation of polymeric geosynthetics in the soil are described in ISO/TR 13434. The following is a summary.

The principal cause of degradation of polyester geosynthetics (which consist of polyethylene terephthalate (PET) is by hydrolysis. The rate of hydrolysis is slow at typical soil temperatures but increases rapidly as the temperature is raised. The rate can be less if the polyester is fully coated, but this is discounted since the coating may become damaged by the installation process in the ground. Since PET wicks moisture quite well, any exposure of the fibres due to coating damage could result in hydrolysis at the rate which would occur if the coating was not present. The rate of hydrolysis will be less if the soil is partially instead of fully saturated, but is not zero. Alkaline liquids with $pH \geqslant 9$ can, in addition, erode the surface. Polyester reinforced geosynthetics should not be used in natural or industrially polluted soils where $pH > 9$ is maintained unless proof of their durability can be provided.

The principal cause of degradation of polypropylene and polyethylene is oxidation, also resulting in chain scission, reduced molecular weight and strength loss. Other effects are embrittlement, surface cracking and a change in colour. Oxidation of these materials is a chain reaction whose chemistry is complex but quite well understood. The reaction may be started by ultraviolet light or by heat, and may be accelerated by catalysts such as ions of heavy metals, including iron. The resistance of these materials to oxidation is improved dramatically by the addition of a selection of antioxidant stabilizers which can extend the lifetime by hundreds or thousands of times. Ultimately, the antioxidant is consumed by oxidation, if it has not been lost prematurely by migration, evaporation or leaching. Assessment of the rate of oxidation is complex and is further described in 9.4.4.

Polyamides can degrade by either mechanism. Aliphatic polyamides such as PA 6 are susceptible to thermal degradation, oxidation, ultraviolet radiation, acid or alkali attack causing chain scission and by hydrolysis through contact with water at elevated temperatures. They are stabilized by copper salts, aromatic amines and hindered phenolic antioxidants which all act as heat stabilizers. Hindered phenol antioxidants are the most effective as they also resist thermoxidative degradation. Aromatic polyamides such as aramids are more resistant than PA 6 to degradation by oxidation, acids, alkalis and hydrolysis but are susceptible to ultraviolet degradation. Stabilization of these polyamides is effected by adding chlorine and nitro substituents into the recurring structural unit of the polymers.

Lifetime prediction can be based on evidence from service or from accelerated testing. In some cases, there is sufficient experience to define index tests that will assure a certain minimum level of durability.

9.4.2 Evidence from service experience

The rate of degradation, or evidence for lack of degradation, can be based on results of analysis of specimens of the product exposed to a comparable environment and then exhumed, or of products with a similar physical structure and chemical formulation and including the same additives.

The plan of exhumation and testing should be in accordance with ISO 13437. The following additional points should be noted.

— The observation period should be of sufficient length for extrapolation to the full design life to be justified. This justification is particularly important when rapid degradation follows a long incubation period, or when degradation takes place in a series of separate stages (e.g. 9.4.4.3). Service experience of at least 10 years may be necessary for extrapolation to a service life of 50 to 100 years for PET geosynthetics. Longer periods of time may be needed for polyolefins due to the presence of antioxidants, as no loss in strength will be observed until the antioxidants are used up. Without knowing how long this will take, it is impossible to predict lifetime.

— Generally, a minimum of three retrievals are to be made (i.e., the first retrieval is taken right after installation, the second retrieval is taken at some time during the middle of this period, and the third retrieval is taken at the end of the study period).

— Enough specimens for each retrieval should be taken into account for statistical variability in the properties measured. For a more detailed description, see [11] in the Bibliography.

— The polymer and physical characteristics of the exhumed material should meet the recommendations for “similar” products in 7.9.

An assessment and lifetime prediction should then be made on the basis of this evidence. For a more detailed description of the issues that should be considered when evaluating results from service experience, see [2], [11] and [12] in the Bibliography.

9.4.3 Accelerated chemical degradation tests

The rate of degradation can be estimated using accelerated testing, in which either temperature or chemical concentration, or both, is increased in order to accelerate the rate of reaction. The relation between the rate of degradation under service conditions to that during accelerated testing can be derived from chemical rate kinetics or from Arrhenius’ equation. Take care that the conditions during the accelerated tests are representative of those in service. There should be no change in the mechanism of degradation or in the physical structure of the material; and no barrier layers should form or be present that might retard the degradation process in a manner that does not occur in service.

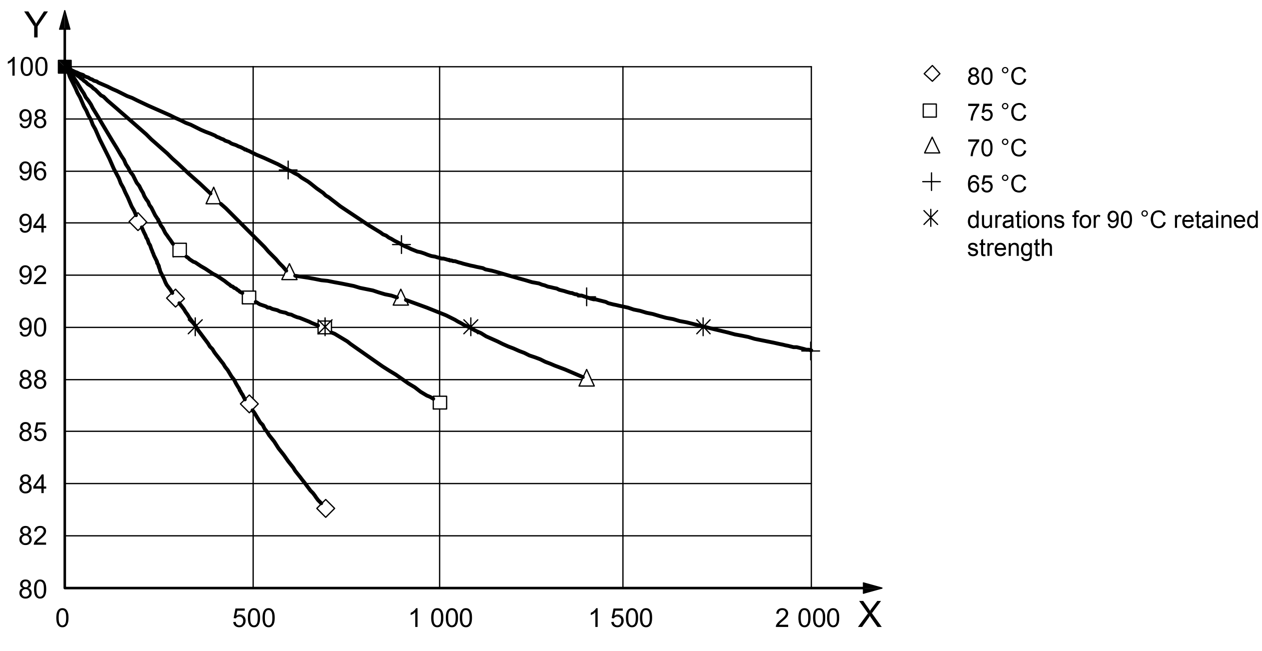
In such a programme, carry out the following procedures.

— Select the parameter to be measured, for example, a level of retained strength such as 90 %, 80 %, 70 %, 60 % or 50 %. If experience has shown that another physical or chemical quantity, such as CEG, gives more precise results, then this may be used instead, provided there is an established relationship between the parameter measured and the strength. It is important that the degradation can be observed and measured; if not, the degree of acceleration cannot be ascertained.

— Decide on the environment: pure water, air or a special chemical environment. If the geosynthetic is to be placed in a natural soil with pH $<$ 4 or $>$ 9, or in a soil with non-natural contaminants, e.g. industrial waste, immersion tests should be performed in liquids with corresponding chemical composition and extrapolated to the corresponding design soil temperature, chemical composition and service life. ISO/TR 12960 describes a method of immersion. In testing with alkaline solutions, care should be taken to reduce conversion of hydroxide to carbonate ions by reaction with atmospheric carbon dioxide.

— Select a range of at least three to four temperatures, spaced typically at 10 °C intervals. The lowest test temperature should ideally be not more than 25 °C above the service temperature, allowing for the fact that the test duration at this temperature has to lie within the time-scale of the test programme. This can extend for as long as four years. Caution is advised if any transition occurs in the physical state of the polymer or the mechanism of degradation less than 10 °C above the highest test temperature, or between the lowest test temperature and the service temperature. A glass transition occurs in the range of 50 °C to 80 °C in polyester and crystalline melting in high density polyethylene (HDPE) takes place at a range of temperatures, peaking at 128 °C. Furthermore, drawn polyethylene tends to lose its orientation at temperatures of around 70 °C. If a transition is present, then it should be demonstrated that it leads to no significant change in the rate of degradation, for example by confirming that the Arrhenius plot is a straight line.

— Measure the reduction in strength (or other parameter) over time at each of a range of temperatures. To do this, expose groups of samples over a range of times at each temperature. Include spare sets for exposure over longer times in case the rate of reduction in strength is less than predicted. Note that full wide-width specimens are preferred for this testing; however, single rib or yarn specimens can be used if necessary. Plot the retained strength against time and determine either the rate of change or, by interpolation, the exact times to the desired retained strength (Figure 9). In Figure 9, the durations for 90 % retained strength are interpolated from the lines, noting that these are often irregular in shape. Examine each test sample for any change in the nature of degradation or of failure, for example, the growth of a barrier layer on the surface or circumferential cracking on the fibre surface, or increased ductility as evidenced by the geosynthetic modulus and peak strain at the higher temperatures. Scanning electron microscopy is a useful aid to this purpose. If a change is observed, only those results should be retained which are regarded as being representative of long-term degradation. If process of degradation comprises two or more separate stages, separate extrapolations should be made for each stage.



Key

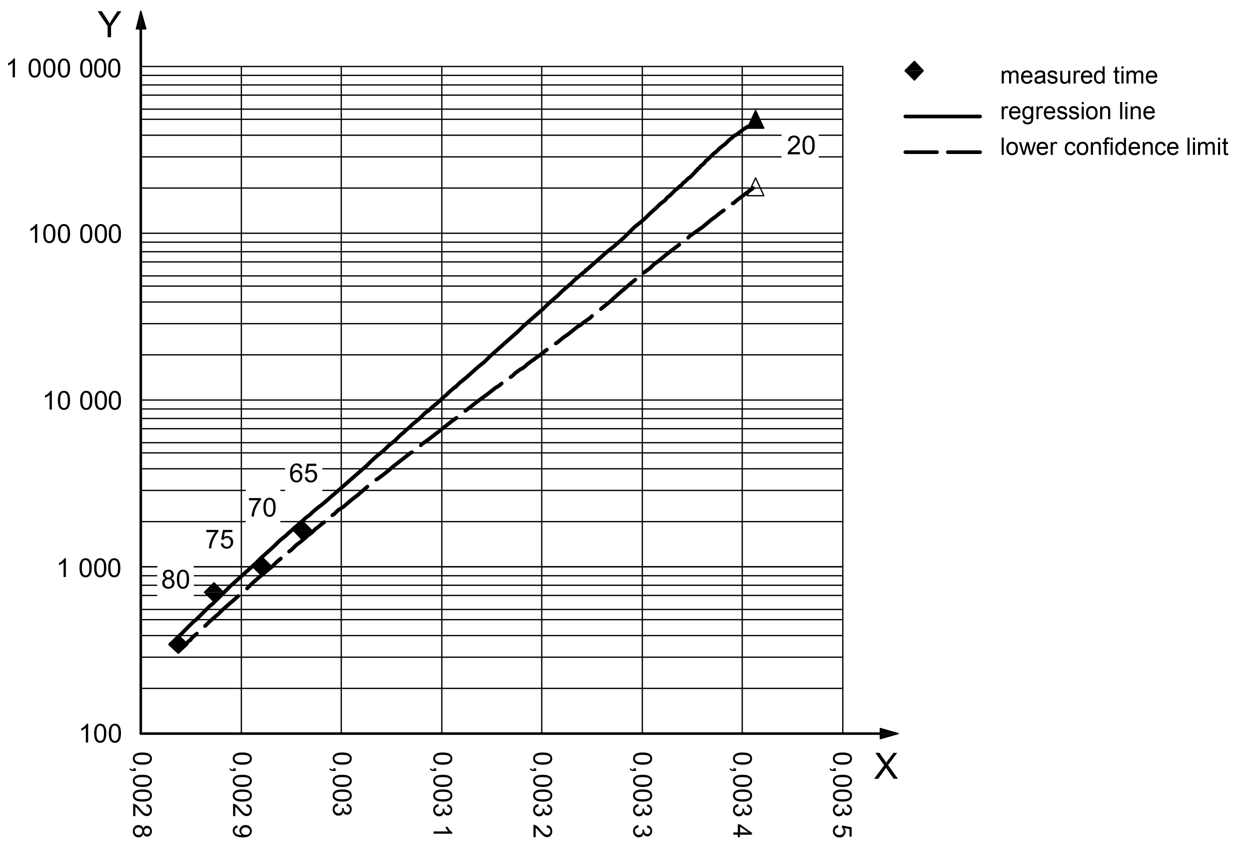
X Time (h)

Y % retained strength

Figure 9 — Reduction in strength at selected temperatures prior to application of Arrhenius' formula

— The number of specimens taken at each retrieval for testing may need to be greater than what is required for testing of the unaged material. This is because the degradation may lead to additional variability in the strength.

— Plot the times to a particular retained strength or other parameter against the inverse of the absolute temperature θ_K in K (see Figure 10). If Arrhenius' formula applies this plot should be a straight line. If it is not a straight line, then the order of the chemical reaction may be different (for the procedure, see [13] in the Bibliography, or a transition may have occurred within the range of test temperatures selected as discussed above. If no straight line is obtained, then Arrhenius' formula does not apply and extrapolation is invalid.



Key

X Inverse absolute temperature (1/K)

Y Time to 90 % retained strength (h)

Figure 10 — Arrhenius diagram

— Calculate the equation of the straight line, with $y = \log t_{90}$ and $x = 1/\theta_j$, as:

$$y = \bar{y} + b_a (x - \bar{x})$$

where

$b_a = S_{xy}/S_{xx}$;

$S_{xx} = \Sigma (x - \bar{x})^2$;

$S_{yy} = \Sigma (y - \bar{y})^2$;

$S_{xy} = \Sigma (x - \bar{x})(y - \bar{y})$.

— Calculate the lower confidence limit (LCL) of the line:

$$y = \bar{y} + b_a (x - \bar{x}) - t_{n-2}\, \sigma_0 \sqrt{[1 + 1/n + (x - \bar{x})^2/S_{xx}]}$$

where

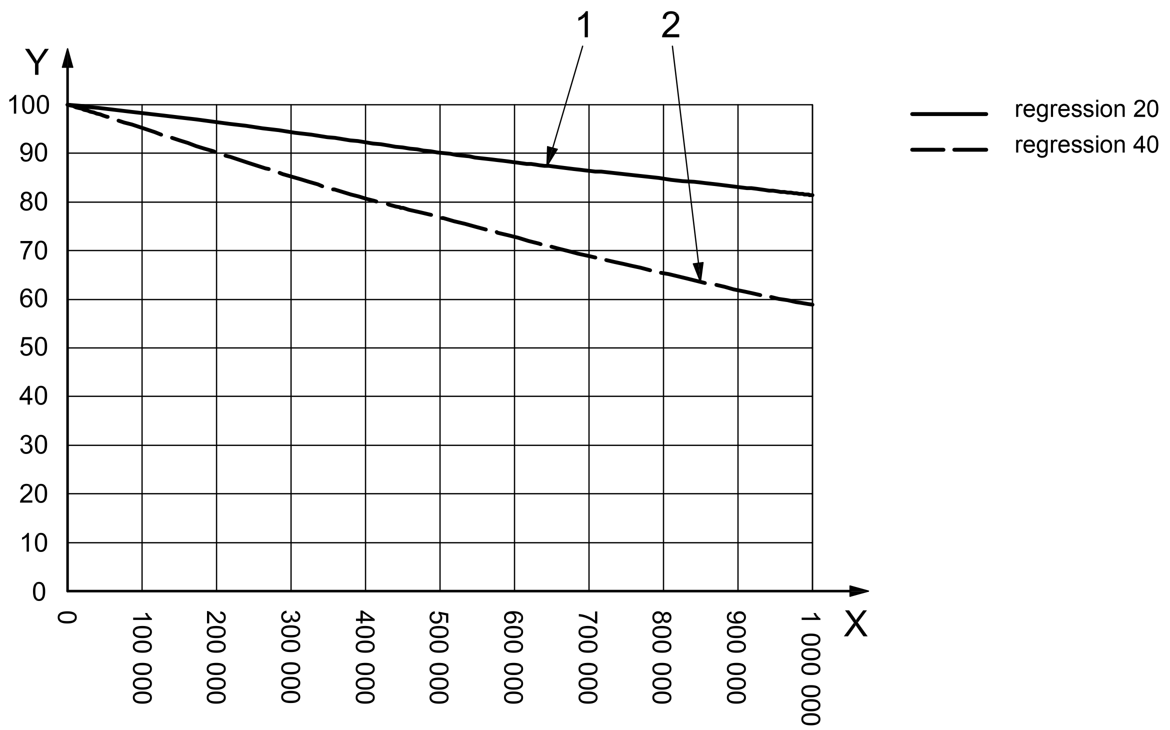
t_{n-2} is the Student's t for $n - 2$ degrees of freedom and a stated probability;

n is the number of Arrhenius points;

σ_0 is the $\sqrt{[(S_{yy} - S_{xy}{}^2/S_{xx})/(n - 2)]}$.

— Plot these lines as in Figure 10; from the regression line read off the time t_s to the defined retained strength at the service temperature $x = 1/\theta_s$ (noting particularly if this exceeds 25 °C); from the lower confidence limit read off the time t_{LCL}; in Figure 10, these two values are 516 000 h and 199 000 h respectively. Such large differences are typical of logarithmic scales.

— Using the shape of the observed degradation curves as a guide, plot the shape of the degradation curve such that the defined retained strength is reached after time t_s (Figure 11). Read off the unfactored long-term strength per width T_x (expressed as a percentage of the batch tensile strength) after the design life t_D. $RF_{CH} = 100/T_x$. Make a similar plot for t_{LCL} and derive the LCL T_{LCL}. The ratio $R_2 = T_x/T_{LCL}$. In Figure 11, 90 % retained strength is reached at the predicted duration for the service temperature – in this example, 90 % after 516 000 h. The predicted strength after 1 000 000 h is 81,5 % and the RF_{CH} = 100/81,59 = 1,23. A similar derivation is carried out for the LCL for which the predicted strength after 1 000 000 h is 58,8 %. The ratio R_2 = 81,5/58,8 = 1,39.



Key

X Time (h)

Y % retained strength

Figure 11 — Degradation curve at the service temperature

Further guidance is given in IEC 60216 and in [2], [11], [13] and [17] in the Bibliography.

9.4.4 Oxidation of polyolefins

9.4.4.1 General

There are currently three approaches to the assessment of the oxidation resistance of polyolefins: simple Arrhenius testing, multiple Arrhenius testing and pressurized oxygen testing.

9.4.4.2 Simple Arrhenius testing

Historically, overall lifetime has been predicted by treating the entire oxidation process as a single stage. Time to end of life is measured at different temperatures and extrapolated to the service temperature to define the service life, or to the service life to define the operating temperature (e.g. see IEC 60216). The degradation of polypropylene fibre can be extremely sudden and thus give an indication of lifetime prediction. However, the methods have suffered from inaccuracies due to the following.

— The antioxidants present delay the onset of oxidation of the main polymer, causing the reaction rate with oxygen to change over time for the material.

— The oven temperature should stay well below the melting temperature of the polymer, thus restricting the exposure temperatures to a narrow range.

— The mechanism of oxidation can change at higher temperatures, invalidating the extrapolation.

— The different rates of degradation described above can lead to large errors in the measurement of time to end of life and of its extrapolation.

— Surface cracking has been observed in certain grades of polypropylene. This increases the access of oxygen to the polymer and invalidates any prediction based on uncracked material; furthermore, at elevated temperatures, these cracks can heal, which will possibly occur at lower temperatures.

— Diffusion of antioxidants plays a major part at all stages of oxidation. The rate of diffusion of oxygen from the outside, the rate of diffusion of antioxidants and the rate of migration of radicals produced by the chain reaction all increase at higher temperatures and decrease with crystallinity and orientation of the polymer. These effects are accelerated by a high surface-to-volume ratio. Hence, a high surface-to-volume ratio and a low degree of orientation will clearly shorten all stages of oxidation.

— Leaching may also occur in materials having a high surface-to-volume ratio or containing leach-sensitive antioxidants. For these materials, correct selection of stabilizers is essential.

Polyethylene and polypropylene geotextiles cover a wide range of structures from fine, highly oriented fibres to thick and less strongly oriented polymeric geosynthetic barriers. They contain different combinations of antioxidants. Some exhibit surface cracking. In polymeric geosynthetic barriers and the less oriented areas of extruded geogrids, the rate of oxidation should be higher due to the lack of orientation, but simultaneously lower due to the small surface-to-volume ratio.

This explains why it has proved impossible to define a single oven ageing test as a screening test for all geosynthetics. Various attempts to do so have either failed to eliminate poorly stabilized material or conversely have eliminated material which would be expected to be durable. Better results can be obtained by restricting the temperature to 80 °C or below, by dividing the process into stages of oxidation or by raising the oxygen pressure as in ISO 13438.

9.4.4.3 Multiple Arrhenius testing

The degradation of a stabilized polypropylene or polyethylene can be divided into two stages: consumption of the antioxidant, and degradation of the unprotected polymer. To establish which stage has been reached, use is made of oxidation induction time (OIT) measurement or high pressure oxidation induction time (HPOIT) where hindered amine light stabilizers (HALS) are present. OIT cannot be applied universally because it only relates to antioxidants active at the testing temperature, which is in the molten state. In these methods, a sample of material is raised to a high temperature in an inert atmosphere, pure oxygen is admitted and the time to oxidation measured thermally by differential scanning calorimetry (DSC). For materials in the first stage of oxidation, the OIT reduces progressively as the antioxidant is consumed, but the mechanical properties remain unchanged. In the second stage, the OIT is low and the mechanical strength and elongation at break diminish. It is possible that the antioxidants intended to increase the durability are only effective at lower temperatures. It should be recognized that this two-stage procedure is a simplified model.

Accelerated oxidation testing is performed by heating the geosynthetic in a forced air oven. For details of representative methods and equipment, see IEC 60216. Sets of specimens should be exposed at different test temperatures as described in 9.4.3, but separate estimates should be made for the different stages described above:

— t_{ind}: the induction time during oxidation, i.e. the duration of the first stage over which mechanical strength does not change, but OIT can drop;

— t_{deg}: the degradation time during oxidation, i.e. duration of the second stage until the set retained strength is reached.

Make separate Arrhenius plots for t_{ind} and t_{deg}. Examine all specimens for examples of surface cracking (this can require the use of a scanning electron microscope with a magnification of 4 000 x) and eliminate those where the cracking can be shown to accelerate the oxidation process.

If a reduction in strength can be accepted, estimate the total lifetime (t_{ind} + t_{deg}) for each set retained strength and plot retained strength against total lifetime. Read off, by interpolation, the retained strength for the service lifetime at the service temperature. Set RF_{CH} equal to the reciprocal of the retained strength.

NOTE Testing under oxygen pressure. Raising the availability of oxygen by using pure oxygen gas under pressure presents an alternative method of acceleration [13] and [18] in the Bibliography. It compensates the distortion of rate of oxidation found by limiting oxygen diffusion in products with a high surface-to-volume ratio in oven testing at elevated temperatures and accelerates oxidation to a certain degree due to a higher oxygen concentration in all the materials. Furthermore, the test can be performed with the geosynthetics suspended in an aqueous phase in order to simulate leaching effects, which could be especially serious for materials with a high surface-to-volume ratio. Such a test is specified in ISO 13438. Correlation of this test with long-term durability has not yet been completed.

9.4.5 Hydrolysis of polyesters

9.4.5.1 General

An assessment of the rate of degradation, or evidence of lack of degradation, should be made according to 9.4.2 or 9.4.3. For a laboratory assessment based on 9.4.3, particular attention should be paid to the following:

— testing should consist of elevated temperature immersion tests to evaluate potential for hydrolysis effects in water or a specific solution to evaluate a specific environment;

— the reactor should be capable of maintaining temperature uniformity (± 1 °C) and stability during long-term use;

— at least three temperatures below the physical transition of polyester at 70 °C to 80 °C should be included: if a change in the gradient of the Arrhenius curve is observed in this temperature range then results from testing at higher temperatures should be excluded from the extrapolation;

— specimens should be suspended in the solution on a hanger made of a material that will not react with or contaminate the immersion fluid and specimens [e.g. polytetrafluorethylene (PTFE), HDPE, stainless steel];

— the specimens should be free to contract in either direction and not framed to prevent shrinkage;

— the tests should be performed on the uncoated yarns, strips or fabric;

— the solution should be intensively stirred to ensure solution uniformity;

— the pH should be monitored and the liquid replaced if the pH > 8.

The assessment should predict either

— no statistically significant reduction in strength during the service life. In this case RF_{CH} equals 1, or

— a reduction in strength with time. In this case, RF_{CH} should equal the ratio of the strength of the unexposed material to the predicted strength for the design life t_D.

In both cases, the assumed ambient conditions such as soil temperature and pH should be stated.

Predictions based on accelerated testing are subject to a level of uncertainty. This is taken into account in the ratio R_2 which contributes to the factor of safety f_s. The method for calculating R_2 is described in 10.1.

A geosynthetic that comprises more than one polymer should be subject to a separate assessment for each polymer.

For a range of products identical except for mass per area, then initially only the product with the lowest mass per area should be subjected to the test or assessment procedure. The value(s) of RF_{CH} assigned to this product may then be applied to the other products in the range.

For further information, see [11] and [19] in the Bibliography.

9.4.5.2 Index tests for polyesters

The long-term chemical durability of polyesters in relatively neutral aqueous environments can be tested by one of the following sets of index tests.

— The polyester geosynthetics used for reinforcement, or the yarns from which they are made, should exhibit no more than a 50 % reduction in strength when subjected to EN 12224.

— The CEG measured according to GRI-GG 7 should be less than 30 meq/g, and the number averaged molecular weight, M_n, determined according to GRI-GG 8 should be 25,000 or more. Both criteria should be satisfied.

NOTE A condition of both criteria is that the polyester contains no post-consumer or post-industrial recycled material.

For a geosynthetic that satisfies either recommendation used in saturated soil, estimated values of RF_{CH} are listed in Table 2. Lower values may be considered when the soil is not saturated and/or if further evidence is provided.

Table 2 — Estimated values of RF_{CH} for polyesters

pH range	**Design lifetime (years)**	**Service temperature** (°C)	RF_{CH}	R_2
4 to 9	25	25	1,0	1,0
4 to 8	100	25	1,2	1,0
8 to 9	100	25	1,3	1,0
4 to 9	25	35	1,4	1,0

9.4.5.3 Index test for polypropylene and polyethylene

The long-term chemical durability of polyolefins can be tested according to ISO 13438. If the retained strength exceeds 50 % when tested according to method A2 or C2 for polypropylene, or method B2 or C2 for polyethylene, then for 100 years at a service temperature of up to 25 °C a value of 1,3 is estimated for with R_2 = 1,0. Lower values for RF_{CH} may be considered if further evidence is provided.

9.4.6 Procedure in the absence of sufficient data

If RF_{CH} is based on data obtained from long-term service experience (see 9.4.2) or long-term chemical degradation tests (see 9.4.3) performed on older product lines, or other products within the same product line, RF_{CH} determined in this manner can be applied to new product lines, or a similar product within the same product line, if one or both of the following conditions apply:

- the materials and structure of the proposed product are similar to those of the tested product. Data should be provided which shows that the minor differences between the tested and the untested products will result in equal or greater long-term chemical durability for the untested products;
- the results of a limited testing programme on the proposed product are not significantly different from those predicted from the data on the tested product. For chemical durability evaluation, this limited testing programme should include tests taken to at least 2 000 h in length at a temperature just below any significant transition in durability behaviour. This approach should only be used for materials for which this testing will conclusively demonstrate the similarity or dissimilarity of the long-term durability of the material.

Similarity can be judged on the criteria listed in 7.9. Also note fibre surface characteristics (e.g. presence of surface cracking).

The data provided should show that the performance of the new or similar product is equal to or better than the performance of the product previously tested. If so, the results from the full testing programme on the older or similar product could be used for the new/similar product. If these conditions do not apply, then a full testing and evaluation programme for the new product should be conducted.

9.5 Biological degradation

Biological degradation has not proved a serious factor in the service life of geosynthetics. This is because the high molecular weight polyethylene, polyester, polypropylene and polyamide used are not easily broken down by bacteria and fungi. The high tensile strength of soil reinforcements prevents them from damage by roots and burrowing animals, such as rabbits. For this reason it is not in general necessary to consider biological degradation in calculating RF_{CH}. However, the possibility of biological degradation should be reviewed if new polymers other than those described are used, or an index test performed to EN 12225 indicates degradation is possible, or if there are unusual biological circumstances, e.g. termites. Certain additives have been known to be subject to biological attack, and if the function of the additive was to prevent, for example, oxidation, then without it the base polymer will be subject to more rapid degradation.

Biological attack, if it occurs, is believed to take place relatively rapidly (Mode 3). It is more appropriate to define a minimum period over which no biological attack is predicted to occur than to define a reduction factor.

10 Determination of long-term strength

10.1 Factor of safety f_s

A factor of safety should be applied to T_{char}. The purpose of the factor of safety f_s is to allow for extrapolation uncertainty, particularly in extrapolation over long durations.

To take into account uncertainty due to the extrapolation of the creep rupture data, set $R_1 = 1{,}2^{r-1}$ where $r = \log(t_D/t_{max})$ with a minimum value of 1,0. t_{max} refers to the duration of the longest observed time to creep rupture, expressed in h, after TTS if appropriate.

To take into account uncertainty due to the extrapolation of accelerated chemical data, it is recommended that $R_2 = T_x/T_{LCL}$ (see 9.4.3)

Set $f_s = 1 + \sqrt{((1-R_1)^2 + (1-R_2)^2)}$.

Lower values may be considered if further evidence is provided.

10.2 Design for residual strength

If the design is based on a sustained load together with the ability to withstand a temporary seismic or other overload, then the design lifetime should be a fraction (e.g. < 10 %) of the time over which the sustained load would lead to rupture. The residual strength at any point during this lifetime should then be taken to be

$$T_{DR} = T_{char}/(\mathrm{RF}_{ID} \cdot F_W \cdot RF_{CH} \cdot f_s)$$

11 Reporting

The final statement should include the items in Table 3.

Table 3 — List of items to be stated

Item	Symbol	Clause
Material	—	—
Design lifetime	t_D	4.2
Assumed soil conditions: gradation, angularity, saturation, pH, presence of contaminants, nature of compaction and fill depth both above and below the geosynthetic	—	—
Design temperature	θ_s	4.4
Isochronous diagram, if appropriate	—	5.4
Characteristic strength (per width)	T_{char}	6.1
Recommended maximum time of exposure to light	—	9.3
Reduction factor to allow for the effect of sustained static load	RF_{CR}	7.6
Reduction factor to allow for the effect of mechanical damage	RF_{ID}	8.3
Reduction factor to allow for weathering	RF_W	9.3 (Table 1)
Reduction factor to allow for chemical and biological effects	RF_{CH}	9.4.2 (service experience) 9.4.3 (accelerated testing) 9.4.4 (oxidation) 9.4.5 (hydrolysis)
Factor of safety	f_s	10.1
Long-term strength per width (including factor of safety)	T_D	$= T_{char}/(\mathrm{RF}_{CR} \cdot \mathrm{RF}_{ID} \cdot \mathrm{RF}_W \cdot \mathrm{RF}_{CH} \cdot f_s)$
Residual strength	T_{DR}	$= T_{char}/(\mathrm{RF}_{ID} \cdot \mathrm{RF}_W \cdot \mathrm{RF}_{CH} \cdot f_s)$

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Annexe XI : Dimensionnement du bassin plâtre (SAS BETA ENVIRONNEMENT – 15/10/19)

SYNDICAT DE DESTRUCTION DES ORDURES MÉNAGÈRES DE L'OUEST DU DÉPARTEMENT DE L'EURE

CETRAVAL commune de Malleville sur le Bec

Département du Eure (27)

MAÎTRISE D'OEUVRE POUR LA CRÉATION D'UN CASIER DE STOCKAGE DE DÉCHETS ULTIMES (VIII c-d-e) ET D'UN CASIER « PLÂTRE » AU CETRAVAL DE MALLEVILLE SUR LE BEC

Note de dimensionnement du bassin du casier plâtre

SAS BETA ENVIRONNEMENT

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Affaire N°	Date	Version	Rédacteur	Visa
B19014A	15/10/19	1	A.Fourmond	P.Brémaud

TABLE DES MATIÈRES

I. PRÉAMBULE

Le Syndicat de Destruction des Ordures Ménagères de l'Ouest du département de L'Eure est le maître d'ouvrage du Centre de Traitement et Valorisation Énergétique, CETRAVAL, à Malleville sur le Bec.

L'exploitation du site de Malleville sur le Bec a débuté en 1973.

L'exploitation pour la mise en oeuvre du stockage des déchets est réalisée en interne depuis avril 2016. Le casier n° VIII destiné à l'enfouissement des ordures ménagères résiduelles est autorisé par l'arrêté préfectoral du 28 novembre 2017 et l'arrêté préfectoral modificatif du le 13 juillet 2018.

Les travaux d'aménagement des casiers VIII.a, VIII.b1 et VIII.b2 ont été réalisés de février 2018 à octobre 2018.

Le Sdomode souhaite aménager :
- un casier plâtre et un casier amiante en réhausse des casiers 2, 4, 5, 6, 7, 8, 9, 10, 12, 11, 13, 14 et 15 exploités de 1996 à 1999,
- les casiers VIII c-d-e.

La mission de maîtrise d'oeuvre a été confiée au bureau d'étude BETA Environnement (85).

Le présent dossier concerne la note de dimensionnement du bassin de gestion des eaux du casier plâtre.

II. CADRE RÉGLEMENTAIRE ET NORMATIF

II.1. Arrêté ministériel du 15/02/216

L'AM 2016 prévoit pour l'aménagement de casiers de stockage mono-déchets dédiés à des déchets présentant une fraction soluble inférieur à 5% la gestion des effluents type :

- **lixiviats** (art 11) :
    - ***Dispositif de collecte et de traitement des lixiviats :***
        - collecte gravitaire avec puisard en point bas,
        - évacuation gravitaire ou pompage si impossible, si gravitaire avec une vanne d'obturation sur collecteur en amont du bassin lixiviats,
        - dispositif contrôle niveau lixiviats dans casier pour respect des 30 cm,
        - prise en compte du risque de pollution en cas rupture sur réseau.
    - ***Bassins de stockage de lixiviats***
        - *étanchéité de haut en bas :*
            - *BSA : géomembrane,*
            - *BSP : 50 cm < 1.10-9 m/s,*
        - *sécurité : clôture, bouée, échelle, signalisation,*
        - *dispositif d'arrêt d'alimentation des lixiviats : vannes.*
        - *volume : 15 jour de décennale,*
        - *volume de réserve en cas d'aléa avec repère visuel en paroi interne du bassin*
    - ***Installation de traitement des lixiviats et de gestion des boues.***

III. PROJET DU CASIER PLÂTRE

Le projet du casier plâtre est établi selon les caractéristiques détaillées dans le tableau ci après.

Principe d'aménagement du casier plâtre en réhausse

Situation avant travaux	
Côte actuelle de la couverture en mNGF	de 145 à 149 m NGF
Couverture existante	- épaisseur initiale de 0,70 à 3,95 m
Conception du fond casier en rehausse	
Couche de forme - assise	- décapage de 0 à 3 m de la couverture existante, - couche minimal de 0,50 m de matériau compacté.
Principe conceptuel de la BSP en Fond et en flanc	Équivalence avec de haut en bas : - Géosynthétique bentonitique de perméabilité ≤ 5.10-11 m/s, - 0,5 m de matériau de perméabilité ≤ 1.10-9 m/s en fond et 2 m de remontée au niveau de la digue périphérique
Principe conceptuel de la BSA en Fond	Dispositif d'étanchéité par géosynthétiques constitué de haut en bas : - 50 cm de concassé (provenant du site) ou gravier drainant , - Géotextile de protection supérieur, - Géomembrane 2 mm.
Pente en fond de casier	≥ 1 %
Géométrie du casier en rehausse	
Surface du fond de casier en m2	3 735 m2
Surface d'exploitation en m2	4 110 m2
Surface de couverture en m2	4 110 m2
Volume total stocké (vide de fouille) en m3	19 900
Volume annuel en m3	2 250
Durée de vie en année	9
Densité estimé par le SDOMODE	1 m3 = 0,8 t
Tonnage stocké total en t	15 920

IV. INSTALLATION DE GESTION DES LIXIVIATS

IV.1. Description de l'installation de gestion des lixiviats

Le captage des lixiviats sera assuré par la barrière de sécurité active constituée d'une géomembrane et 50 cm de gravier drainent associé à un réseau de drain et un puits.

Les lixiviats du casier plâtre seront collectés et dirigés vers un bassin de gestion des eaux du casier plâtre.

En accord avec l'article 11 de l'AM du 15 février 2016, le bassin est dimensionné pour un évènement pluvieux décennal 15 jour.

IV.2. Données météorologique

La station météorologique utilisée dans le cadre de l'étude est la station météorologique de Rouen - Boos (76) située à environ 45 km de Malleville sur le bec.

La pluviométrie moyenne annuelle au niveau de la station sur la période 1981-2010 est de 851,7 mm.

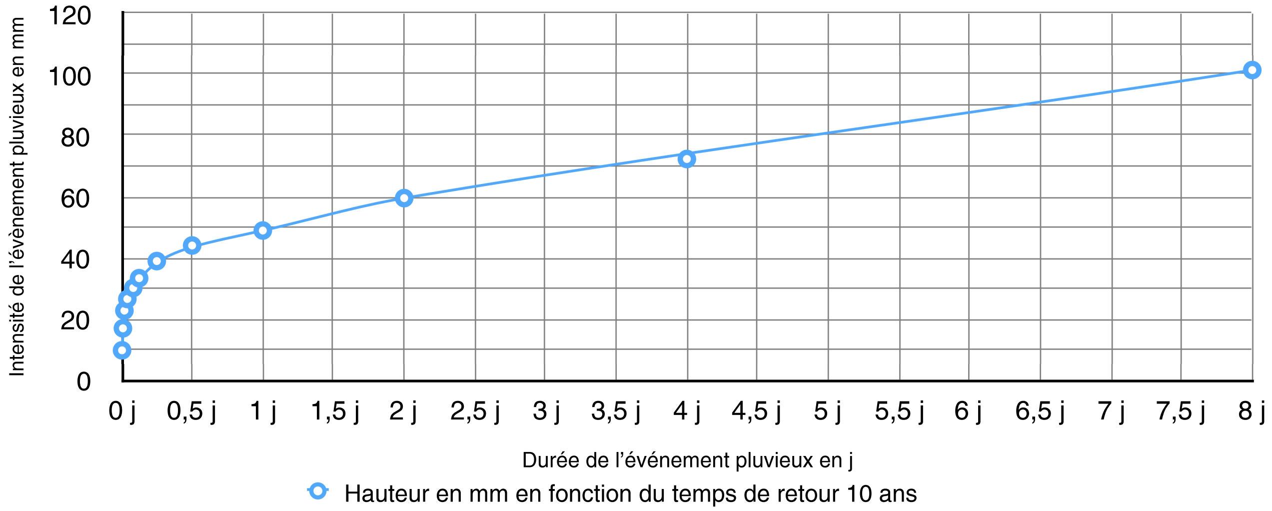
Les données d'intensité de pluviométrie de retour 10 ans sont disponibles de 6 min à 8 jours. L'intensité de pluviométrie d'un évènement de 15 jours de retour 10 ans est obtenue est extrapolant la courbe. L'extrapolation de la courbe est réalisée avec la pluviométrie moyenne annuelle observée la plus importante sur la station depuis 1981. La pluviométrie annuelle moyenne de 1982 est de 1310,9 mm.

L'intensité de l'événement pluvieux décennale de 15 jours est estimé par extrapolation à **125 mm.**

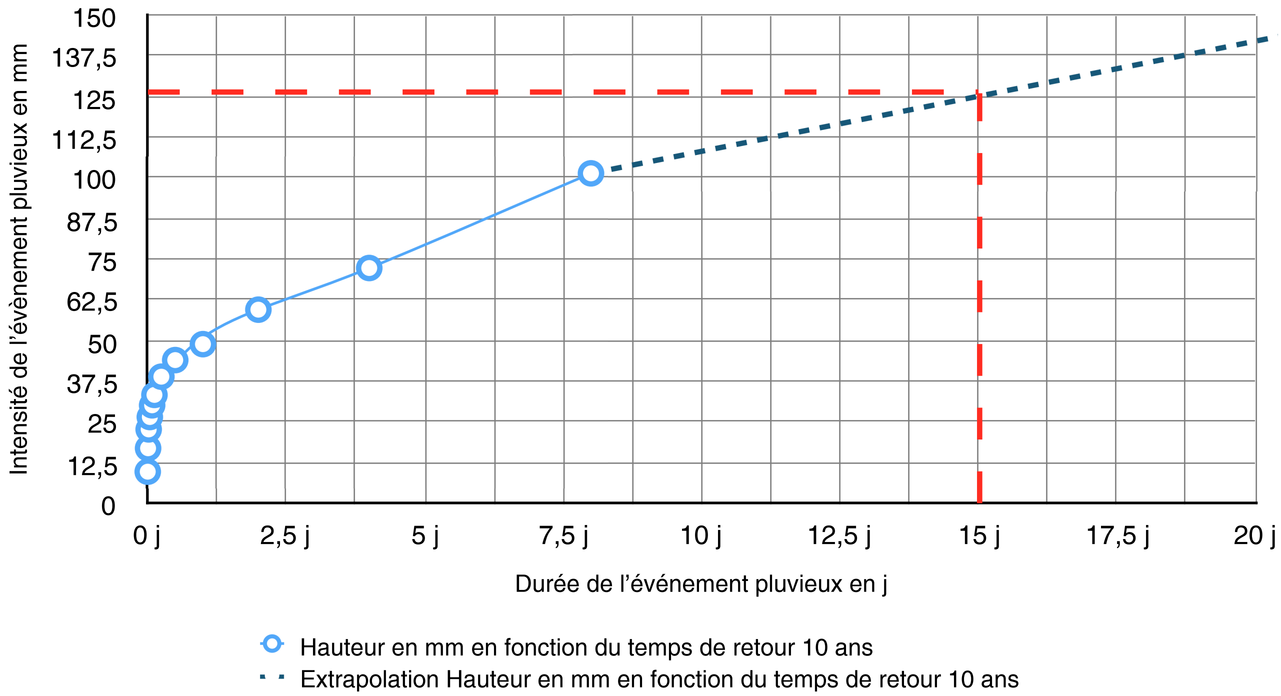
Hauteurs de précipitations moyennes en mm, source météofrance

Statistique	janv	févr	mars	avr	mai	juin	juil	août	sept	oct	nov	déc	total
ROUEN BOOS 1981-2010	76,3	60,4	67,1	59,2	74,3	63,7	68,9	65,1	65,5	83,5	76,8	90,9	851,7

Graphique des précipitations de durée de retour 10 ans - station Rouen Boos (76) - période 1989 - 2016 - source météofrance



Extrapolation d'un évènement pluvieux 15 jours de durée de retour 10 ans - station Rouen Boos (76) - période 1989 - 2016 - source météofrance



IV.3. Calcul de la capacité de stockage.

L'impluvium de la surface d'exploitation est de 4 110 m2.

L'hypothèse de dimensionnement est que 100 % de la pluviométrie est capté en lixiviats.

La capacité de stockage du bassin du casier plâtre doit donc être au minimum de **550 m3.**

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