Technical Information

Styropor®

800

24558 June 1991/September 1993

Highway construction/ Ground insulation

® = Registered trademark

Styropor foam as a lightweight construction material for road base-courses

1 General

The main consideration when constructing roads on poor load-bearing subsoil is that every load deforms the soft soil layers; and the greater the load, the greater the deformation. This deformation process continues over years, depending on the thickness of the soil layers. The low shear resistance of poor loadbearing subsoils means that concentrated loads should be avoided as far as possible, otherwise these layers will give at the sides. Compensating for this form of subsidence by laying new material leads to further settlement due to the additional burden.

The conventional techniques of subsoil improvement by complete or partial replacement of the soil are often time consuming and therefore costly. By employing lightweight materials, the weight of the road embankment – and with it the load on the subsoil – is reduced considerably.

A largely subsidence-free method of construction is thus obtained when practically no additional loads are brought to bear – ie, by using extremely lightweight materials in the embankment such as blocks of Styropor foam (see figs. 1 and 2).

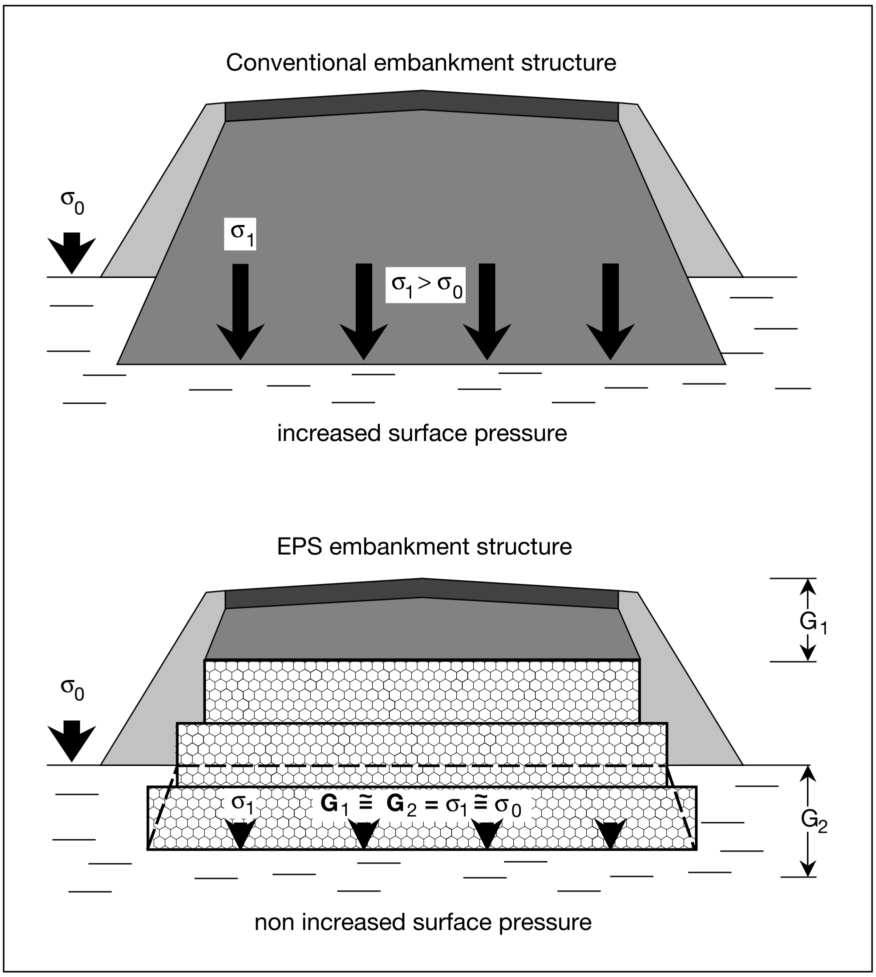
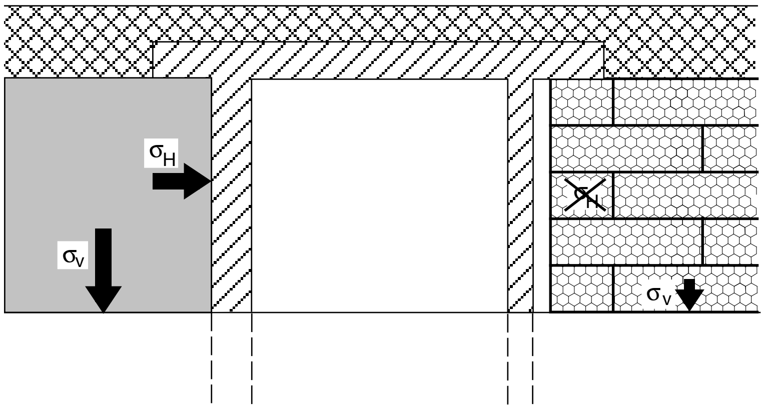


Fig. 1 Comparison of conventional and EPS embankment structures.

2 Experience to date

Experience with Styropor (EPS) foam boards used as frost protection for roads and railways formed the basis for the development of this construction technique. This method of construction has been applied since the middle of the 1960s, mainly in countries with severe winters (eg, alpine regions, Canada and the Scandinavian countries) where the deeply penetrating ground frosts make it necessary to provide costly frostproof subbases for roads and railways (see figs. 3 and 4). With the appearance in 1984 of a booklet “Road surfacing with thermal insulation layers made from foam plastics” by the German Institute for Road & Transport Research (Soil Mechanics Working Group), “antifrost construction methods” can now be ranked alongside other conventional construction techniques.



With the EPS method no horizontal forces act on the bridge abutment and supporting walls (lighter design)

Fig. 2

Fig. 3 and 4 Frost protection in road and railway construction using EPS rigid foam boards.

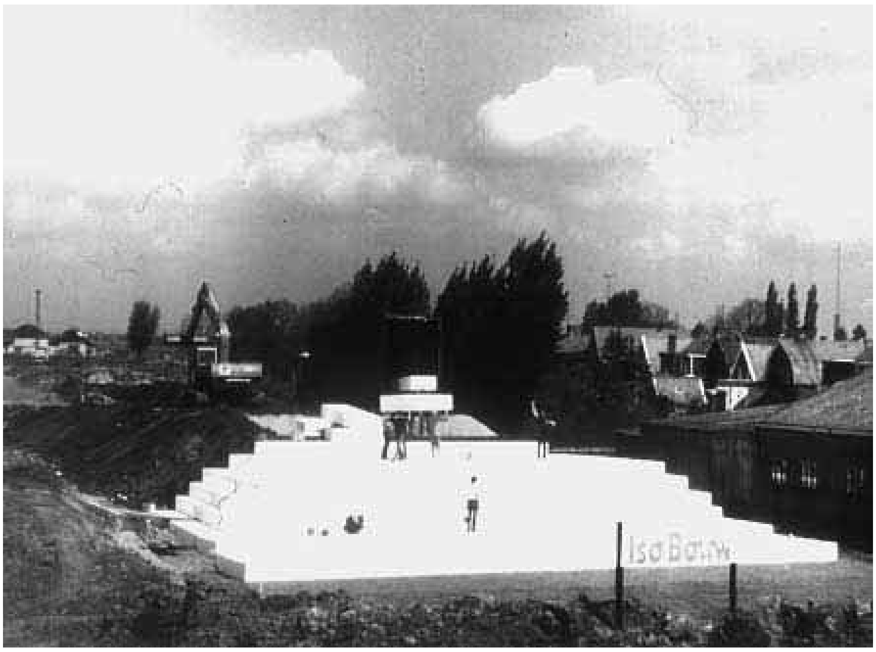


Fig. 5 Construction of an embankment using EPS (Hardinxveld-Giessendam, NL).

The use of rigid EPS foam, not only for protective antifrost layers in the form of insulating boards, but as a load-carrying substructure for roads and bridge abutments in the form of large blocks, is based on this practical experience and on the fact that lightweight (ca. 20 kg/m^3) Styropor foam possesses high bending and shear strength for distributing both dead weight and live loads; and so offers higher efficiency than conventional building materials (fig. 5).

2.1 Economy

The price of rigid EPS is much lower than that of other foam materials, but compared with conventional materials used in road substructures, it is considerably more expensive. However, a simple cost comparison is not enough – the alternative construction methods must be also considered. Dependent upon the local conditions, constructing with Styropor offers a definite technical and economically interesting solution – mostly for existing structures (eg, bridges, supporting walls, pipe ducts) where subsidence is to be avoided. Experience from abroad has shown that in certain cases a cost reduction of 50 % can be achieved over conventional building techniques. Styropor also offers obvious advantages if, for instance, material has to be transported to the construction site over long distances or special conditions have to be met on environmental grounds.

3 Styropor – rigid EPS

EPS is the standard abbreviation for **E**xpanded **P**oly**s**tyrene. The standard used for rigid EPS foam as an insulating material in the building and construction industry is DIN 18164, part 1. Styropor EPS foam has been produced worldwide for over 40 years, and is mainly used in the construction and packaging industries.

Starting with the Styropor granulate, which contains a blowing agent, the manufacture of EPS foam takes place in three stages: **Pre-expanding, intermediate storage and moulding** (fig 6). During the first stage the granulate is heated and made to expand – rather like popcorn when it is made (fig. 7). The blowing agent used is pentane, a naturally occurring hydrocarbon. The pentane expands the Styropor granules into individual foam particles five times their original volume. Next, the pre-expanded material is stored to allow air to diffuse into it and the blowing agent partly to diffuse out. Finally, the pre-expanded material is placed in a mould and further expanded so that the foam particles fuse together. The result is a compacted foam material whose volume consists mostly of air trapped in many microscopically sized cells.

The special manufacturing process makes it possible to vary the density of the Styropor foam. Because the properties of the material largely depend on its density, the foam can be made with application-specific properties: from insulating boards to lightweight construction material.

Fig. 6 The processing stages in the production of EPS foam: raw material (left), pre-expanded particles, moulded foam.

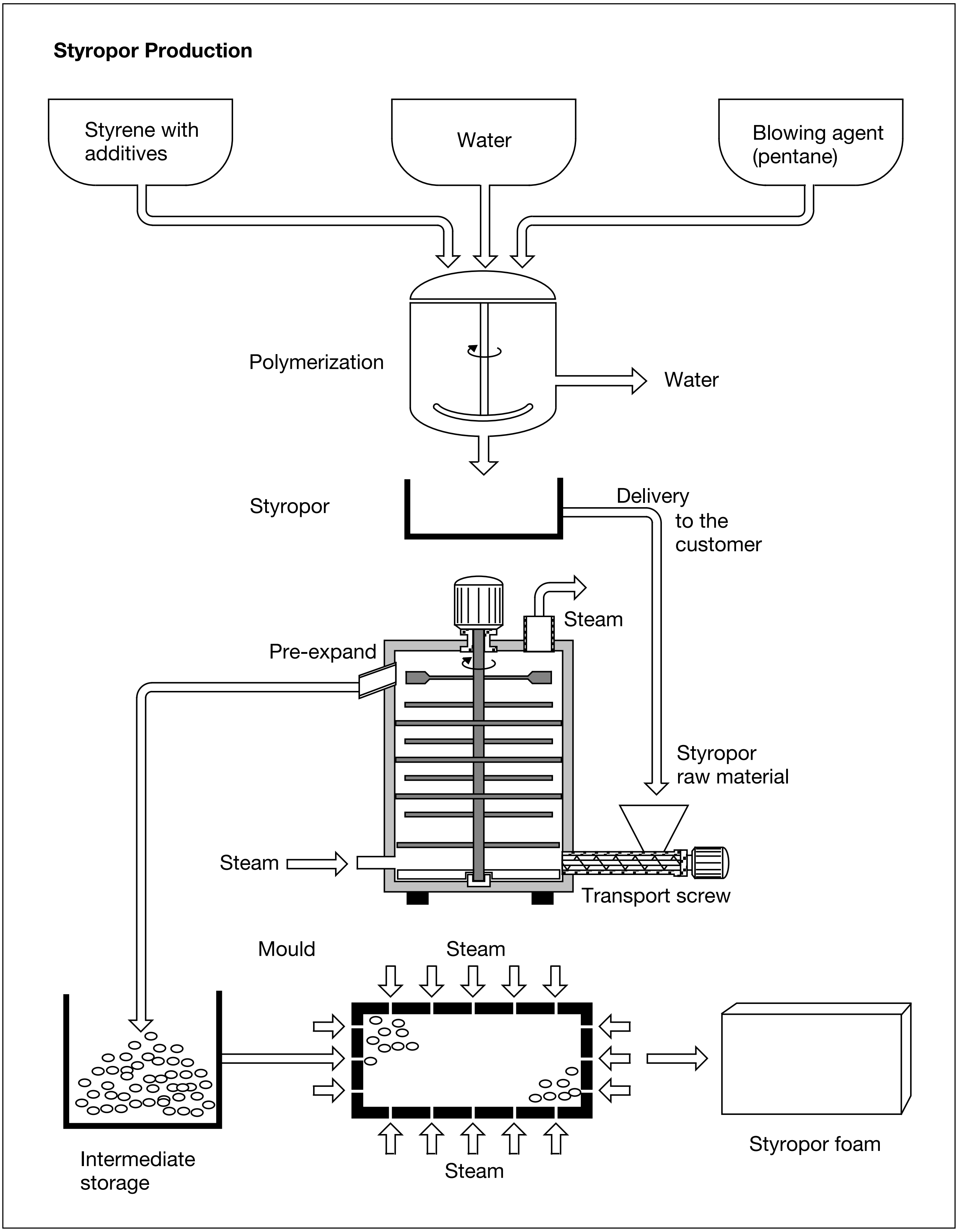

Styropor Production
Styrene with additives
Water
Blowing agent (pentane)
Polymerization
Water
Styropor
Delivery to the customer
Steam
Pre-expand
Styropor raw material
Steam
Transport screw
Mould
Steam
Intermediate storage
Steam
Styropor foam

Fig. 7

Table 1 The most important physical properties of Styropor foam

Physical properties	Test standard	Unit	Test result		
Application types	Part		PS 15 SE	PS 20 SE	PS 30 SE
Application types	DIN 18 164, Part 1		W	WD	WS + WD
Minimum density	DIN 53 420	kg/m^3	15	20	30
Building material class	DIN 4102		B 1, difficultly flammable	B 1, difficultly flammable	B 1, difficultly flammable
Thermal conductivity					
Measured value at + 10 °C	DIN 52 612	W/(m · K)	0.036–0.038	0.033–0.036	0.031–0.035
Calculated value according to DIN 4108		W/(m · K)	0.040	0.040	0.035
Compressive stress at 10% compressive strain	DIN 53 421	N/mm^2*	0.06–0.11	0.11–0.16	0.20–0.25
Resistance to sustained compressive loads at < 2% strain		N/mm^2	0.015–0.025	0.025–0.050	0.050–0.070
Flexural strength	DIN 53 423	N/mm^2	0.06–0.30	0.15–0.39	0.33–0.57
Shear strength	DIN 53 427	N/mm^2	0.08–0.13	0.12–0.17	0.21–0.26
Tensile strength	DIN 53 430	N/mm^2	0.11–0.29	0.17–0.35	0.30–0.48
Modulus of elasticity (compressive tests)	DIN 53 457	N/mm^2	1.6–5.2	3.4–7.0	7.7–11.3
Heat-deflection temperature					
short-term	based on DIN 53 424	°C	100	100	100
long-term at 5000 N/m^2	based on DIN 18 164	°C	80–85	80–85	80–85
long-term at 20000 N/m^2	based on DIN 18 164	°C	75–80	80–85	80–85
Coefficient of linear expansion		1/K	$5–7 \cdot 10^{-5}$	$5–7 \cdot 10^{-5}$	$5–7 \cdot 10^{-5}$
Specific heat capacity	DIN 4108	J/(kg · K)	1210	1210	1210
Water absorption when kept under water (percent by volume)					
After 7 days	DIN 53 434	%	0.5–1.5	0.5–1.5	0.5–1.5
After 28 days		%	1.0–3.0	1.0–3.0	1.0–3.0
Water vapor diffusion current density	DIN 52 615	g/(m^2 · d)	40	35	20
Water vapor diffusion resistance coefficient. Design value as specified in DIN 4108.		1	20/50	30/70	40/100

** 1 MPa $\triangleq$ 1 N/mm^2*

Table 2 Resistance of Styropor foam to chemical agents

Chemical agent	Styropor P + F
Salt solution (sea water)	+
Soaps solution and wetting agents	+
Bleach agents, such as hypochlorite, chlorine water, hydrogen peroxide	+
Dilute acids	+
36% hydrochloric acid, 50% nitric acid	+
Anhydrous acids (eg, fuming sulfuric acid, glacial acetic acid)	–
Sodium hydroxide, potassium hydroxide and ammonia solutions	+
Organic solvents such as acetone, ethyl acetone, benzene, xylene, paint thinner, trichloroethylene	–
Saturated aliphatic hydrocarbons, surgical spirit, white spirit	–
Paraffin oil, Vaseline	+ –
Diesel oil	–
Petroleum spirit	–
Alcohols (eg, methanol, ethanol)	+ –
Silicon oil	+

+ *Resistant: the foam remains unaffected even after long exposure.*
+ – *Limited resistance: the foam may shrink or suffer surface damage on prolonged exposure.*
– *Not resistant: the foam shrinks or is dissolved.*

Styropor FH is a grade for making foam with enhanced resistance to aromatic-free hydrocarbons compared with other Styropor grades.

The suitability of this product for a specific application must be tested in each case.

3.1 Physical properties

The most important properties of rigid Styropor foam are described in Tables 1 and 2.

The following properties are of most significance in road construction:

- closed cell structure, which means very low water absorption
- frost resistant and rotproof
- no breeding ground for pests, mould or putrefying bacteria
- biologically harmless (no danger to ground water, no ozone-damaging blowing agent)
- good performance under sustained static and dynamic loading.

3.1.1 Mechanical performance

EPS foam is a thermoplastic which exhibits visco-elastic behaviour when under load. This is why the compressive stress at 10 % compressive strain is quoted (DIN 53421) instead of the compression strength. This value lies well within the plastic region (the compressed material does not return to its original shape) and therefore is not used when designing.

The compressive stress/compressive strain curves in fig. 8 show that stress increases linearly until the limit of the elasticity is reached at 1.5 % to 2 % of strain, according to the density of the material. As permanent material deformation begins, the value of strain climbs more rapidly; however there is no definite break separating the elastic and plastic regions of the curve.

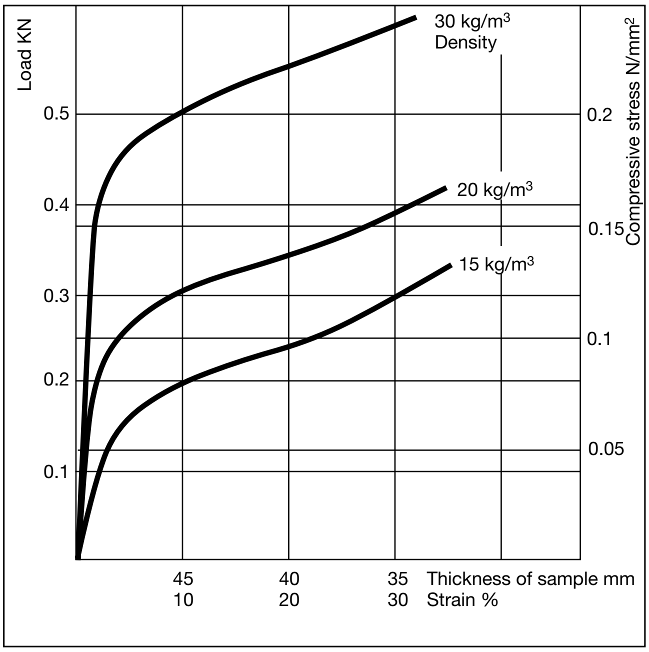


Fig. 8 Compressive stress – Compressive strain curves.

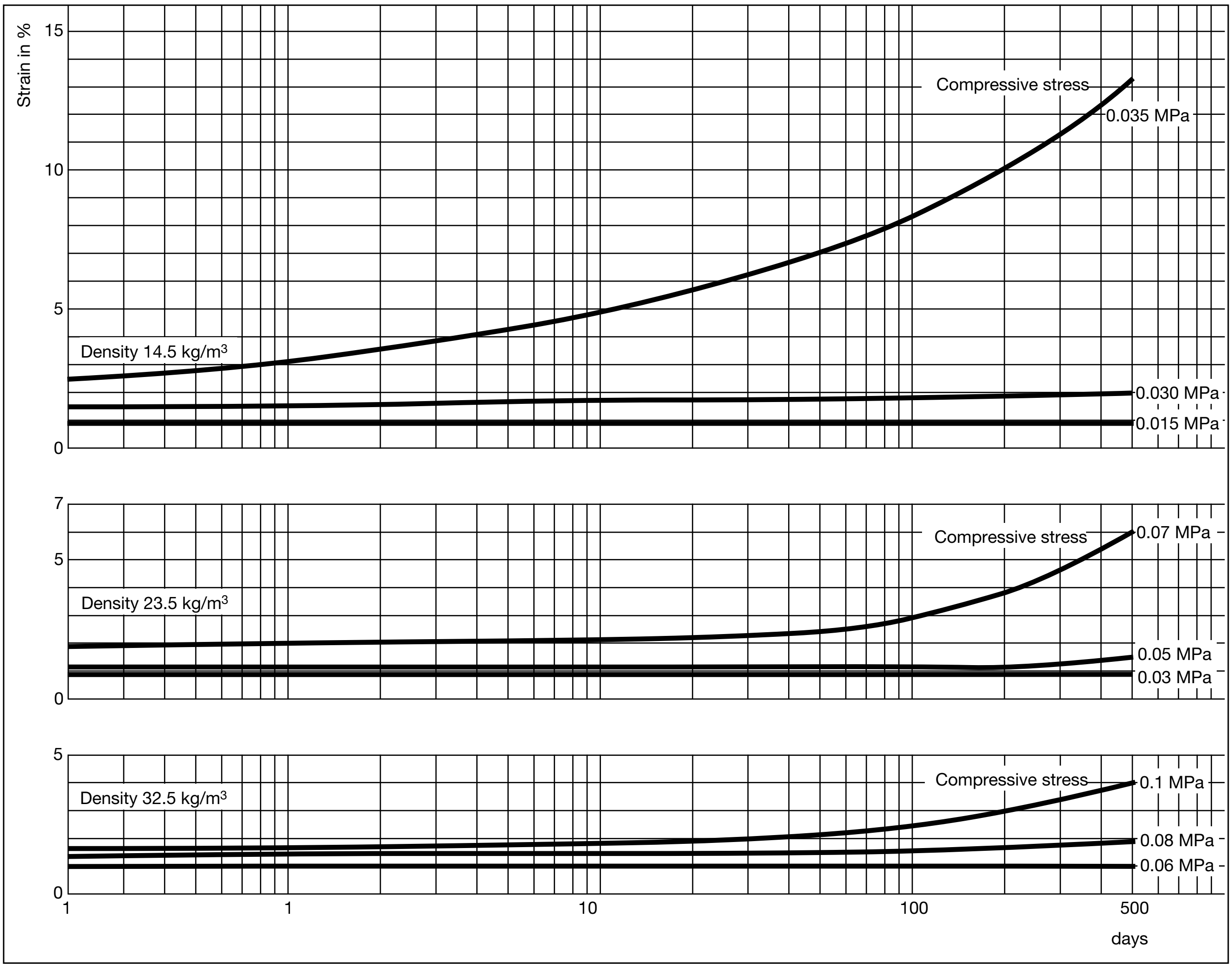


Fig. 9 The behaviour of Styropor foam under sustained loading for various loads and densities.

When designing for permanent loads, values must therefore be chosen which lie below the 2 % strain limit (fig. 9). Rigid EPS foam with a density of 20 kg/m^3 can sustain loads in the region of 0.025 to 0.050 N/mm^2 (2.5 – 5 t/m^2).

3.1.2 Behaviour towards chemicals

EPS foam is resistant to alkalis, soaps, dilute acids and salts (see Table 2). Organic solvents attack the foam to a greater or lesser extent. The long-term effects of the solvents contained in petrol and diesel fuel are the foam's shrinkage or partial dissolution.

Experience has shown that the upper layers of material that cover the foam are enough to protect it from small amounts of escaped fuel. When there are larger amounts of fuel involved (eg, a ruptured road tanker), the foam can be replaced at the same time as the contaminated earth is removed; this work would have to take place in any case – on environmental grounds.

Covering the foam substructure with PE sheeting gives it additional protection; however, this is not normally necessary.

3.1.3 Behaviour towards living organisms

Rigid EPS foam offers microorganisms no habitat. It does not rot or turn mouldy. Bacteria in the soil do not attack the foam. Animals can damage it by burrowing, but many years of road building experience have shown that they do not prefer it to other conventional insulating materials. EPS foams have no environmentally damaging effects and do not endanger water (crushed EPS waste is used in agriculture to break up and drain the soil).

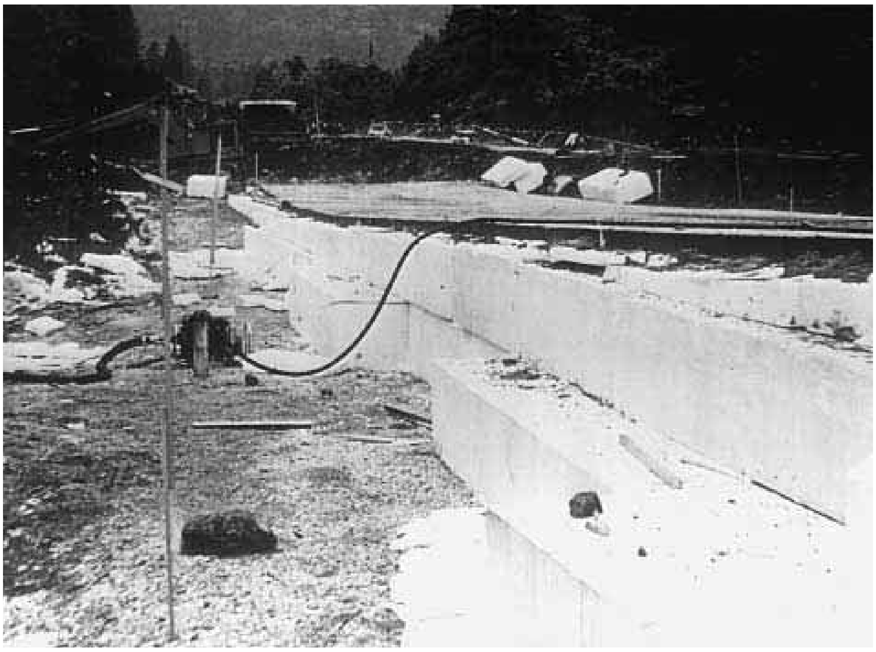


Fig. 10 An embankment in Norway built of EPS.

4 Experience in other countries

The first large stretch of road to use rigid EPS foam as a substructure was build in Norway in 1972 (fig. 10). This development was initiated by the Norwegian Road Research Laboratory in Oslo which, for many years, has evaluated the use of rigid EPS foam board as an antifrost layer in road and railway construction. Although positive results about this method of embankment construction were published, interest was initially confined to Scandinavia. It was in 1985, at an international road building conference in Oslo, that this construction method first caught the attention of experts from countries in which difficult soil conditions are common and where significant economic advantages were to be gained by the use of EPS foam rather than conventional materials (eg, in the polder areas of Holland, in southern France, USA, Canada and in Japan).

In the meantime, numerous data is available from research institutes in different countries on the theory and practical use of EPS in construction.

4.1 Areas of application

EPS is mainly used in the following areas of road construction:

Substructure on poor load-bearing subsoils

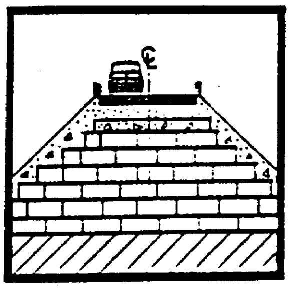
Reduced loads on subsoil. The most common application so far.

Backfill at bridge abutments

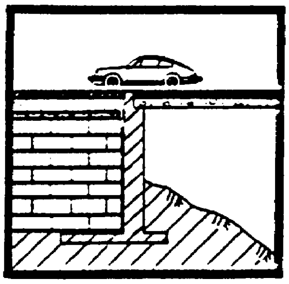
To reduce the earth pressure (caused by horizontal forces) and differential settlement at bridge abutments.

Valleyside roads

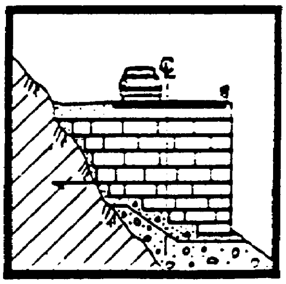
To reconstruct the slide areas of valleyside roads that have failed.



ROAD EMBANKMENTS
Reduced loads on subsoil compared to conventional embankment. Most common application so far.



ABUTMENT BACKFILL
to reduce earth pressure and differential settlement at bridge abutments.



EMBANKMENT FAILURE
Reconstruction of slide areas.

4.2 EPS quality assurance

The following are tested:

- Dimensional accuracy of the foam blocks
- Density (≥ 20 kg/m^3)
- Compressive stress (≥ 0.11 N/mm^2 at 10 % strain) according to DIN 53 421. For sustained loading, values can be relied upon which are 20 – 25 % of this measured value.
- Bending strength (≥ 0.22 N/mm^2 according to DIN 53 423).

The above tests are carried out on a representative sample of foam specimens.

The absorption of water (eg, ground water) is simply used to calculate the dead weight and has no effect on the mechanical properties of the foam.

Long-term experience in Norway has shown that even under unfavourable conditions the volume of water absorbed does not rise above 10 %. (For determining settlement, a weight of 1.0 kN/m^3 is used).

The flame resistance of EPS blocks complies with material class B 1 DIN 4102 P. 1 (difficultly flammable). The foam block must be stored for at least 2 weeks between manufacture and use.

4.3 Method of construction work

The following information on construction work is based on practical experience in the use of EPS techniques in different European countries:

The first layer of foam blocks is placed on a compacted levelling course. The amount of unevenness in the levelling course must not be more than 10 mm in 4 m; this guarantees a flat enough surface for laying the foam. All the layers of foam are positioned with a joint packing compound.

The coefficient of friction between the foam blocks is approximately 0.5. To avoid slippage when many layers are built, the blocks are bound to each other using either 2 spike grids or 2 spots of PUR adhesive per block (see fig. 11). Until now, heights of up to 8 m have been achieved. It is important to determine the height of the water table. Any lifting forces which occur as a result of the water level reaching the foam blocks must be compensated for.

Structures bordering the carriageway (eg, guard rails) may be anchored into the 10 cm-thick concrete layer that is usually placed above the EPS course to distribute compression. If such a layer of concrete is not used, an anchorage can be achieved by concreting in transverse beams between the Styropor blocks at set intervals to produce a formwork.

Steep-sided embankments (see fig. 12) can be drained of water by creating openings in the EPS substructure. Water channels can be cut into the foam blocks with a chain saw. Small holes and gaps between the blocks do not damage the substructure.

The sub-base course on top of the EPS substructure is always deposited ahead the of the advancing machinery. Compacting the loose sub-base course can be achieved with the usual equipment. Because of the vibrational damping behaviour of the EPS substructure, the sub-base course is, as a rule, layed down in several relatively thin layers and compacted by static means (eg, with a road roller as opposed to a pounding machine).

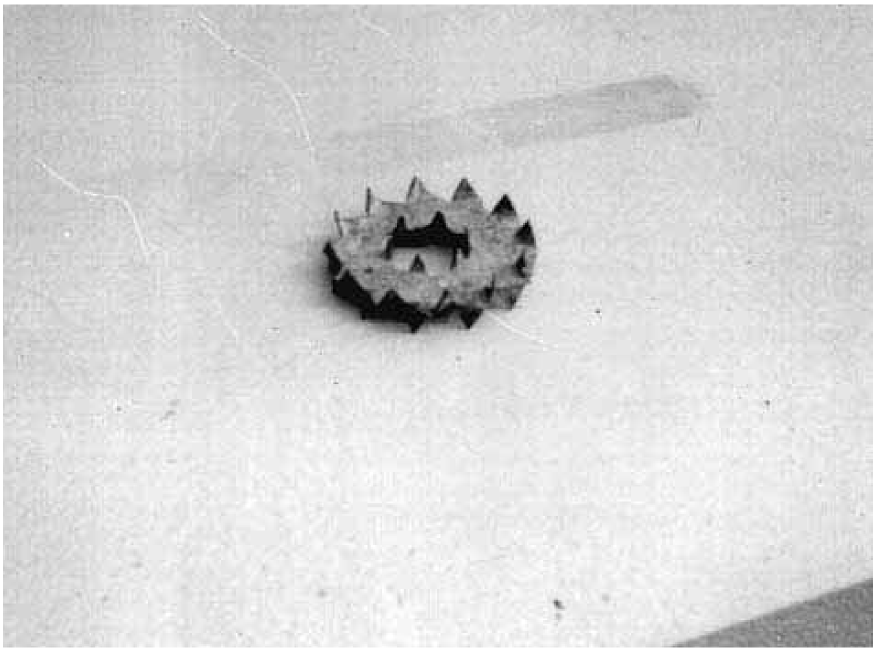


Fig. 11 Fixing the EPS blocks together by means of a spike grid.

Fig. 12 Draining a steep-sided embankment.

4.4 Design

When designing the road, the EPS substructure is viewed as a stratum with an elastic modulus of 5000 kN/m^2. In Holland, dimensioning was carried out based on this “linear elastic” multi-layer model with the aid of a computer program called CIRCLY; this proved to be accurate in practice.

In Norway, because of the many years of practical experience that has been gained, dimensioning is carried out on a “half empirical” basis. Here the thickness of the material above the EPS substructure is between 35 cm and 60 cm depending on the projected volume of traffic that will use the road.

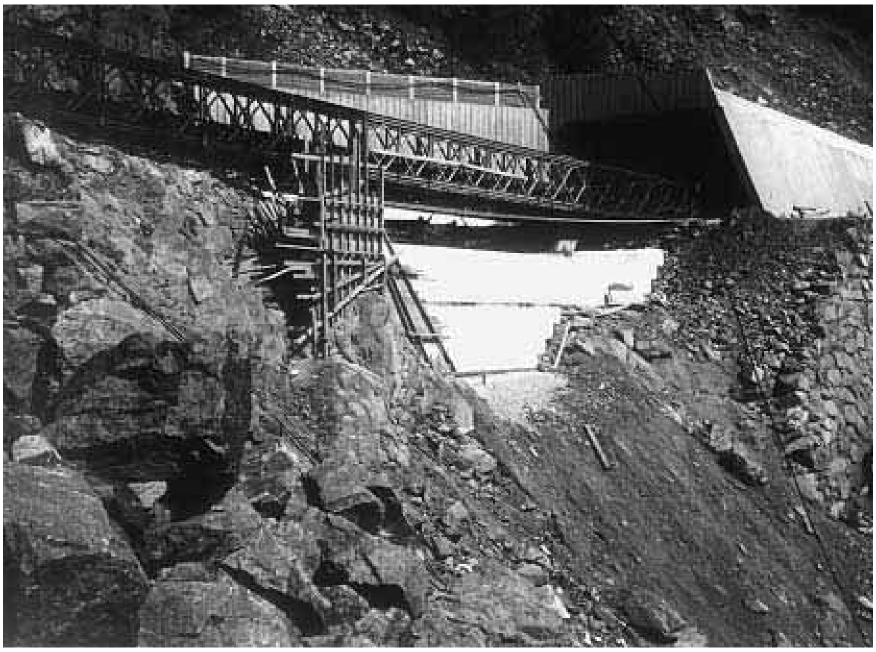


Fig. 13 Reconstructing a subsided mountainside road near Sougdahl in Norway using EPS.

As observations have shown up to now, there is no risk of early frost formation on the road surface if the layer above the EPS is thicker than 35 cm.

5 Prospects

In Norway, around 50000 m^3 of EPS foam block are used annually for road construction (see fig. 13). In Holland – mainly in the area of the polders – this construction technique has been increasingly used as an economic alternative since 1985. In 1988, on just one construction project alone (Capelle a/d Ijssel), 35000 m^3 of EPS foam were used to build an embankment.

In the period 1990–1991 in Sweden, between the towns of Stora Höga and Ljungskile (about 100 km north of Gothenburg) part of the Europastraße 6 was converted to a four-lane highway. Here 40000 m^3 of EPS foam were used owing to difficult soil conditions.

In the last 3–4 years, in the extremely difficult subsoil conditions of Japan (about 70 % of Japan consists of impassable mountains, a large part of the rest is moor and bog), success has also been achieved with EPS construction techniques based not only on experience from abroad, but also from much of the country’s own basic research (figs 14 and 15).

Today, the German Institute for Road Research is testing the EPS building technique using full scale models.

Simulations of sustained traffic loads are being carried out to understand the performance of the entire structure, with the aim of obtaining a reliable method for designing different variations of superstructure.

These findings, as well as the practical experience gained from abroad, are gathered together in a study on light-weight building materials by a working party from the German Road and Transport Research Association. Before drawing up a set of regulations, it is planned in the meantime to publish a paper entitled “Advice for the use of light-weight building materials in earthworks, Part 1: Rigid EPS foam”*.

** German: “Hinweise zur Anwendung von Leichtbaustoffen im Erdbau, Teil 1: EPS-Hartschaumstoffe”.*

6 Summary

The low resistance to shear of unstable soils that are subjected to excessive loads, leads to settlement and deformation which can often take place over many years.

Road construction – especially in the connecting areas around existing structures – frequently requires measures to be taken that involve the soil being replaced, but, on grounds of cost and environmental protection, these are becoming increasingly more difficult.

A largely subsidence-free construction is obtained when practically no additional loads are applied to the unstable subsoil; this means that the weight of the embankment should be extremely small. Styropor rigid foam (EPS) fulfils this requirement. Styropor was first employed

Fig. 14 EPS substructure (18000 m^3) at an abutment of the Kasai Nagisa Bridge, Tokio.

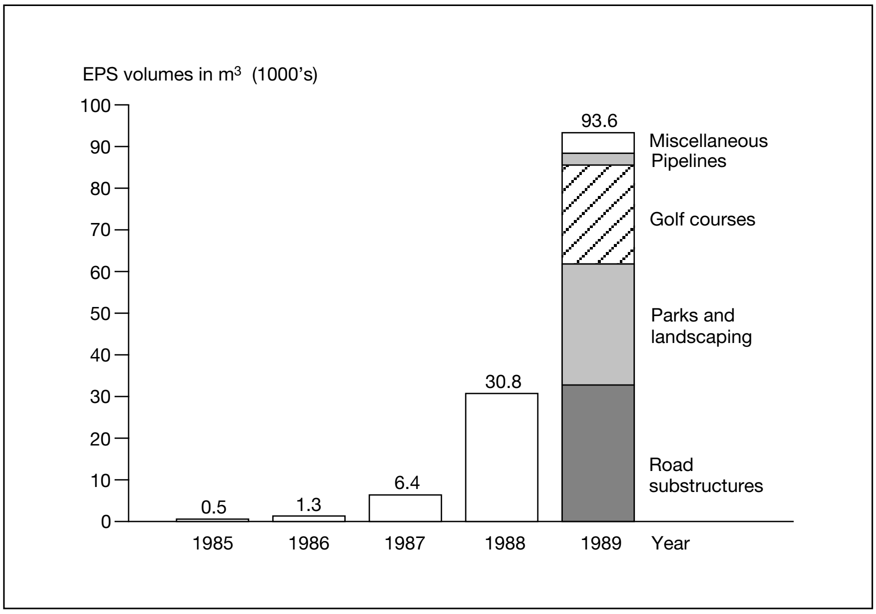


Fig. 15 Chart showing the development of EPS foam block in earthworks in Japan.

(mainly in Scandinavia) in the mid-1960's as a frost protection layer in road and railway construction. The years of positive experience which followed formed the basis for the development of a technique of building roads upon unstable subsoils using EPS. This construction method then won a place in road-building technology when, starting with Norway in 1972, blocks of EPS were used as a lightweight material for the first large stretch of highway. EPS was later used in other countries where difficult sub-soil conditions predominate, such as the polder area of Holland, in southern France, the USA, Canada and Japan. Also in Germany in areas where poor soil conditions exist, the EPS method of construction will be used increasingly as an economic alternative.

Bibliography

[1] Norwegian Road Research Laboratory: "Plastic Foam in Road Embankments" Schrift Nr. 61, Aug. 87

[2] Stichting Bouw Research, Rotterdam: "Wegen op PS-hardschuim" Schrift Nr. 176, 1989

[3] EPS-Construction Method Development Organization, Tokio 1989: "Technical Reports of Construction Method using EPS"

[4] F. Hohwiller, EPS-Hartschaum als Leichtbaustoff im Straßenunterbau, "Straßen- und Tiefbau", Heft 1/2.91

Note

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