6 Highway construction/ Ground insulation

Rigid Styropor foam as a lightweight construction
BASF material for highway foundations: GEOFOAM®

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 load-bearing 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 (e.g. in structures at highway intersections) 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 in poor subsoil conditions when practically no additional loads are brought to bear – i.e. by using extremely lightweight materials in the embank-

![Comparison of conventional and EPS embankment structures.](image)

Fig. 1 Comparison of conventional and EPS embankment structures.
ment such as blocks of Styropor foam (see Figs. 1 and 2).
Among specialists in the trade this type of construction is also known as the GEOFOAM method.

2 Experience to date

Experience with Styropor (EPS) foam panels used as frost protection for highways and railroads 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 (e.g. alpine regions, Canada and the Scandinavian countries) where the deeply penetrating ground frosts make it necessary to provide correspondingly costly frost-proof sub-bases for highways and railroads (see Figs. 3 and 4). With the appearance in 1984 of the code of practice "Stabilization of roadways with thermal insulation layers made from rigid foam plastics" by the German Institute for Road and Transport Research (Soil Mechanics Working Party), "antifrost construction methods" can now be ranked alongside other standard construction techniques.

The use of rigid EPS foam, not only for protective antifrost layers in the form of insulating panels, but as a load-transmitting substructure for highways and bridge approach ramps in the form of large blocks, is based on this practical experience and on the fact that lightweight (— approx. 20 kg/m³) Styropor foam possesses high bending and shear strength for distributing both dead weight and live loads over poor load-bearing subsoils. It therefore offers higher efficiency than conventional building materials (Fig. 5).

In Germany, the Lightweight Building Materials Study Group of the Working Committee for Highway Construction on Poor Load-bearing Subsoils in the aforementioned Soil Mechanics Working Party produced a "Code of practice for the use of rigid EPS foams in the construction of highway embankments" which was published in 1995 [6].

2.1 Economic efficiency

The price of rigid EPS is much lower than that of other foam materials, but in comparison 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. When this is done

Fig. 2

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

Fig. 3 and 4  Frost protection in highway and railroad construction using EPS rigid foam panels.
it turns out that, depending on local conditions, the Geofoam method certainly affords a technically and economically interesting solution. This is particularly the case for engineering structures (e.g. bridges, supporting walls, pipelines, etc.) where subsidence is to be avoided. Experience from abroad has shown that in certain cases it was possible to achieve a cost reduction of 50% by comparison with conventional building techniques. There are also obvious advantages when the filler material has to be transported to the construction site over long distances or special conditions have to be met on environmental grounds.

3 Rigid foam made from Styropor

EPS is the standard abbreviation for Expanded Polystyrene. The German standard used for rigid EPS foam as an insulating material in the building and construction industry is DIN 18 164, Part 1. Expanded foams made from Styropor have been produced worldwide since 1950 and they have mainly been used in the construction and packaging industries.

Starting with the beads of Styropor granulate, which contains a blowing agent, the manufacture of EPS foams takes place in three stages: preexpansion, intermediate aging and molding (Fig. 6). During the first stage, the granulate is heated and made to expand – rather like pop-corn when it is made (Fig. 7). The blowing agent contained in the raw Styropor is pentane, a naturally occurring hydrocarbon. The pentane expands the Styropor granules into individual closed-cell foam particles about fifty times their original volume. Next, the preexpanded material is stored to allow air to diffuse into it and the blowing agent partly to diffuse out. Finally, the preexpanded particles are placed in a mold 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 bulk density of the Styropor foam over a wide range. Because the properties of the material largely depend on its density, foams can be made with a range of application-specific properties: from insulating panels to light-weight construction material.

Styropor FH is a grade for making foams with enhanced resistance to aromatic-free hydrocarbons by comparison with foams made from 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, mold or putrefactive bacteria
- biologically safe (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 unusually for elastic materials exhibits viscoelastic behavior when under load. This is why the compressive stress at 10% compressive strain is quoted (DIN 53 421/EN 826) instead of the compression strength. This value, however, already lies in the range of irreversible compressive strain and is therefore only of infor-
Styropor Production

Styrene with additives

Water

Blowing agent (pentane)

Polymerization

Water

Delivery to the customer

Preexpansion

Steam

Styropor raw material

Steam

Molding

Transport screw

Intermediate storage

Styropor foam

Steam

Fig. 7

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## Table 1 Properties of expanded foams made from Styropor for building applications

<table>
<thead>
<tr>
<th>Properties</th>
<th>Test standard</th>
<th>Unit</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality grades</td>
<td>Quality terms</td>
<td>PS 15 SE</td>
<td>PS 20 SE</td>
</tr>
<tr>
<td>Application types</td>
<td>DIN 18164, Part 1</td>
<td>kg/m³</td>
<td>15</td>
</tr>
<tr>
<td>Minimum bulk density</td>
<td>DIN ISO 845</td>
<td>mm</td>
<td>35</td>
</tr>
<tr>
<td>Building material class (product type Styropor F)</td>
<td>DIN 4102</td>
<td>B1, flameproof</td>
<td>B1, flameproof</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>Measured value at ±10 °C</td>
<td>DIN 52612</td>
<td>mW/(m·K)</td>
</tr>
<tr>
<td></td>
<td>Calculated value</td>
<td>DIN 4108</td>
<td>mW/(m·K)</td>
</tr>
<tr>
<td>Compressive stress at 10% compressive strain</td>
<td>DIN 12089</td>
<td>kPa</td>
<td>65-100</td>
</tr>
<tr>
<td>Sustained compressive load-bearing capacity at 1.5–2% compressive strain after 50 years</td>
<td>ISO 785</td>
<td>kPa</td>
<td>20–30</td>
</tr>
<tr>
<td>Flexural strength (without foam skin)</td>
<td>DIN 53427</td>
<td>MPa</td>
<td>1.0–4.0</td>
</tr>
<tr>
<td>Shear strength</td>
<td>DIN 53430</td>
<td>MPa</td>
<td>150–230</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>DIN 53424</td>
<td>MPa</td>
<td>80–130</td>
</tr>
<tr>
<td>Modulus of elasticity (compressive tests)</td>
<td>ISO 826</td>
<td>kPa</td>
<td>150–230</td>
</tr>
<tr>
<td>Heat deflection temperature, short-term</td>
<td>DIN 53424</td>
<td>°C</td>
<td>100</td>
</tr>
<tr>
<td>Heat deflection temperature, long-term at 20 kPa</td>
<td>DIN 53434</td>
<td>°C</td>
<td>75</td>
</tr>
<tr>
<td>Coefficient of linear thermal expansion</td>
<td>DIN 53765</td>
<td>J/(kg·K)</td>
<td>1,210</td>
</tr>
<tr>
<td>Water absorption when kept under water, after 7 days</td>
<td>DIN 53434</td>
<td>vol.%</td>
<td>0.5–1.5</td>
</tr>
<tr>
<td>Water absorption when kept under water, after 20 days</td>
<td>DIN 53434</td>
<td>vol.%</td>
<td>1.0–3.0</td>
</tr>
<tr>
<td>Water vapor diffusion resistance coefficient</td>
<td>Calculated value by DIN 4108, Part 4</td>
<td>DIN 52615</td>
<td>20/50</td>
</tr>
<tr>
<td>1) Values are laid down in DIN 55471, Part 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2) Depending on test standard</td>
<td></td>
<td></td>
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</tbody>
</table>

\[1 \text{ N/mm}^2 = 1,000 \text{ kPa}\]

## Table 2 Resistance of Styropor foam to chemical agents

### Chemical agent

<table>
<thead>
<tr>
<th>Chemical agent</th>
<th>Styropor P + F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt solution (sea water)</td>
<td>+</td>
</tr>
<tr>
<td>Soap and wetting agent solutions</td>
<td>+</td>
</tr>
<tr>
<td>Bleaching agents, such as hypochlorite, chlorine water, hydrogen peroxide solutions</td>
<td>+</td>
</tr>
<tr>
<td>Dilute acids</td>
<td>+</td>
</tr>
<tr>
<td>36% hydrochloric acid, nitric acid up to 50%</td>
<td>+</td>
</tr>
<tr>
<td>Anhydrous acids (eg. fuming sulfuric acid, 100% formic acid)</td>
<td>–</td>
</tr>
<tr>
<td>Sodium hydroxide, potassium hydroxide and ammonia solutions</td>
<td>+</td>
</tr>
<tr>
<td>Organic solvents</td>
<td>+</td>
</tr>
<tr>
<td>such as acetone, acetate esters, benzene, xylene, paint thinner, trichloroethylene</td>
<td>–</td>
</tr>
<tr>
<td>Saturated aliphatic hydrocarbons, surgical spirit, white spirit</td>
<td>–</td>
</tr>
<tr>
<td>Paraffin oil, Vaseline</td>
<td>+ –</td>
</tr>
<tr>
<td>Diesel oil</td>
<td>–</td>
</tr>
<tr>
<td>Gasoline (regular and premium grades)</td>
<td>–</td>
</tr>
<tr>
<td>Alcohol (e. g., methanol, ethanol)</td>
<td>+ –</td>
</tr>
<tr>
<td>Silicone oil</td>
<td>+</td>
</tr>
</tbody>
</table>

+ = 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.
The amount of creep (%) occurring during this sustained loading is given by the difference between the initial and the total compressive strains. On grounds of safety the bulk density of the rigid Styropor foam blocks is to be chosen such that the planned loads bring about a total compressive strain of at most 1.5%.

This is illustrated by way of example in Fig. 9c. For a compressive load of 35 kN/m² a rigid Styropor foam having a bulk density of 20 kg/m³ is chosen. Its total compressive strain over a period of 50 years is 1.3% (≤ 1.5%). The initial compressive strain on application of load is 0.7%. The difference of 0.6% between the initial compressive strain (after completion of construction) and the total compressive strain yields the level of creep deformation of the rigid foam during the 50 years of operation of a highway structure.

In studies by the German Federal Institute for Highways [5] traffic loads were simulated by means of an impulse generator which are equivalent to a million wheel loads with a weight on the axle of 10 metric tons. In all variants the overburden height of the rigid Styropor foam blocks (of bulk density 20 kg/m³) amounted to 55 cm. The results showed that no permanent deformations of the rigid foam surface occurred as a result of the (simulated) live loads, i.e. formation of depressions could not be found. This has now been confirmed by experience in practice which has since been documented.

3.1.2 Behavior towards chemicals

Expanded foams made from Styropor are resistant to alkalis, soaps, dilute acids and salts (see Table 2). Organic solvents attack the foam to a greater or lesser extent. In the longer-term the action of the solvents contained in gasoline or diesel oil causes the foam to shrink or to start dissolving.

Practical trials have shown that the protection afforded by the upper layers of material usual in highway construction is enough to prevent damage to the EPS substructure from small amounts of escaped fuel. When larger amounts of fuel are involved (e.g. in a tank truck accident), 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 expanded foam substructure with PE sheeting gives it additional protection; however, this is not normally necessary.

3.1.3 Biological properties

Rigid EPS foams made from Styropor offer no breeding ground for microorganisms. It does not decay, rot or turn moldy. Bacteria in the soil do not attack the foam. Animals can damage it by gnawing or 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).

4 Experience in other countries

The first large stretch of road to use rigid EPS foam blocks as a substructure was built in Norway in 1972 (Fig. 10). This development was initiated by the Norwegian Road Research Laboratory in Oslo which, for many years, has gathered and evaluated experience gained in practice of the use of rigid EPS foam panels as an antifrost layer in highway and railroad construction (see "Frost J. Jord" series of publications from NRCC). Although positive results about this method of embankment construction were published, interest was initially confined to Scandinavia. It was only in 1985, when at an international road building conference in Oslo a report was given on the practical experience then extending over a decade, that this construction method first caught the attention of experts from countries in which difficult soil conditions are common (e.g. in the polder areas of Holland, in southern France, USA, Canada and in Japan). Here the Geofoam technique affords an economic alternative to conventional building methods.

In the meantime, numerous studies have become available from research institutes in different countries on the theory and practical use of the Geofoam method.

4.1 Areas of application

It is mainly used in the following areas of highway construction:

Substructure directly on top of 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

For rebuilding slide areas on valleyside roads with vertical construction on the valley side.

In order to reach the correct decision as to the appropriate construction method the following aspects have to be taken into consideration:

- the volume of traffic using the highway
- the subsoil conditions
- the prevailing water conditions
- the nature and extent of pre-stresses on the subsoil, and
- the local conditions, such as e.g. position of pipes and peripheral development.

In Germany the code of practice issued by the Institute for Road & Transport Research [6] should be followed when using the EPS construction method. This provides guidance inter alia on sizing and structural principles (see Fig. 11).

If the subsoil conditions and gradients permit it, method "A" with EPS in the lower part of the embankment is recommended. In this case without any restrictions on traffic loading it is possible not only to achieve maximum reduction in weight of the embankment but also no special measures are necessary for the foundations of road signs, barrier devices, etc. Where there are high traffic loads method "C" can only be implemented when there are adequately sized, load-distributing layers above the EPS and is probably only rarely employed in such cases.

4.2 EPS quality assurance

The following are tested:
- Dimensional accuracy of the expanded foam blocks
- Bulk density (≥ 20 kg/m³)
- Compressive stress (≥ 0.11 N/mm² at 10% compressive strain) according to DIN 53421. For sustained loading, values which are 20–25% of this measured value can be expected.
- Bending strength (≥ 0.22 N/mm²) according to DIN 53423.

The above tests are carried out on a representative sample of foam specimens according to the volume to be installed.

The absorption of water (e.g., when in contact with ground water) is simply used to calculate the dead weight and has no effect on the mechanical properties of the foam.

Many years of experience in Norway has shown that even under unfavorable conditions the volume of water absorbed does not rise above 10%. (For determining settlement, a weight of 1.0 kN/m³ is used.)

As long as the EPS blocks are made from Styropor F their fire behavior complies with building material class B 1 according to DIN 4102, Part 1 (flame-resistant). The foam blocks must be stored for at least two 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 lightweight construction techniques in different European countries.

The first layer of foam blocks is placed on a compacted leveling course. The amount of unevenness in the leveling 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 their joints offset with respect to one another.

The coefficient of friction between the foam blocks is approximately 0.5. To avoid slippage when several layers are built, the blocks are bound to each other using either two spike grids or two spots of PUR adhesive per block (see Fig. 12). So far 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 pavement (e.g., guard rails) may be anchored into the 10 cm-thick concrete layer that is usually placed above the EPS course to distribute compressive forces. If such a layer of concrete is not used, an anchorage can be achieved by casting concrete transverse beams between the Styropor blocks at set intervals, the blocks themselves acting as formwork.

Steep-sided embankments (see Fig. 13) can be drained of water by creating openings in the EPS substructure. Water channels can be cut into the foam blocks at the building site 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 deposited ahead of the advancing machinery. Compacting the loose sub-base course can be achieved with the usual construction site equipment. Because of the vibrational damping behavior of the EPS substructure, the sub-base course is, as a rule, compacted by static means in several relatively thin layers.

4.4 Design

When designing the highway, the EPS substructure is viewed as a stratum with an elastic modulus of 5 N/mm². In Holland, dimensioning calculations have been carried out on this basis using the "linear elastic" multi-layer model with the aid of a computer program called CIRCLY; these have proved to be reliable in practice.

In Norway, because of the many years of practical experience that has been gained there, dimensioning is carried out on a "semi-empirical" basis. Here the thickness of the material above the EPS substructure lies between 35 cm and 60 cm depending on the projected volume of traffic that will use the road (see Section 3.1.1).

As observations so far have shown, 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 50,000 m³ of EPS foam block are used annually for highway construction (see Fig. 14).
cost and environmental protection, these are becoming increasingly more difficult.

In Holland - mainly in the polder regions - 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), 35,000 m³ of EPS foam were used for embankment construction.

In the period from 1990 to 1991 in Sweden, between the towns of Stora Höga and Ljungskile (about 100 km north of Gothenburg) part of the European Route 6 was converted to a four-lane highway. Here 40,000 m³ of EPS foam were used owing to difficult soil and terrain conditions.

Since 1985, the EPS construction technique has been successfully applied (Fig. 15) in the extremely difficult subsoil conditions of Japan (about 70% of the area of Japan consists of impassable mountains, a large part of the rest is moor and bog). This has been based not only on experience from abroad, but also on the country's own basic research [8].

In the Federal Republic of Germany the EPS method was tested on a practical scale in the course of a research project conducted by the German Institute for Road and Transport Research and published as a set of regulations (code of practice) [6]. Since 1995 the Geofoam technique has also been finding increasing application in Germany as an economic alternative [9].

6 Summary

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

Road construction - especially in the area adjoining existing structures - frequently requires measures to be taken that involve the soil being replaced, but, on grounds of...
References

[1] Norwegian Road Research Laboratory: "Plastic Foam in Road Embankments" Publication No. 61, Aug. 87


Note

The information submitted in this publication is based on our current knowledge and experience. In view of the many factors that may affect processing and application, these data do not relieve processors from the responsibility of carrying out their own tests and experiments; neither do they imply any legally binding assurance of certain properties or of suitability for a specific purpose. It is the responsibility of those to whom we supply our products to ensure that any proprietary rights and existing laws and legislation are observed.

Fig. 14 Reconstruction of a mountainside road damaged by landslide using a vertical EPS construction method (h = 5 m, Sougdahl, Norway)

Fig. 15 EPS substructure (18,000 m³) at an approach to the Kasai Nagisa Bridge, Tokyo