VERENIGING EPS FABRIKANTEN
STYBENEX

EPS in CIVIL ENGINEERING APLLICATIONS:
Product properties and performance requirements connected

ABSTRACT

Since decades expanded polystyrene (EPS) is successfully applied as light weight fill for roads railroads and other civil engineering applications. EPS is then often called "Geofoam". Since 1st January 2009 a harmonised European product standard is in force, EN 14933, with the obligation of CE marking and labelling.
Design in civil engineering was in most EU countries not subject to legal regulations but to guidelines, craftsmanship of engineers and common sense. From now on Eurocodes – especially EN 1997 EUROCODE 7 Geotechnical design - come into force which are equal for all EU countries (with some national application annexes).
For simple constructions these two phenomena can easily connected via the stress – strain relationship.

MATERIAL PROPERTIES

In this chapter the material properties of expanded polystyrene (EPS) are given for the calculation of EPS in geotechnical applications. The data correspond with the content of EN 14933 on compressive strength, modulus of elasticity and compressive creep.

Compressive strength

Short-term

EPS product types are based on the declared value of the compressive strength at 10% deformation and has been an arbitrary choice. For the calculation of the design value of the short-term compressive strength $\sigma_{10;d}$ a material factor has to be taken into account (EN 1997 art 2.4.6.2); following EN 1990 and EN 14509 [1] this factor (γ_m) is 1,25 (e.g. for EPS 100: $\sigma_{10;d}$ =100/1,25 = 80 kPa). This material factor is based on the steel sandwich panel standard supposing a variance of 8% in production of EPS, using a substantial amount of secondary materials. See: www.geoblock.nl

Permanent strength

As EPS is expected to have a compressive creep deformation of 2% or less after 50 years when subjected to a permanent compressive stress of less than 0,30 * σ_{10}, the declared value of the permanent compressive strength $\sigma_{10;perm}$ = 0,30 * σ_{10}. For the calculation of the design value $\sigma_{10;perm;d}$ the material factor (γ_m) has to be taken in to account (EN 1997 art 2.4.6.2); this factor (γ_m) is 1,25 (e.g. for EPS 100: $\sigma_{10;perm;d}$ = 0,3 * 100/1,25 = 24 kPa).

Compressive strength under cyclic load

On the basis of extensive studies it has been concluded that, with a relative light permanent loading at the top (15 kN/m^2) and if the deformation under a cyclic load remains under 0,4% that deformation will be elastic and there will be no permanent

[1] EN 14509, the European harmonized sandwich product standard

deformation. Translated into stresses the maximum safe value due to cyclic loading is 0,35 * σ_{10}. This value has been recalculated from Duskov [2] thesis. Thus the declared compressive strength under cyclic load $\sigma_{10;cycl;d}$ = 0,35 * σ_{10} (e.g. for EPS 100: $\sigma_{10;cycl;d}$ =0,35 * 100 = 35 kPa). For the calculation of the design value $\sigma_{10;cycl;d}$ the material factor (γ_m) has to be taken in to account (EN 1997 art 2.4.6.2); this factor (γ_m) is 1,25 (e.g. for EPS 100: $\sigma_{10;cycl;d}$ = 35/ 1.25 = 28 kPa).

Modulus of elasticity

Declared values can be derived using test results from EN 826 and are valid for the elastic part of the stress/strain curve. The same value can be used for the calculation of the dynamic behaviour due to cyclic loading. Values in the next table are based on the formula developed by Horvath[3]: E_t = (0,45 ρ -3) mPa (e.g. for EPS 100 (with a density ρ of 20 kg/m^3) this gives E_t = 0,45 * 20 -3 = 6 mPa = 6000 kPa). This is a "safe" approach. The relationship between density and compressive strength ("old" versus "new" product types) is defined in "Eumeps Product Types" in 2003; see: www.eumeps.org

Compressive creep

In 1989 dr. ing. Norbert Krollmann[4] made a first proposal to determine and calculate the effect of compressive creep of thermal insulating materials, by suggesting to take the "Findley equation" to predict long term effects -"for the first decades"- based on testing during a period of 667 days, the result taken over in EN 1606. For civil engineering applications a prediction over a longer period is necessary. The Swedish testing institute SP proposed another extrapolation equation for long term creep based on the lin-log method ("Struik"). This was discussed in the CEN working groups and concluded that the "Findley" equation gives conservative results where "Struik" gives only good results for the longer period. This has to do also with two effects: tests are always carried out with small samples whilst in reality EPS light weight fill is using big blocks and secondly EPS shows stiffening of the product matrix at longer exposure to loadings.
Taking into account that EN 1606 is the official harmonised European test method and with the knowledge that the creep behaviour of EPS corresponds with the "Struik"-method for extrapolation a specific declaration is given in the EPS standards in an informative annex. This information is in addition to the conservative extrapolation method following "Findley". The information in the annex is also conservative but saves a lot of extra testing and costs to manufacturers.

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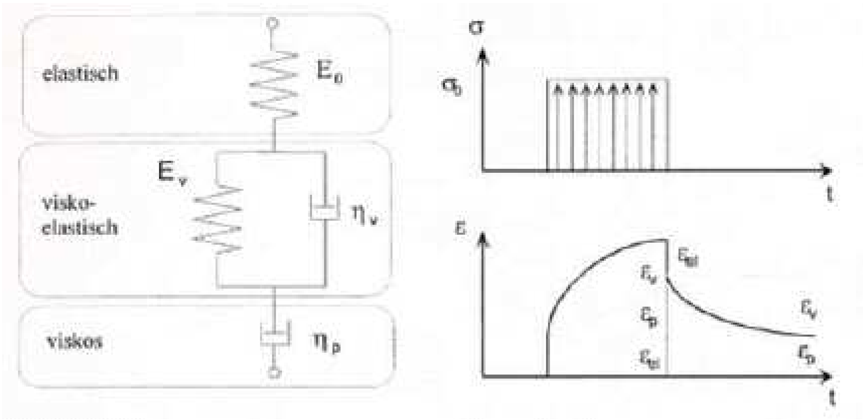
[2] Duškov, Milan: EPS as alight weight sub-base material; 1997 Delft NL
[3] Horvath, J.S.: Geofoam Geosynthetic, Horvath Engineering, 1995 Scarsdale USA
[4] Krollmann, Norbert: CEN TC 88 WG 4 N31-N111 dated 890425



Rheological model EPS

Creep data published by the SP in Goteborg in 2001 and published in EUMEPS' WHITEBOOK 2003 prove the above given data in EN 13163 and EN 14933: at 0,3 (or 0,35 for EPS 150) times the compressive strength at 10% strain (σ_{10}) the creep will be around 2% and the initial deformation around 0,5%, thus the total deflection ($\varepsilon_t = \varepsilon_0 + \varepsilon_{ct}$) will be 2,5% over 50 years at a permanent load of 0,3 σ_{10}.
The data in this chapter are very useful for practical calculations. This was already presented at the Global Insulation Conference in Berlin 2007.

Tabulated properties

The above obtained values are put in the next matrix:

Table 1: Design properties of EPS

Property			**EPS product type**				
Description	Symbol	Unit	EPS60	EPS100	EPS150	EPS200	EPS250
Declared value short-term compressive strength	σ_{10}	kPa	60	100	150	200	250
Design value short-term compressive strength	$\sigma_{10;d}$	kPa	48	80	120	160	200
Modulus of elasticity	E_t; E_{dyn}	kPa	4000	6000	8000	10000	12000
Declared value permanent compressive strength	$\sigma_{10;perm}$	kPa	18	30	45	60	75
Design value permanent compressive strength	$\sigma_{10;perm;d}$	kPa	14,4	24	36	48	60
Declared value compressive strength under cyclic load	$\sigma_{10;cycl}$	kPa	21	35	52,5	70	87,5
Design value compressive strength under cyclic load	$\sigma_{10;cycl;d}$	kPa	17	28	42	56	70

PERFORMANCE REQUIREMENTS

Geotechnical design

Only an integral approach of the design makes that design to a successful one – not only regarding its fitness for purpose or use but also in terms of sustainability and socio-economic parameters. For this kind of road building anyhow the solution can be split up into three partial calculations.
Most of the roads and railroads built on EPS use the equilibrium method: with bad subsoil and the possibility to avoid almost any settlements the concept with EPS is designed. For the subsoil the calculation method is than easy: as long as the permanent imposed load does not exceed the existing stresses zero settlements are to be expected. In case an load on the existing foundation is imposed well known calculations can follow to designate the settlements.
For the load distributing top layer also tools are available to calculate the different layers in order to get a predicted equally distributed load on the EPS body. For difficult constructions software like PLAXIS can be used; for simple ones several Pavements Manuals exist.
A lot of nonofficial, voluntary design rules in the EU are used (e.g. BAST, CROW and NRRL guidelines). Anyhow Eurocodes EN 1990 up until EN 1997 come into force and that means that the known calculation route via safety factors is left and the modern method with loading factors is more and more used. In this document general rules are described as a help to design simple civil engineering applications with EPS.

Loadings and combinations

The given values are in conformity with EN 1990 and EN 1997 (Eurocode 7).

Permanent loadings
Permanent loadings of own weight and imposed dead loads can be derived from Eurocodes; for EPS a design value of 100 kg/m^3 is taken into account "for possible water uptake" but the total load is small in comparison with sand, gravel and soil. For a light weight top layer 15 kPa can be taken.

Traffic loads
Traffic (cyclic) loads can be derived from Eurocodes. For the calculation of the EPS body in the Netherlands we often apply a uniform distributed load of 15 kPa thus already taken the load distribution by the gravel/ sand top layers and the bitumen reinforcement into account.

Loading factors
For permanent loads a loading factor of $\gamma_{F;G}$ = 1,35 has to be applied; for traffic load a loading factor of $\gamma_{F;Q}$ = 1,50 has to be applied (see EN 1997 Annex A3 Table A3 Collection A1); in case of the possibility of floating on ground water other factors have to be used.

Design criteria
The following design criteria can be taken from EN 1990 to EN 1997:

Ultimate Limit state short term criterion ("STR")
Loading combination: Multiply the dead and imposed load with their respective loading factors and combine both loads. Calculate the acting design compressive stress at the top of the EPS blocks and compare it with the short term design compressive strength $\sigma_{10;d}$ (e.g. 80 kPa for EPS 100). The short term acting stress should be less than or equal to the short term strength.
Ultimate Limit state permanent criterion ("STR")
Loading combination: Multiply the dead load and the permanent part of the imposed load (mostly zero in civil applications) with their respective loading factors and combine both loads. Calculate the acting design compressive stress and compare it with the permanent design strength $\sigma_{10;perm;d}$ (e.g. 24 kPa for EPS100). The permanent acting stress should be less than or equal to the permanent strength.
Ultimate Limit state for cyclic loads ("GEO")
Loading: Multiply the cyclic load with the factor γ_Q = 1,50. Calculate the acting design compressive stress and compare it with the design cyclic strength $\sigma_{10;cycl;d}$ (e.g. 24 kPa for EPS100). Note that a maximum dead load of 15 kPa is aalowed.
Ultimate Limit state for floating ("UPL")
See for this Annex A4 of Eurocode 7; the load factor $\gamma_{G;stb}$ = 0,9 in favourable situations and $\gamma_{G;dst}$ = 1,0 in unfavourable situation for permanent actions. Load factor $\gamma_{Q;dst}$ = 1,5 in unfavourable situation for variable actions.
Limit state during the construction phase
A worst case scenario has to be taken, no further defined criteria.

EXAMPLE OF APPLICATION

As an example a typical road in the "Polders' in the western part of the Netherlands is taken. The road is constructed by removing the peat soil to a depth of around 1,5 m; adding EPS blocks to a height of 2 m, putting a sand/gravel combination over it to distribute the point loads; it is finished with a double asphalt layer.

Cross section typical Polderroad NL

Permanent loads (γ=1,35)

0,15 m asphalt bitumen layers	0,15 * 2100 kg/m^3	=	3,1 kN/m^2
0,50 m gravel/sand	0,50 * 1800 kg/m^3	=	9,0 kN/m^2
2,0 m EPS 100	2,00 * 100 kg/m^3	=	2,0 kN/m^2
	TOTAL	=	14,1 kN/m^2

Traffic load (γ =1,50)

Cyclic and uniformly distributed on EPS = 15,0 kN/m^2

STR- short:

1,35 * 14,1 + 1,50 * 15 = 41,35 < 80 ? O.K.

STR-permanent

1,35 * 14,1 = 19,05 < 24 ? O.K.

GEO-Cyclic

1,50 * 15 = 22,50 < 28? O.K.

Conclusion: The product properties of EPS 100 fulfil the performance requirements

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