Meddelelse nr
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Plastic Foam in Road Embankments

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Ø. Myhre	EPS — material specifications
G. Refsdal	EPS — design considerations
R. Aabøe	13 years of experience with EPS as a lightweight fill material in road embankments
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This report is written on request of NRRL, but any views expressed by the authors are not necessarely those of NRRL.

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PREFACE

Problems with road building on soft and compressible subgrade is a constant challenge to Norwegian road engineers. When super-lightweight blocks of expanded polystyrene (EPS) were proposed by NRRL to solve settlement problems on road traversing a peat area just outside Oslo in 1972, it was the first EPS fill ever constructed. Thirteen years of experience with the use of EPS in frost protection of road pavements indicated that the material would be good enough also in a road fill.

Following a rapid growth of this construction method a one day conference was held in Oslo, Norway on June 22, 1985. The conference was attended by 150 delegates from many countries. In this volume, papers by NRRL authors to this conference are presented as well as several case histories. Together they give a state of the art for the use of EPS in road embankment.

SOFT GROUND PROBLEMS

OUTLINE OF ALTERNATIVE SOLUTIONS AND THE VARIOUS APPLICATIONS OF EXPANDED POLYSTYRENE AS A LIGHT FILL MATERIAL IN NORWAY.

by Tor Erik Frydenlund, Senior Engineer, NRRL

Difficult soil conditions encountered in road construction and construction activities in general have caused different solutions to develop in different areas depending on the local ground conditions and availability of suitable construction materials. When discussing the use of expanded polystyrene as a light fill material in road embankments and for other purposes, it is therefore useful to consider the development of this method in relation to other solutions available and varying soil conditions.

Soft ground conditions

When applying a load to the ground, two conditions must be considered to avoid «failure» or malfunction of the structural element carrying the load, e.g. a road embankment:

- Bearing capacity of the subsoil
- Settlement characteristics of the subsoil

As a rule it is an absolute requirement that the bearing capacity of the subsoil is sufficient to sustain the load. This follows from the hazards encountered should part of the road fail. Regardless of road class it is therefore necessary to make a design which provides a certain factor of safety against bearing capacity failure.

As to settlements, certain amounts may be accommodated without malfunction of the road. If settlements become excessive, however, traffic hazards may result either directly due to inferior riding quality or indirectly due to water problems caused by improper runoff from the road surface.

Often it is not possible to reduce settlements altogether within reasonable costs, but expected settlements should be considered and their effect on the particular stretch of road evaluated prior to construction in order to adopt a suitable design with minimum future maintenance.

Difficult soft ground conditions are often encountered in areas below the former marine level where soft clay deposits are likely to be found. This is the case in the most densly populated areas in Norway where the major part of the road network is located. Clay with a high content of fines ($< 2\ \mu m$) and high water content may cause both bearing capacity problems and settlement problems.

Also in non-cohesive materials (sand/gravel deposits) with a high content of organic matter, settlement conditions should be considered. As the content of organic matter increases in soils, both bearing capacity and settlement may be a problem, with peat deposits representing one end of the scale.

Alternative solutions

In general six different approaches may be employed when soft ground problems are encountered in connection with road construction:

- Adjusting road alignment
- Soil improvement
- Soil replacement
- Load transfer to firm ground
- Counter weights
- Load reduction

Adjusting road alignment

When soft ground areas are limited in size, an obvious choice would be to bypass the problem by realigning the road. On the other hand, in built up areas the cost of superior sites are high and sometimes not available for road construction purposes. Also when the soft ground areas are large, it is sometimes also a matter of minimizing the soft ground problems by adjusting the road alignment.

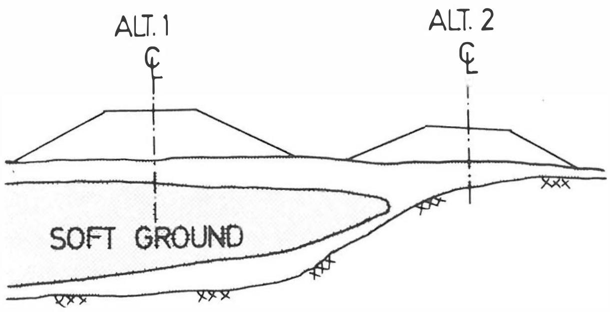


Fig. 1 Alternative road alignments.

Soil improvement

Load increments

When the load is applied gradually and time is allowed for settlements to occur between each load increment, the bearing capacity is improved with the increasing load. To control settlements after the construction is completed, a surcharge which is later removed, may also be applied. A disadvantage is that the process is time consuming and this limits its applicability. For road construction purposes this procedure may be used in areas with subsoils consisting of silt and clayey silt while limited construction periods usually prohibit such an approach on clay.

Vertical drains

To speed up the consolidation process vertical drains may be employed. This involves either installing sand columns or prefabricated drains consisting of a plastic ribbon with logitudinal drainage paths wrapped in a filter cover (paper or geotextile fabric). When loads are applied, increased porewater pressure in the subsoil will set up a hydraulic gradient towards the drains, allowing excess porewater to escape more rapidly. The distance between drains is usually adjusted to allow 70-80 % of calculated total settlement to occur within a year. Beside settlement control increase in subsoil strength may also be obtained depending somewhat on the amount of soil disturbance introduced when installing the drains. Depending on soil strength it may also in this case be necessary to apply the load in increments.

In Norway this method is not commonly employed for road construction purposes.

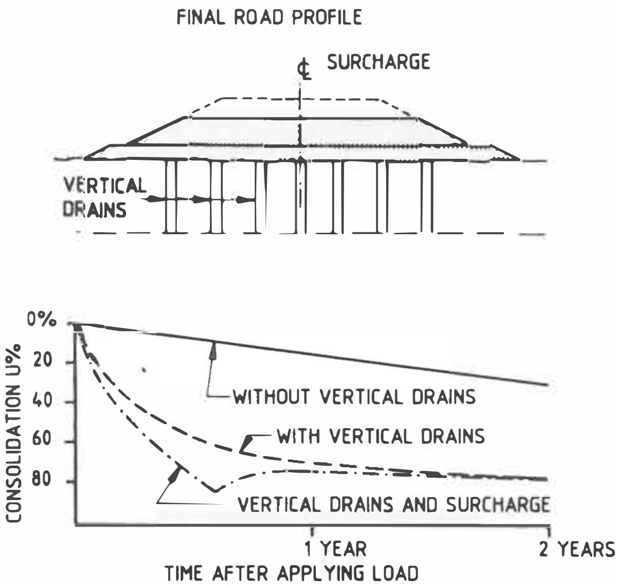


Fig. 2 Effect of vertical drains on consolidation.

Chemical treatment

The strength and settlement characteristics of clay may be improved by adding certain chemicals. The increase in strength is partly due to chemical bonding between soil particles and partly due to a reduction in water content since the chemical process binds water. Among the chemicals most commonly applied are lime and sodium or calcium chloride.

Lime may either be used for stabilizing the top subsoil layer by mixing clay and lime with a mechanical mixer or to produce lime columns. A special mixing device is then required to perform the mixing down to the required depth.

Common column dimensions employed are diameter 0,5 m and maximum depth 10 m. Lime columns may both improve stability and settlement conditions. So far lime columns have only been used on a couple of road projects in Norway, and then as a stabilizing factor to improve stability conditions.

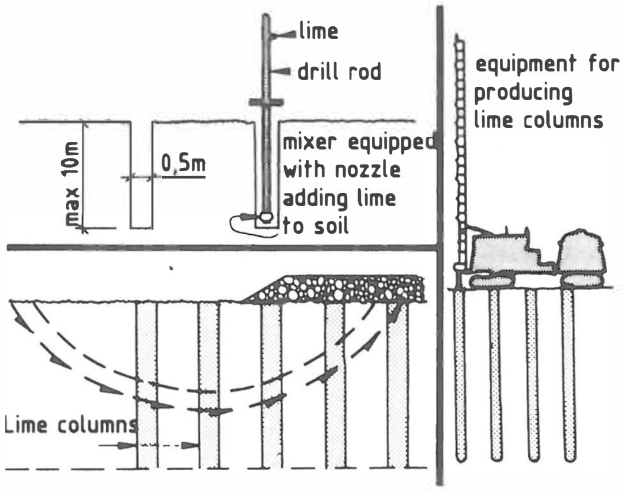


Fig. 3 Lime columns.

If salt ions are added to soft sensitive clays, the chemical bondage between the mineral particles is strengthened and the soil strength increased. A practical application of this effect is to establish salt wells by drilling or jetting holes in the ground and filling these with salt. The hole diameter may be of the order of 0,15 m and the distance between holes are adjusted according to the time available for soil improvements to take place. Typically a distance of 0,8 m between holes may provide a 100 % increase in shear strength over a period of 2 years. Apart from the increase in soil strength, settlement characteristics are also improved due to the binding of water in the chemical process. The method has so far seen only limited application in Norway.

Electrochemical treatment

It is also possible to remove water from soil in situ by applying an electrical potential to electrodes inserted into the ground. An electric current will then flow releasing water at the cathode. The method is applicable to clay or fine grained silty soils and has so far only been applied to limited volumes of soil. Due to the electrical hazards of high currents, the area must be fenced off. The reduction in water content will improve both soil strength and settlement characteristics.

Dynamic consolidation

Soil density and strength may be improved by pounding the soil surface with heavy weights. For large depth effects heavier weights must be employed. This method is suited for cohesionless soils and not applicable to soft cohesive soils.

Soil replacement

Often it may be economically more advantageous to replace soft soil than to improve the soil on site. The obvious approach is then to excavate the soft soil and replace it by firmer soil (rock, gravel, sand). In order to obtain proper compaction of the backfill material, water, if possible, should be removed from the excavation pit. Possible depth of excavation may, however, be limited due to low shear strength of the soft soil. Necessary excavation width is indicated on figure 4.

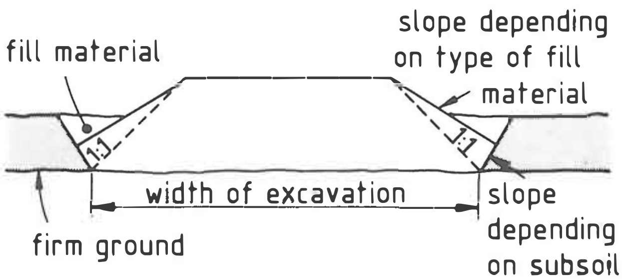


Fig. 4 Soil replacement by excavation.

In areas where the layer thickness of the soft soil exceeds the stable excavation depth, the soft soil may be displaced by a fill of coarse aggregate, preferably a rockfill assisted by blasting if necessary. The rockfill, with excess height, is pushed forward by bulldozer continuously overloading the soft subsoil. The remoulded soil is squeezed up in front of the rockfill where it may be removed by excavation. Account of displaced soil volume and hence the efficiency of the operation is kept by recording the volume of rockfill used. The displacement efficiency may be improved by setting off dynamite charges in front of the fill, say for every 5 m of fill advancement. The dynamite, 2-10 kg per charge, is installed in tubes placed along the front fill perimeter 2-3 m apart.

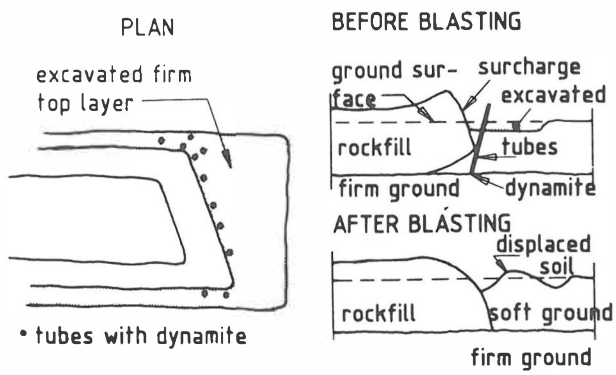


Fig. 5 Soil displacement by blasting.

When the fill is completed, additional blasting may be performed by installing charges along the sides of the fill. This procedure will prevent long term sideways deformations of the fill.

This method is commonly applied in Norway when cheap rockfill aggregate is available, and has been successfully employed in displacing layers of soft subsoil 10-15 m thick. The stability of adjoining areas must, however, be considered.

Load transfer to firm ground

An alternative to soil improvement or soil removal is to transfer loads through the soft soil to firmer layers. In some cases this requires a bridge construction, but a solution may also be achieved by founding the embankment on piles, either wooden piles or concrete piles depending on the loads to be carried. The piles are capped by concrete slabs mounted on the pile head, thus covering a certain percentage of the total fill area.

In general this method is somewhat expensive, but cots will vary with embankment height and thickness of the soft soil layer.

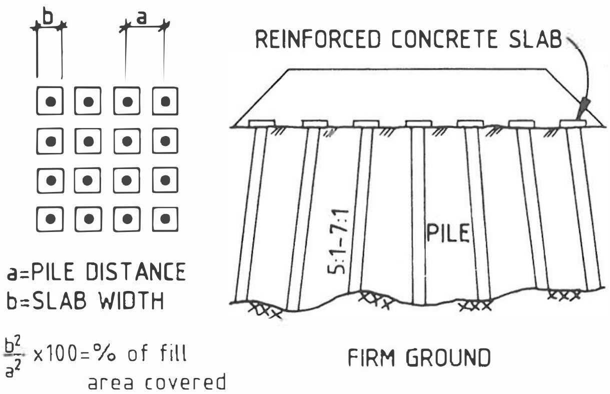


Fig. 6 Embankment load carried by piles.

Counter weights

When the height of the road embankment exceeds the bearing capacity of the soft subsoil, apart from the methods mentioned above, sufficient stability conditions may be achieved by adding counter weights to the sides of the embankment. This is by far the most commonly applied method as even material of inferior quality may be used for counter weights as long as sufficient weight is achieved. Furthermore the surface of the counter-weights or berms may be adjusted so that it may still be used for agricultural or other purposes. However, adding counterweights will also add to settlements both in total magnitude and in time.

Load reduction

The most obvious solution to overload problems is of course to reduce the load. For road construction purposes this may be achieved in several ways. If the longitudinal profile of the road may be altered, the embankment height can be reduced where the road crosses soft ground, keeping the loads and settlements within permissible levels.

However, in many cases the longitudinal profile cannot be altered at all or not altered sufficiently. Reducing the embankment load by applying light fill materials may then be considered.

Bark and sawdust

Traditionally wastes from the timber industry like bark and sawdust have been employed as a light fill material for many years in this country. To prevent decay, the fill material should be kept moist and access of oxygen prevented by covering the slopes with materials of low permeability. For stability calculations a nominal design density in the moist condition of 1 t/m^3 is used. Both fills of sawdust and bark have performed well but in general it is not recommended for use in major roads with layer thicknesses exceeding 0,5 m and 3 m in minor roads. Also due to internal settlements, bark is not recommended in fills adjoining bridge abutments where differential settlements may occur. In general internal settlements of 10 % of the total layer thickness may be expected in bark fills.

Drainage water from bark fills may also represent a pollution hazard, and bark fills should not be used near wells or other drinking water reservoirs.

In recent years sawdust and bark residue have become somewhat sparse for road construction purposes as other applications have been introduced (heating purposes, soil improvement for agricultural purposes etc.). Previously the residue represented a problem for the timber industry and the road builder only had to pay for haulage to the construction site.

Cellular concrete and light expanded clay aggregate

Both waste from cellular concrete production and production of building blocks with light expanded clay aggregate may be used as a light fill material in road construction in addition to light expanded clay aggregate (Leca) as such. Leca may have a dry unit density of 350-800 kg/m^3 depending on the gradation. In Norway a dry density of 600-800 kg/m^3 is usually specified, including waste material from block production. Expected volume reduction due to placing and compaction is of the order of 10-15 %. For stability calculations a nominal unit density of 800-1000 kg/m^3 is used depending on the particular gradation employed.

Cellular concrete may be used in much the same way as Leca. It absorbs water more readily and the nominal density used for calculations is 1000 kg/m^3. Also the volume reduction when placed and compacted is somewhat greater than for Leca (50 %).

Other light fill material is available in the form of fly ash and slag from power plants and other industrial processes. Also volcanic pumice may be employed. The densities are, however, somewhat higher. In Norway such materials are not readily available.

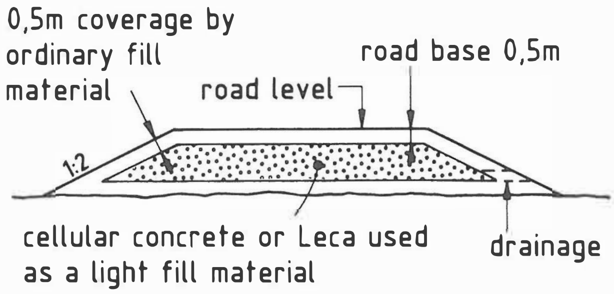


Fig. 7 Cellular concrete or Leca used as a lightweight fill material

Expanded Polystyrene

Frost protection of roads

Since 1965 various sorts of insulation materials have been tested for road frost protection purposes in Norway, and among these boards of polystyrene. An extensive test programme was then carried out on polystyrene materials, both expanded and extruded, to investigate compressive strength under repeated loading, and water absorbtion properties in particular. From these tests the material properties of polystyrene are fairly well known. One particular quality is the extremely low unit density of the material, approximately 20 kg/m^3 when delivered from the producer.

A total distance of approximately 150 km of roads have since been provided with frost insulation using 5-10 cm thick polystyrene boards. Mainly the extruded type has been used for this purpose since its resistance to water pickup is superior to the expanded type. Also the compressive strength is higher. Such use of extruded polystyrene (compressive strength 350 kN/m^2) with a pavement «cover» of 30-50 cm has not given any strength problems. Even in the (few) cases when expanded polystyrene has been employed (compressive strength 150 kN/m^2) for frost protection, good results have been obtained. Based on this experience it was clear that from a technical point of view it would not matter if the thickness of polystyrene material was increased from 5 cm to 50 cm or even to 500 cm.

Polystyrene as a light fill material

In 1972 when reconstruction of a 85 m long road section on NR 159 was considered, the use of polystyrene in greater thickness than the insulation boards was looked into at the Norwegian Road Research Laboratory for the first time. At the particular site the road, including a short bridge, crosses a peat bog and every year 10 cm of settlements had to be compensated. The idea that emerged was that if blocks of polystyrene could be used to replace the exixting road fill adjoining the bridge abutments, a considerable reduction in the load on the subsoil would be achieved and reduced settlements could be expected.

Due to its low unit density polystyrene only exerts a fraction of the load caused by ordinary road construction materials. Although the consept at the time appeared rather unusual, there were no reasons why this should not work. It was therefore decided to replace 1 m of the existing road fill with polystyrene blocks using a pavement of 50 cm on top.

The fill was successfully completed and the expected reduction in settlements achieved. Today further movemements have nearly stopped and no adverse effects have been observed neither to the road structure or otherwise.

Special advantages

Since the first fill in 1972, the use of polystyrene blocks as a light fill material has developed rapidly, and has now become a standard practice in road construction in Norway. Polystyrene fills of varying sizes from 0,5 m to 6 m in thickness and volumes from a few hundred m^3 to several thousand m^3 have been constructed. From 1972 to 1980 a total volume of approximately 35.000 m^3 was used for road construction purposes while today approximately 35.000 m^3 is used anually approaching a total volume near the 150.000 m^3 mark.

Why has expanded polystyrene (EPS) in many cases proved to be an advantageous method compared to alternative solutions available?

The major advantage is of course its low unit density (20 kg/m^3) as already mentioned. Although a design value of 100 kg/m^3 is applied for stability and settlement calculations to allow for some increase in water content over its service life, this is by far a lighter fill material than other light fill materials commonly used in road construction.

Apart from the small forces it exerts on the subsoil, the low unit density of course also makes EPS easy to handle on site. One EPS block of normal size (0,5 x 1 x 3 m) can easily be handled by one man as it only requires a lifting force of 300 N (30 kg) to be moved. Furthermore cranes on site can handle whole truckloads in one unit, placing the blocks on the required spot.

Also the material is easily formed and adjustments to block shapes can be made by hand or chain saw or even with a knife if necessary to shape details where the EPS fill joins on to other structures like bridge abutments, drainage systems and so on.

With the low unit density it is furthermore possible to haul large quantities in one truckload. In general one truck with trailer may take up to 100 m^3 of EPS-blocks, the limiting factor beeing the freight volume rather than freight load. This of course keeps transportation costs down.

The combined effect of low transportation cost and a distributed net of factories around Norway make the material easily accessible for most sites across the country.

Also the production capacity of one EPS plant is fairly high. Working shifts, the manufacturers quote that one unit may produce a maximum of 350 m^3 per day. The required volume of EPS-blocks for a fill of say 1500 m^3 therefore theoretically represents one weeks production on one unit. However, since EPS products for other purposes are also in demand, the time from order to delivery may be somewhat longer depending on the season. With the low transportation cost, however, one could also consider import of EPS-blocks from more distant factories in cases of high demand locally.

Finally both the availability of EPS-blocks, transportation in large volumes and easy handling on site assist in achieving short construction times.

Economical and technical aspects

When considering the cost of EPS blocks the present rates quoted in Norway are of the order of 220 NOK/m^3 (1985). When comparing the cost of different light fill material, one should, however, bear in mind that it is the cost per unit of load reduction compared to ordinary road fill materials that should be considered, transportation costs included, since it is weight reduction which is aimed at.

Assuming an average unit density of 1 800 kg/m^3 for ordinary road fill materials, the following picture of cost comparisons is achieved for light fill materials in Norway with varying transportation distances. Apart from material costs, volume reduction and cost of placing and compacting are also considered.

However, in cases where other materials compete favourably on price, they are not always readily available (e.g. sawdust and bark). In some cases EPS

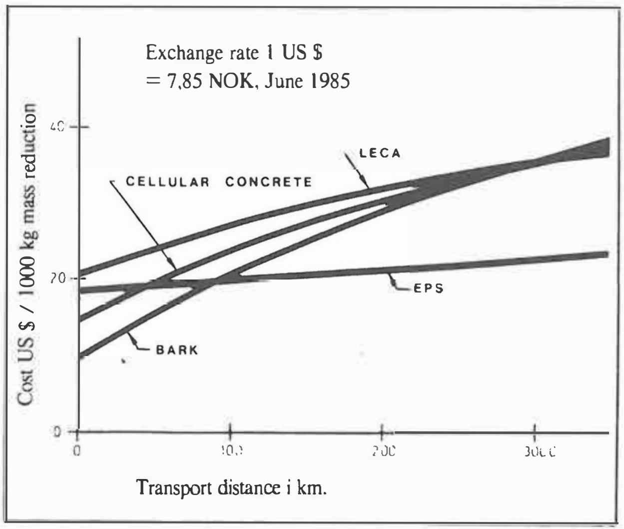


Fig. 8 Relative costs of different light fill materials.

represents the only choice if a certain weight reduction is to be achieved.

In Norway EPS will also in most cases compete favourably with soil improvement methods like lime columns and salt wells, as well as vertical drains and piling. Depending on the local conditions soil replacement/displacement and counter weights will often provide a cheaper solution if applicable, but for technical reasons EPS may still be preferred. On a particular job conditions may vary from the previous job, and all aspects should be considered before selecting a particular design solution.

Various applications of EPS

Apart fron being used in ordinary road fills to control bearing capacity and settlements of the subsoil, special applications of EPS have also developed. To reduce the horizontal earth pressure on bridge abutments EPS blocks are advantageous. Furthermore the problem of differential settlements between the bridge and the adjacent fill will be reduced.

Solutions involving termination of EPS fills in a free vertical wall, only covered with some protective material like metal sheets, have also been adopted. Furthermore designs utilizing the buoyancy effect of EPS when submerged have been successfully completed. Other applications have been to reconstruct areas where landslides have occured and to compensate the load from buildings.

Various new concepts have also been introduced recently, and more variations are likely to occur in the future.

Global applications of EPS fills

To our knowledge the use of EPS blocks as a light fill material have so far, apart from Norway, been adopted in France, the Netherlands and Sweden in Europe. Also in Canada major road construction prodjects involving use of EPS blocks have been completed.

The method may of course have been used in other countries too. Considering the extent of soft ground deposits across the globe, one should expect that there exists construction projects where EPS would compete favourably with alternative solutions. It is therefore expected that EPS as a light fill material will see a wider use in the future both geographically and in modes of application.

EPS - MATERIALS SPECIFICATIONS

by Øistein Myhre, Senior Engineer, NRRL

Summary

A certain compressive strength and uniform block dimensions are considered to be the most important requirements. Density is not considered to be important as far as the function of the fill is concerned. Fire resistant (non-flammable or self-extinguishing) EPS is not generally specified for road embankment applications in Norway. Moisture pickup characteristics will be reason ably good as long as the specified compressive strength is satisfied.

1. Function

What we neeed is a material that can establish a stable volume with very low weight and sufficiently strong enough to take dead and live loads from the pavement and the traffic. The purpose is, of course, to reduce the loads transmitted to the weak subsoil.

2. Fundamental properties to be considered

2.1. General considerations

The major properties that have to be considered for blocks of expanded polystyrene (EPS) are, as far as the construction of super light embankments is concerned:

- Mechanical properties, i.e. compressive strength
- Geometrical size and uniformity
- Resistance against moisture pickup
- Chemical resistance (solvents, fire)
- Long time properties (aging, disintegration, resistance against microorganisms etc.)

The compressive strength is considered to be of major importance in order to prevent large deformations of the EPS material. Generally speaking, it takes a certain amount of polymer material to obtain a certain compressive strength. Beyond this, the density of the material does not count among the major properties that have to be considered. Trade qualities of EPS are super light (about 20 kg/m^3), and minor deviations in the density is not of any importance at the design stage.

The geometric size and uniformity is of great importance in order to get a stable construction and a trouble-free fitting of the layers.

The moisture pickup characteristics are important for the long term behaviour of the fill. Stability problems might occur if the blocks pick up too much water, which means added weight.

Solvents, e.g. petrol, will dissolve EPS. Precautions against accidental fire can be taken by ordering special fire resistant qualities of EPS.

Trade qualities of EPS have good resistance against the environment represented by the soil and against microorganisms and rodents. Overall long term performance is good, as reported elsewhere in this publication.

2.2. Material requirements - current specifications

The Norwegian Road Research Laboratory (NRRL) has put down the following requirements for blocks of expanded polystyrene (EPS) as a lightweight fill material:

2.2.1. Compressive strength

The compressive strength may be determined by the use of an unconfined compression apparatus. The test specimens should be 50 x 50 x 50 mm. The requirements are:

An average of minimum 100 kN/m^2 at 5 % compression (2.5 mm) shall be reached for each block. Single measurements should not be less than 80 kN/m^2.

2.2.2. Geometry

The polystyrene blocks shall be cut at right angles and with even sides as specified below. The requirements are:

Max. allowable deviation from the given dimensions of width, length and height of the blocks is $\pm$ 1 %. The evenness measured with a 3 m straightedge on the horizontal surfaces of the blocks (top and bottom when placed in the fill) shall be within 5 mm. The smallest dimension of the blocks shall be 0.5 m unless a different dimension is specified.

In order to fulfill these requirements, the manufacturer may have to cut the blocks prior to delivery.

2.2.3. Quality control of expanded polystyrene

The quality control should take place before the blocks are placed in the fill. The compressive strength should be measured on specimens cut from a block as shown in figure 1.

Two test specimens should be taken from each of the three columns as shown in figure 1, one in the middle and one in the end of the column. That is, a total of 6 specimens from each block. The size of the specimens should be 50 x 50 x 50 mm. The compressive strength

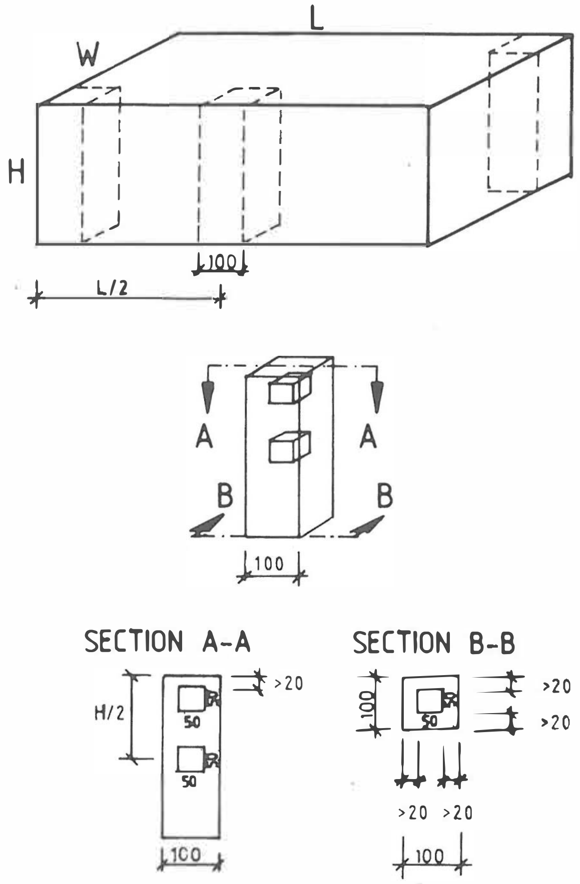


Figure 1. Outline of one EPS block. The dotted lines show the three columns that are cut from the corners and the side of the block. The size of the columns should be 100 x 100 mm x block height.

and the geometry should be checked on the following number of blocks:

Fill volume, m^3	Minimum number of blocks
Less than 500	3
500 - 1000	4
More than 1000	5

2.3. Fire resistance

In Norway, the normal quality of EPS for road embankment applications is of the flammable (non self extinguishing) type. No general specifications have been put down with respect to the fire resistance of the material.

Future specifications may call for a minimum oxygen index when self-extinguishing (non-flammable) EPS has been specified. Decisions when to specify the self-extinguishing EPS will depend on several things outside the scope of this chapter.

2.4. Moisture pickup

At present, there is no quantified specification with respect to the moisture pickup of EPS. This is not likely to cause much trouble under normal conditions, as long as the current design procedures calculate with a design density of 100 kg/m^3.

Future specifications may call for requirements with respect to moisture pickup or bonding characteristics in order to bring design density down.

3. Comments on the specifications

3.1. Compressive strength - testing procedure

As mentioned above, the specimen size should be 50 x 50 x 50 mm.

The testing equipment is an unconfined compression apparatus with a load capacity of more than 0.25 kN and a displacement range of more than 2.5 mm. The rate of compression is 4 mm/min.

Specimens are cut by using a fine-edge saw or a hot wire. There are no specifications with respect to conditioning of the specimens. It is, however, recommended that the specimens are brought to a dry condition before the compression test is carried out. This will be achieved by storing the specimens in a heater at 60 degrees C for 24 hours.

The compressive strength will somewhat depend on several conditions: Specimen size, rate of compression, temperature, specimen age and the degree of aging. There is also a fairly good correlation between specimen density and compressive strength.

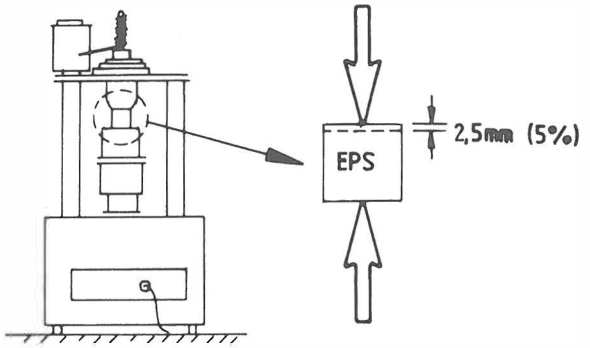


Fig. 2. Compression test set-up.

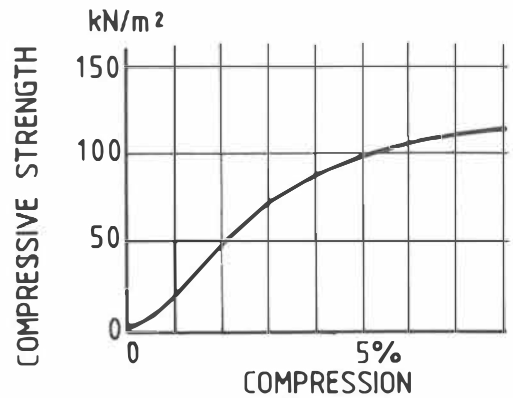


Fig. 3. Typical strain-stress curve for EPS.

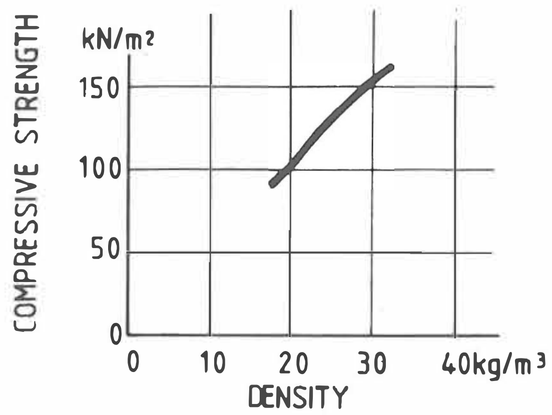


Fig. 4. Density versus compressive strength for a good quality of material.

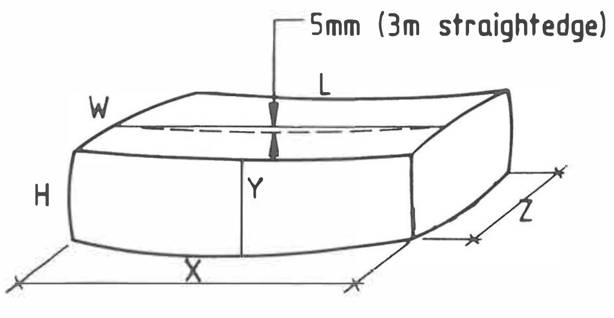
3.2. Geometry

Standard block dimensions:

Height	Width	Length	Displace-ment	Weight
m	m	m	m^3	kg
0.5	1.0	3.0	1.5	30
0.5	1.0	5.0	2.5	50
0.6	1.2	2.5	1.8	36
0.6	1.0	2.5	1.5	30
0.5	1.0	2.0	1.0	20

Clean-cutting is normally done when the blocks are at least 24 hours old, to avoid excessive shrinkage, swelling or distortion. The EPS manufacturers in Norway have occasionally had some problems to deliver blocks in compliance with the geometric requirements.

The stability of a lightweight embankment depends heavily on equal size and even surfaces of the blocks. The geometric requirements are especially important when building high fills.



$0.99L < X < 1.01L$
$0.99H < Y < 1.01H$
$0.99W < Z < 1.01W$

H, W and L are nominal dimensions

X, Y and Z are measured dimensions

Fig. 5. Geometric requirements.
L = length, W = width, H = height.

3.3. Fire resistance

The fire resistance of EPS is expressed by the oxygen index (O_2-index). The oxygen index indicates the amount of oxygen (percent by volume) in the surrounding air that will make a fire in the plastic foam self-supporting. Normal air has an oxygen index of 21, which means that a self-extinguishing (non-flammable) quality of EPS will demand a higher oxygen index to support a fire. When a non-flammable EPS quality is chosen for road construction applications, an oxygen index of 25 may be recommendable. The normal quality of EPS (flammable) has an oxygen index of 18. The oxygen index depends largely on the polymer material for the production of the blocks.

O_2-index = 18	Normal quality EPS for road fills
O_2-index < 21	Flammable EPS
O_2-index > 21	Non-flammable EPS
O_2-index = 25	Non-flammable EPS for road fills

3.4. Block marking

This is not a criteria of material quality, but it would be convenient for the purpose of quality control if the blocks could be marked in some standardized way. This should indicate:

- Manufacturer
- Date of production
- Normal (flammable) or fire resistant (non-flammable, self-extinguishing) quality

4. Additional Control Work

4.1. Density

Density is easy to check and may give some good indications of the general quality of the EPS. Beyond this, density is not of interest to the engineer, nor is it specified anywhere.

If, for instance, the density is below 18 kg/m³ it is highly probable that the material has a compressive strength below the specified 100 kN/m². On the contrary, a density of 20 kg/m³ will not guarantee that the compressive strength reaches 100 kN/m².

When checking density it is important that the specimens have been brought to a dry condition. This will normally occur by storing them in a heater at 60 deg. C for 24 hours.

4.2. Flammability

A rough test can be done by trying to set fire to a small piece of EPS material, using a lighter or a match (full-scale tests are not recommendable!). Sophisticated laboratory tests can be employed to check the oxygen index. Such tests are somewhat complicated and should only be carried out at authorized laboratories.

It will be more important, and under any circumstances more economical, to take one's precautions against potential fire starters. This will, to a large extent, be a result of how well the work at the site is organized. Special care must be shown when using solvents and welding equipment.

4.3. Moisture pickup

Moisture pickup is determined by the bonding characteristics of the material, i.e. how well the plastic beads are welded to one another during the final step in the manufacturing procedure. Good resistance against moisture pickup requires good bonding. There is a certain relation between the bonding and the compressive strength. Unfortunately, a very good bonding can have a negative influence on the compressive strength. Under normal circumstances, the bonding (or moisture pickup characteristics) will be at a reasonable level as long as the compressive strength meets the specifications. It is possible to determine the moisture pickup characteristics by one of the following tests:

The air resistance number, L, quantifies the quality of the bonding of the beads in the plastic foam and gives a good indication of production quality. An average of $L > 70$ indicates good bonding and an average of $L < 40$ indicates poor bonding. A high L value ensures a limited moisture pickup. A millipneumeter can be used for the test. The test should not be performed closer to the surface of the block than 25 mm.

A tensile strength test may be employed to express the bonding in the material, and hence the moisture pickup characteristics. This test may be performed by using a beam deflection device.

A direct test of the moisture pickup characteristics is the Skogseid-Wøhlk test which expresses the moisture pickup rate of the material (SW 5 value). This test has been used a lot by the NRRL and expresses the moisture pickup rate very precisely. It is, however, an accelerated test utilized mainly for insulation boards and does not necessarily reflect the conditions to which an embankment will be subjected.

4.4. General considerations on quality control of EPS

The general guidelines on EPS fills include a plan for the quality control of the material. Additional samples may be collected if the material obviously is, or is suspected to be, of a quality that can be described as less-than-average. In most cases the EPS delivered is of a reasonable quality, and only in a few cases low quality EPS has caused severe damages to the rest of the construction. It should be noted that at many EPS sites there is no quality control with respect to the materials.

Anyway, it is important to keep an eye to the quality during the construction period, as this is the stage where the opportunity is there to avoid future problems.

5. Interpretation of Specifications

Generally speaking, the material should meet the specifications at the time of delivery. The determination of the quality will normally be done according to the testing methods described above.

Somewhat dependent on the project, EPS blocks which do not meet the specifications may be rejected by the customer or accepted at a reduced payment. There is no fixed practice to solve this, and the procedure differs from one customer to another. Firstly, it will be a matter of making documentation about the quality. Secondly, it will be a question of whether the material really can be used for the intended purpose or not. Here one should consider both the additional problems that could occur during the construction period, and the behaviour of the completed fill. If the customer chooses to accept the blocks, it is quite natural that he will claim a certain compensation as the quality did not exactly meet the specifications. It is not possible to settle on a common practice for such a compensation, but it could for instance go as follows:

EPS with 70 % of specified compressive strength will be paid with only 70 % of its full price, a material with 90 % specification fulfilment gets 90 % payment, and so on. Blocks that do not fulfil the geometrical specifications may be treated in a similar way.

6. Future

The above mentioned requirements will only apply to the trade qualities of EPS as we know them today. One could expect the development of new types of EPS and related materials suitable for road fill purposes. If the industry develops stiffer EPS with a different strain-stress curve, it would be necessary to look once again at the specifications.

It may also be necessary to adjust the materials specifications as more experience is gained with the different structures and construction techniques. The design of the pavement may also have some influence on the EPS requirements.

New and special EPS constructions which have not yet been tried may call for additional or different requirements, but it is likely that most applications could use the current trade qualities. After all, it will be a matter for the engineer to find out, in every single project, if EPS can fill his needs.

EPS - DESIGN CONSIDERATIONS

by Geir Refsdal, Senior Engineer, NRRL

For the design of EPS embankments special consideration should be given to the following items:

- Required EPS quality
- Pavement design
- Road icing

Also a few other factors have to be considered in the design procedure and all of these are dealt with below.

1. Choosing EPS quality

Choosing correct EPS quality is mainly a choise of compressive strength and whether to use a self extinguishing material or not.

1.1 Compressive strength

A compressive strength of 100 kN/m^2, which roughly equals a density of 20 kg/m^3, can be used for the majority of fills. Technically there is no reason why 15 kg/m^3 quality could not be used, but the accompanying drop in compressive strength is somewhat greater than what one would expect if the drop followed a linear relationship. Deflections in the material due to the traffic would increase and consequently the pavement thickness would also have to be increased in order to keep pavement deflections at a tolerable level. On the other hand there is little to gain in increasing the density to say 30 kg/m^3. This would affect the material cost considerably but not so much the technical suitability.

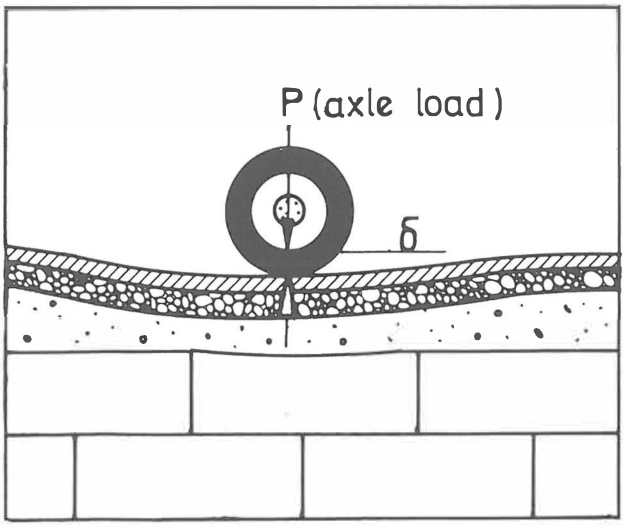


Figure 1. Pavement deflections should be kept at a tolerable level - not to protect the EPS, but to obtain a reasonable pavement service life.

1.2 Self extinguishing material

EPS is produced in two qualities in respect of fire resistance

- a self extinguishing quality, which can be put on fire without to much difficulty by a person who deliberately tries this, and
- a flame resistant quality, which would survive a deliberate attempt to put it on fire

The fire resistance of the EPS is obviously important for the construction period. However, as soon as the foam has been covered with soil materials on all sides, even the non self extinguishing quality will be difficult to put on fire even when this is deliberately attempted in an accidentally exposed area. Such a fire would soon die out from lack of oxygen.

In Norway, the ordinary EPS quality is not self extinguishing. In other countries, the fire resistant quality may be standard. The latter quality may increase the material cost by 5-10 % and when one is free to decide which quality to use, the self extinguishing quality should be considered when

- the construction site is a potential playground for children
- the fill is larger than 1500-2000 m^3
- the construction period is long or when the EPS will be left exposed for a long period
- the fill is near other constructions which could be threatened during an EPS fire

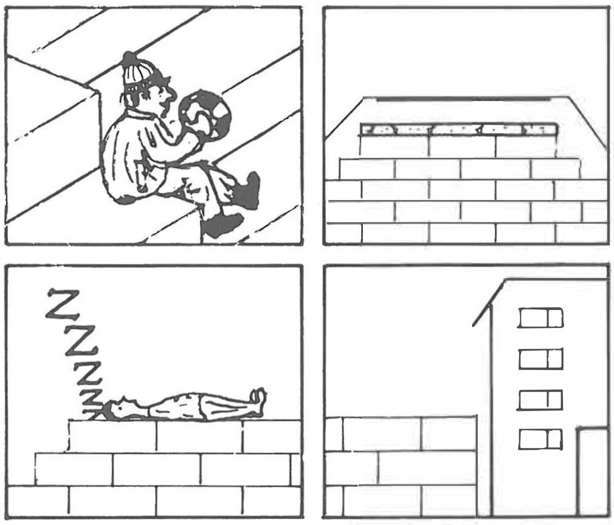


Figure 2. The use of self extinguishing EPS quality is often required.

2. Flooding and Buoyancy

When possible, EPS blocks should be placed in a drained position above the mean water table, although this is not strictly required. If the water level in periods may rise in the polystyrene layer, the buoyancy force has to be taken into account.

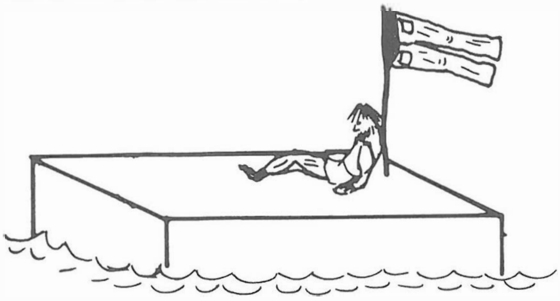


Figure 3. Buoyancy forces should be considered.

Areas where EPS-fills are considered very often also are occationally flooded. Obviously this must be taken into account in the design and it may restrict the lower level of the EPS material. It is therefore essential to know the highest possible water level in order to keep the fill in place. It could be possible to allow for vertical fill movements due to buoyancy but so far this has not been attempted.

For buoyancy calculations an EPS weight of 20 kg/m³ is used, whereas 100 kg/m³ is applied for settlement and stability calculations.

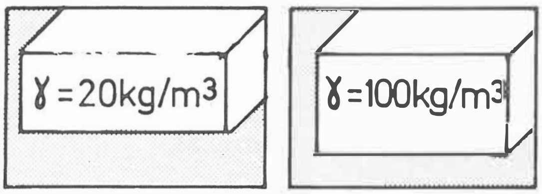


Figure 4. Design densities will vary for buoyancy and settlement calculations.

3. Levelling Course

The first layer of blocks should be placed on a compacted levelling course. With a 3 m straightedge the unevenness should not exceed 10 mm.

A good levelling course is essential in order to obtain smooth levels in the fill itself, thus avoiding high pavement deflections and accompanying reduced pavement service life.

4. Taking care of Horizontal Forces

The friction coefficient between EPS blocks and also between EPS and soil is approx. 0,5. Normally there should be no need to bind the blocks together, but occationally timber fasteners are used, 2 per block.

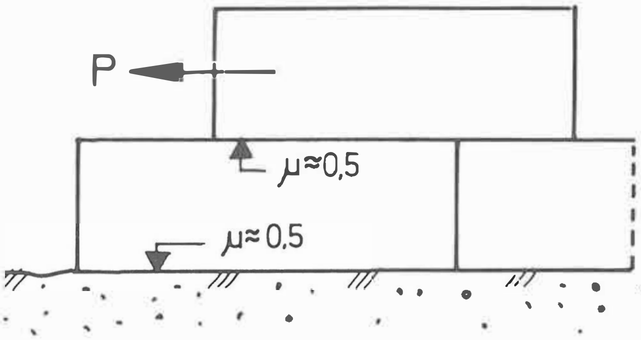


Figure 5. The friction coefficient EPS/EPS and EPS/soil is approximately 0,5.

In sloping terrain, and especially for high fills, the need for anchoring of the whole structure should be looked into. The anchoring shall take care of horizontal forces, which mainly are those connected with heavy lorries crashing into the barrier on top of the fill. 10 t/m is the design value used for this effect.

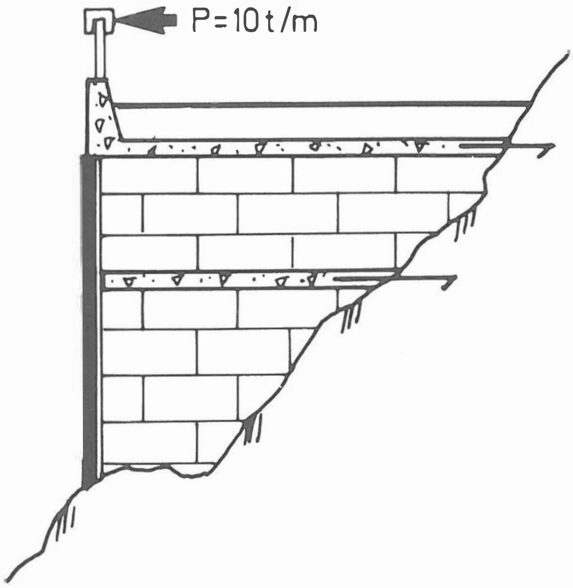


Figure 6. Anchoring may be required to take care of horizontal forces.

In side sloping terrain culverts through the fill may be required in order to prevent horizontal forces due to water ponding at the back of the fill.

An extra concrete slab in the middle of the fill has been used in a few cases in order to tie the anchoring system to this. It may be that the need for anchoring up to now has been somewhat exaggerated, but at least the engineer has slept well at night.

An advantage the designer should remember when dealing with EPS for fills leading up to bridge abutments, is the dramatically reduced horizontal forces against the bridge abutment, which may alone lead to cheaper foundation solutions for the bridge foundations.

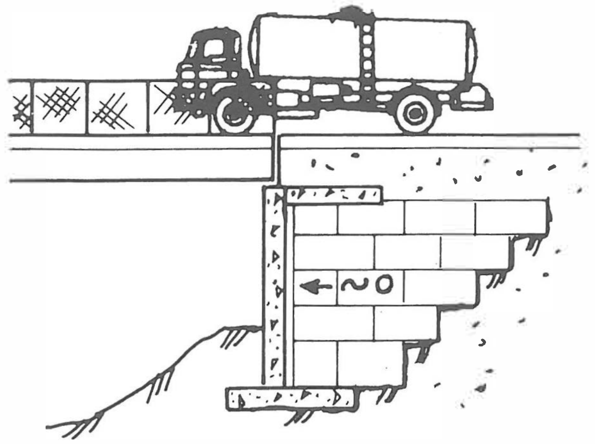


Figure 7. Horizontal forces against the bridge abutment may be dramatically reduced.

5. Block Adjustments

Blocks often have to be cut in order to fit into the fill, around drainage elements etc. Otherwise, cutting of the blocks should not be required, and small gaps left open between blocks will not be very harmfull.

6. Pavement Design

Treating the EPS as a subgrade with an E-value of 5000 kN/m² (50 kg/cm²) pavement design systems based on theory of elasticity should be able to cope with the design.

In Norway, where a semiempirical design approach is used, the subgrades are divided into different classes, and despite little resemblance, a pavement on EPS is designed as if the subgrade was of silt/clay. The details of Norwegian specifications may not be of great interest, but as a general rule the final design ends up with the following minimum total pavement thicknesses (10 t roads):

traffic volume	pavement thickness
low	35 cm
medium	45 cm
high	60 cm

6.1 Concrete slab

The first pavement layer normally consists of a 15 cm lean concrete slab, slightly reinforced. The surfacing and base are standard types.

The concrete slab is normally chosen as this also helps to minimize the weight of the pavement. When the concrete slab is omitted the slab is substituted with a subbase layer of 3 times the slab thickness, i.e. normally 3 x 15 = 45 cm. The specified concrete quality is C 25 (25 N/mm², 28 days) and the reinforcement net used is 5 mm bars in 15 x 15 cm square.

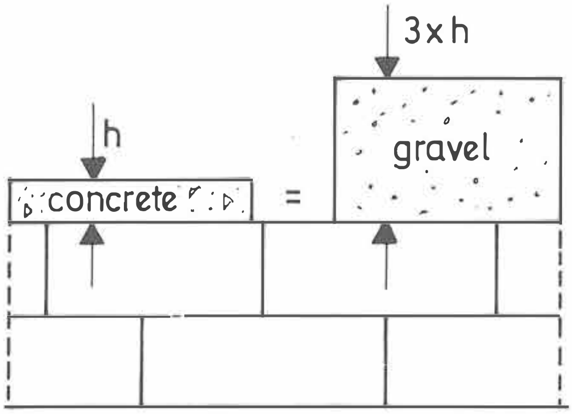


Figure 8. If the concrete slab is omitted, the pavement thickness will have to be increased.

6.2 Road icing problems

In practic, however, in Norway one tends to end up with pavement thicknesses greater than indicated above and this is due to the tendency of road icing on the surfacing. In order to minimize this hazard the icing on the adjacent road is also considered and the minimum pavement thickness varies from 40 cm (low traffic volume, medium icing probability on adjacent road) to 80 cm (high traffic volume, very small icing probably on adjacent road). In general, icing conditions are the design criteria in Norway for pavements on EPS fills. To minimize icing problems it is important that the pavement materials can keep a reasonable water content. This means that a gravel with some fines in it is preferred and that coarse rock materials with a low fines content is the worst one could choose in respect of road icing.

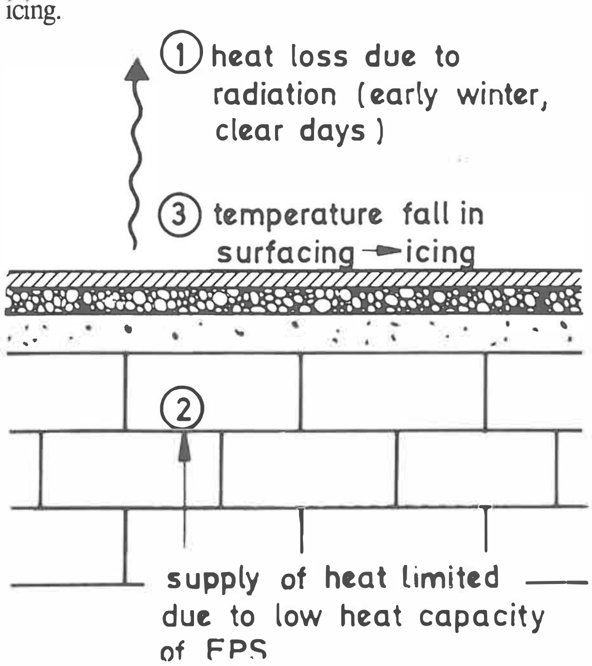


Figure 9. Road icing is a problem which should be dealt with in some countries.

6.3 EPS as free formwork

It is often a difficult task to correctly estimate settlements for a fill, and even with the use of EPS blocks, settlements may occur - in the subgrade. When these settlements are uneven they may affect the serviceability of the road. In order to reduce this problem, it is possible to incorporate longitudinally, or in the transvere direction, concrete beams as part of an integrated structure together with the concrete slab, thus creating a strong bridge effect. In this case the formwork for the beams is of course free.

Design of EPS fills is not a very difficult task, but it certainly requires a basic knowledge of EPS material behaviour. Above all it requires an open mind for new solutions as EPS projects can be very different. The best solution may often be one that is not previously tried.

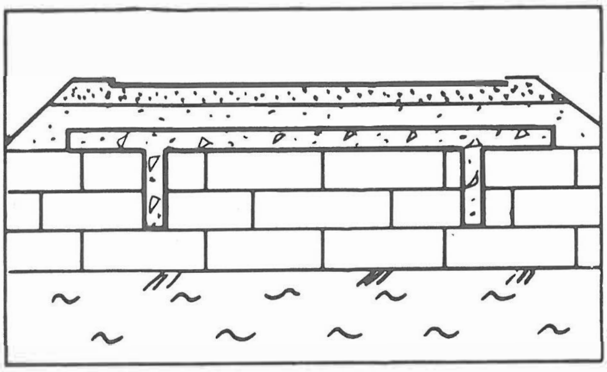


Figure 10. The EPS may provide "free" formwork for concrete beam structures interacting with the concrete slab.

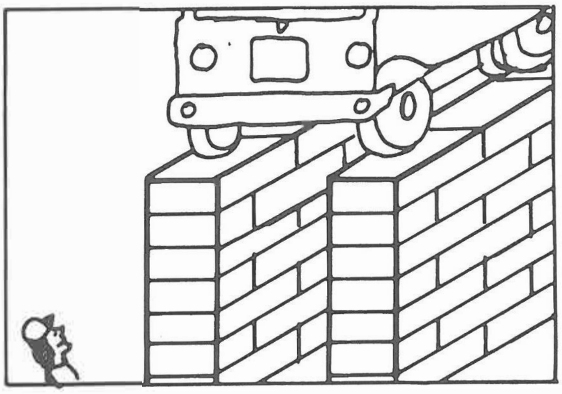


Figure 11. The best solution may the one not yet tried

13 YEARS OF EXPERIENCE WITH EXPANDED POLYSTYRENE AS A LIGHTWEIGHT FILL MATERIAL IN ROAD EMBANKMENTS

by Roald Aabøe, Senior Engineer, NRRL

Summary

What should the service life of different structures in road construction be? This question has to be considered as part of all designs. The question is especially difficult to answer when engineers want to try new methods and new materials.

As for the use of EPS in road embankments in Norway, the "trial and error" approach has been followed. A few theoretical studies have been done and several accelerated tests have been carried out at NRRL and other laboratories, looking at the long time performance of the EPS. Our knowledge of the behaviour of EPS in the soil environment is mainly gained through observations in the construction period and monitoring of structures in service. EPS boards of 3-10 cm thickness for frost insulation were used, for the first time, in 1965. EPS fills have been constructed since 1972.

Our experience up to now is that the method has worked very well. We will not hesitate to use this type of construction on any road if this can bring an obvious benefit to a project, including economical considerations. We are, of course, not able to predict the service life of EPS blocks properly. On the other hand, we can see no reasons for the material to deteriorate abruptly. With the present design spesifications, the service life of pavements on EPS fills seems not to be shorter than the service life of a pavement on the rest of the good quality road network.

Extent of use

Up to 1980 around 25 EPS embankments were built in Norway making up a total volume of approximately 35 000 m^3. The last couple of years have brought a dramatic increase in the use of EPS for road constructions, with an annual consumption of 35 000 m^3 according to the producers of EPS. The method is employed regulary, more or less, for embankments when it can compete economically with other light weight fill materials. It is used extensively by the District Road Administrations, by municipalities and by contractors. At the moment, more than 70 constructions with EPS have been completed. A prognosis based on consulting reports shows that the use of EPS still will increase. In one motorway project in the District of Vestfold more than 50 000 m^3 of EPS, distributed on several fills, will be used the next 3 years. Another project coming up now is a spaghetti junction just outside Oslo, designed with more than 8000 m^3 of EPS in one single fill.

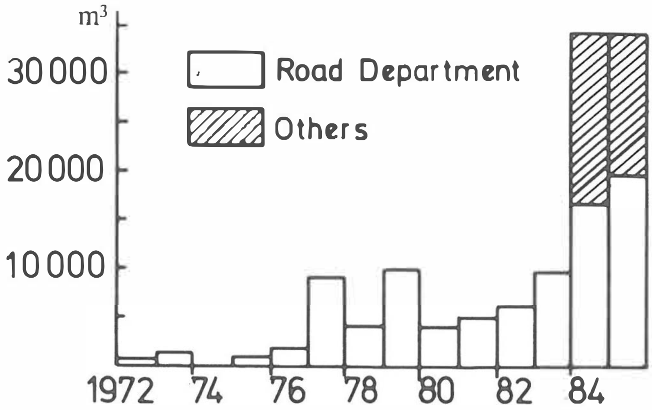


Fig. 1 Consumption of EPS in road embankments.

Long term monitoring

Since the construction of the first EPS fill back in 1972 we have examined a selection of fills with respect to different properties such as:

- Compressive strength
- Moisture pickup
- Bearing capacity
- Settlements
- Deformations of the EPS
- Disintegration

Compressive strength and moisture pickup of the EPS material in service have been measured twice (1979 and 1984). Samples have been taken from a few selected embankments by excavation.

Compressive strength

Each number in the table shown in figure 2 is the average of more than 20 single measurements. Even if we consider several uncertain factors, a comparison of

SITE		SOLBOTMOAN Undrained embankment		SOLBOTMOAN Drained embankment	FLOM Periodically submerged		LANGHUS Drained		LENKEN Drained	
YEAR OF MEASUREMENT		1979	1984	1984	1972	1973	1979	1984	1984	1984
WATER CONTENT	% vol.	3,1	5,4	0,5			2,1	2,3	0,4	0,3
DENSITY	kg/m³	52,2	76,9	22,6			42,2	46,6	22,3	22,1
DRY DENSITY	kg/m³	20,6	23,4	19,2	20,6	23,0	22,9	23,6	17,9	19,0
COMPRESSIVE STRENGTH	kN/m²	105	102	107	88	105	109	130	109	104

Fig. 2 Experiences from 4 embankments.

the results leads us to the conclusion that there are no substantial changes in the compressive strength that has been measured - at least there is not a change towards a lower strength. No result is lower than the design limit of the material. It rather looks like we have an increase of 30 % from 1972 to 1984 at one of the sites (Flom). Compared to a theoretical strength curve for new EPS material, the old material show the same with only two samples below the curve - but with a lower compressive strength than the design requirement. Finnish investigations on insulation boards show the same tendency - no decrease in compressive strength during the period the material has been in service.

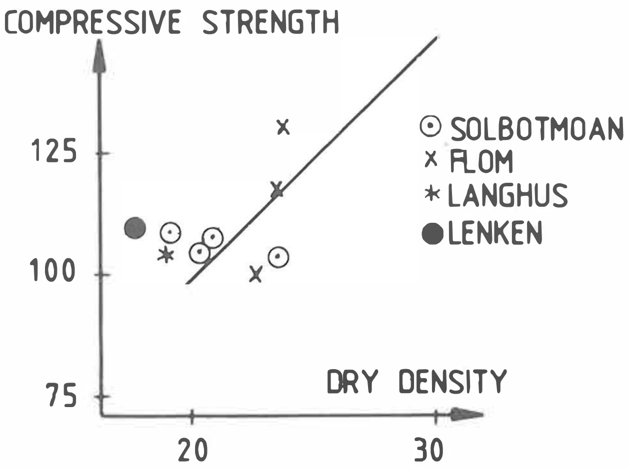


Fig. 3 Compressive strength for 5-12 year old EPS embankments.

Moisture pickup resistance

A moisture pickup of 9 percent by volume at the extreme has been observed with blocks lying permanently under the ground water level for 9 years at Solbotmoan. This means 90 kg/m³ of water in addition to the 20 kg/m³ of the plastic foam itself and makes for a total density of 110 kg/m³ which is a little bit more than the design density (100 kg/m³ is generally chosen as the design density for stability and settlement analysis). This is still only about 5 % of the weight of a conventional fill material like gravel or blasted rock. It is important to notice that for practical purposes the capillary rise seems to be very small. The measurements at Solbotmoan show that at a level 20 cm above the ground water level the water content has dropped from 9 to 1 percent by volume. Quite a different situation will occur at embankments which are periodically submerged in water. A water content of up to 4 percent by volume has been measured under such conditions. Results from drained constructions show, with no exceptions, that the water content is less than 1 % by volume. There are only small changes in water content during the period of the investigations. The maximum water content measured at these investigations are more or less identic with the manufacturers' prognosis.

The density measurements show that except of undrained constructions the design could be changed from 100 kg/m³ to 50 kg/m³.

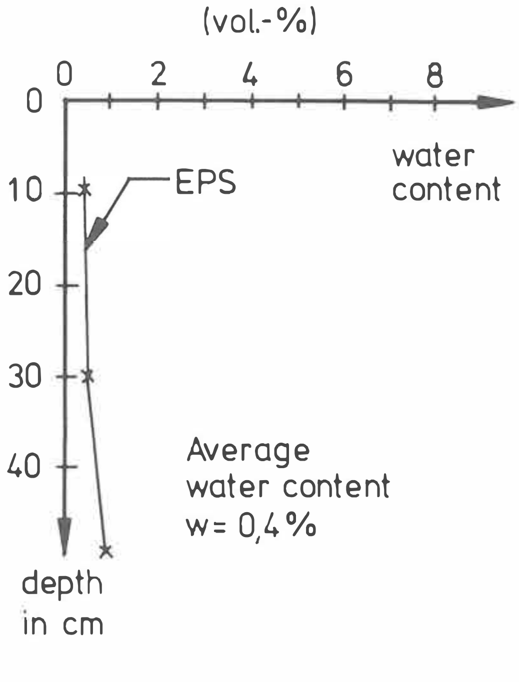


Fig. 4 a) Typical drained construction

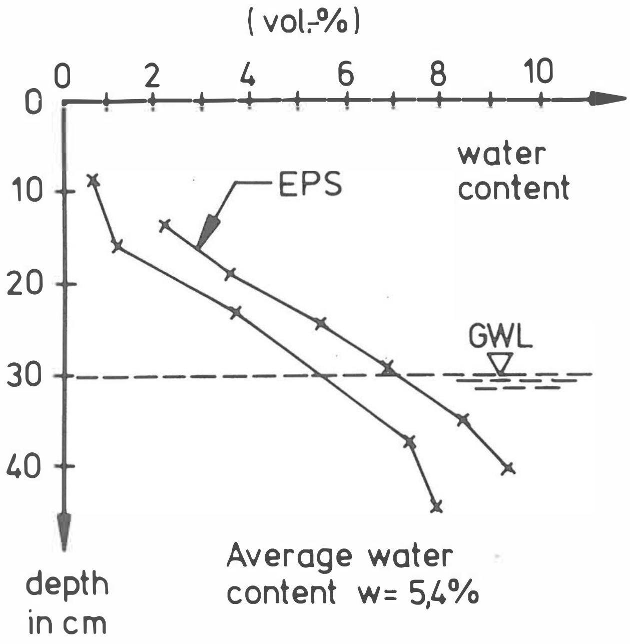


Fig. 4 b) Typical undrained construction

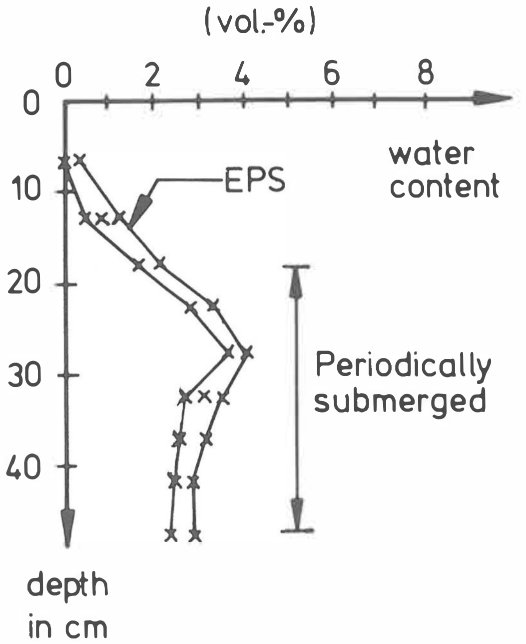


Fig. 4 c) Typical periodically submerged construction

Settlements

When the districts' maintenance divisions observe local settlements in a road section the common practice will often be that they fill up with asphalt or gravel to maintain the serviceability and the longitudinal profile of the road. When such local settlements are caused by soft subsoil, the weight of the additional asphalt layers will lead only to one result - increased settlements and sometimes embankment failure.

At certain roads one has observed more than 1 metre of asphalt, gradually built up by frequent repair to try to keep up with settlements. Actually, such was the situation that led to the construction of the first weight-saving EPS fill in 1972. The main reason for using EPS in the beginning was that the conventional repair technique simply was not able to stop settlements.

Flom bridge

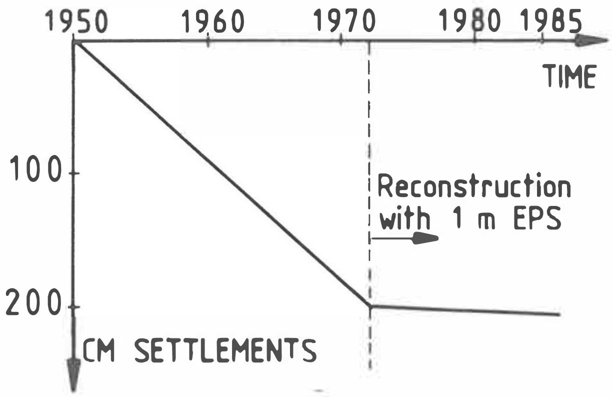


Fig. 5 Flom bridge - Settlements.

At Flom bridge, the first EPS embankment, settlements of more than 2 metres had been measured during a period of 20 years, and the road was in a very bad condition in 1972. The road embankment subsided at a rate of about 10 cm per year. The road was ripped up and 1 m of expanded polystyrene was put in with a normal pavement on top. The construction increased the elevation of the road by 80 cm, but the load of the road embankment was reduced by 5 kN/m^2. Accordingly, the rate of settlement was immediately brought down to 1 cm per year and today it is almost zero.

Sande - Oset "Floating bridge"

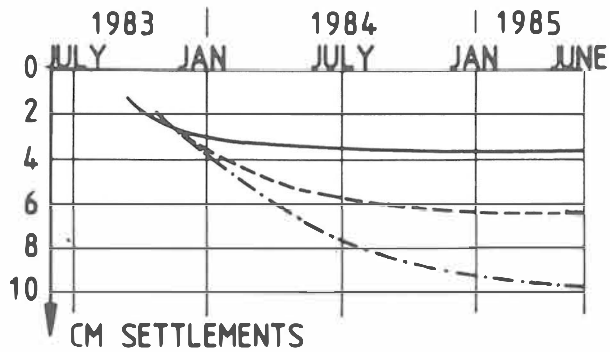


Fig. 6 Floating bridge at Sande - Settlements.

In the "floating bridge" experiment at Sande (District of Sogn og Fjordane) the primary intention was to utilize the buoyancy of EPS submerged in water to carry the weight of the pavement and the traffic. The project was carried out in 1983. Relatively large settlements were observed during the first year after completion, but this seems to have slowed down during the second year and is now at a reasonable rate.

There seems to be two reasons for the initial settlements:

- There were certain problems during the construction period, when the ground water rose to an unexpectedly high level because of a sudden rainfall. Actually, the whole EPS fill lifted with only the weight of the concrete layer on it, as the rest of the pavement had not been completed. The whole construction was at a state of floating.
- The ground water level is lower now than estimated at the stage of planning and designing the road.

Even after these initial settlements occured, the road seems to work very well, with no visible damages to the surface of the pavement. One could talk of a successful construction of innovative design.

Sogndal (Road no. 5) Vertical wall

After a slide accident at Sogndal the road was repaired with an EPS fill 5 metres high. Settlements less than 2 cm. have been measured and they come all at once - probably caused by a slip in the loose rock under the construction. Horizontal movement is less than 5 millimetres.

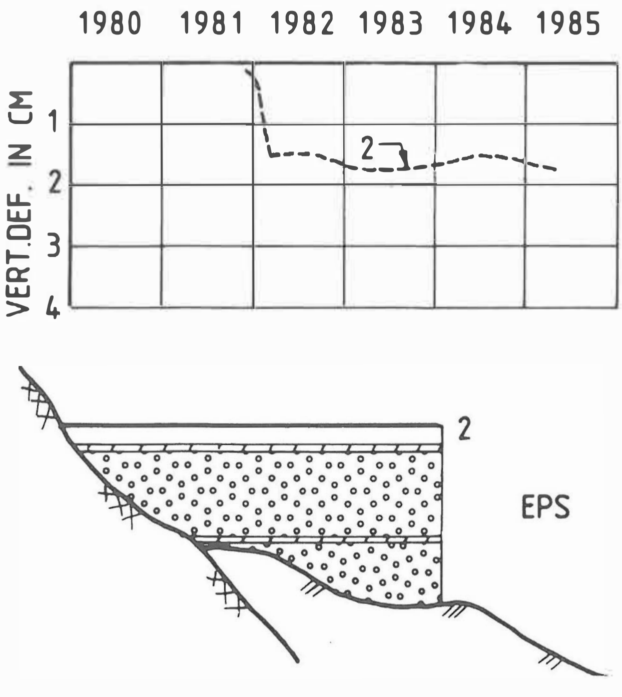


Fig. 7 Sogndal (Vertical wall) - settlements.

It is important to remember that even if we have observed settlements on this EPS fill, it has nothing to do with the method itself. The settlements are rather to be connected with the general design of the construction and is caused by weak material in the underground.

Deformations of EPS

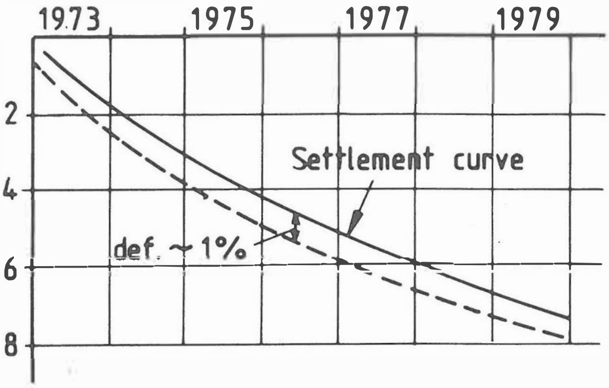


Fig. 8 Deformations at Flom bridge.

EPS deformations has been measured "in situ" at Flom bridge and show values of about 1.0 % , which was measured 7 years after the completion of the construction. These measurements indicate that the main part of the deformation of the EPS will take place soon after the completion. Measurements on samples excavated in 1979 and 1984 show the same tendency - deformation are between 0,5 % and 2 % of the thickness of the blocks. This indicates that there is no reason to calculate with large deformations in the EPS fill itself.

Flammability

So far, there have been two accidents where EPS-blocks went up into smoke, one stockpile and one fill. The 1500 m^3 EPS embankment leading up to Knatten bridge was accidentally set on fire 2 years ago because of badly planned welding works at the bridge abutments. After 15 minutes about 35.000 dollars had disappeared up in the air. A consequence of this fire is that the District of Akershus, where this happened, now specifies self extinguishing EPS for their projects. This may be a somewhat strict requirement and should not be a practice generally followed. Proper planning and well-organized construction sites should make the choice of self extinguishing quality unnecessary for many projects.

If we calculate a slightly more expensive material cost for self extinguishing EPS (5-10 % above the cost of a standard or flammable quality), and assume that every

Fig. 9 EPS embankments in fire.

EPS fill utilized the self extinguishing quality, it would have been cheaper to choose the ordinary flammable EPS type for all projects and accept the economical consequences of the 2 fires.

Chemical resistance

Destruction of the foam can also possibly happen due to dissolving by petrol based chemicals. The probability for such an accident is small and there has been no damages of EPS-fills so far. Precaution that could be taken is a concrete slab or a petrol resistant membrane and a slope cover.

Biological conditions

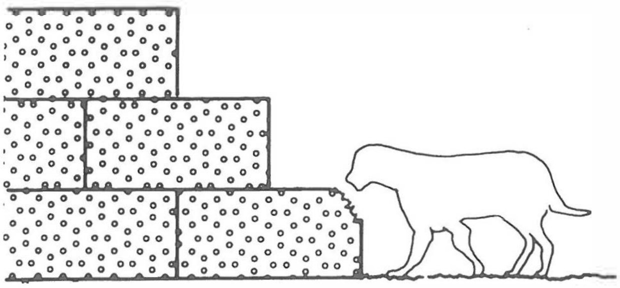


Fig. 10 Animal attacks.

In general, the possibility of a biological disintegration of EPS is very small. So far, no organisms or enzyms are known that could use or attack EPS. If animals should use the materials this would only be for personal housing needs. It is unlikely that this could affect the technical behaviour of a fill and has not been observed.

Temperature problems

EPS will have a low and stable temperature in the road embankments corresponding roughly to the mean air temperature. In Norway this means temperature from 0-7 °C which is an ideal temperature and far away from temperatures that could give aging.

Disintegration, Light and Luminance

Wind, sun and rain has an erosion effect on EPS. The outer layer (a few millimeteres) becomes brittle and yellow because of the UV-light and should preferably be covered against direct sunshine if stockpiled for a long period .

Pavement bearing capacity

From computer programs calculating stresses and strains in pavement and subgrade (Modified Chevron) it is found that the height of the fill will have no influence on the pavement design.

Comparing pavements with and without a 10 cm concrete slab indicates an increase in pavement thickness of 30-40 cm if the concrete slab is omitted, in order to keep stresses and deflections the same level.

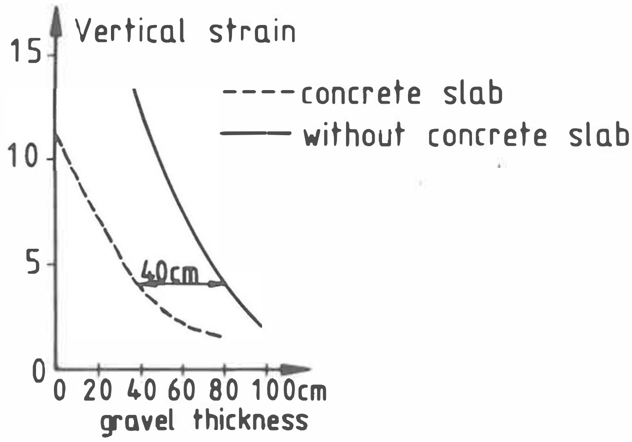


Fig. 11 Significance of concrete slab.

Bearing capacity measurements are confirming these results.

Project	Bearing Capacity tons	Concrete layer cm	Pavement thickness cm	EPS embankment Max. height m
Solbotmoan	> 13	10	48	2,7
Langhus	> 13	10	43	0,6
Lenken	> 13	10	52	3,0
Flom	10	0	70	1,0
Enebakk	10	10	46	0,5
Knatten	> 13	10	40	5,0
Ljabrudiag.	> 13			
Loenga	> 13	15	56	5,5
Fergestadvn	5	0	35	3,5
Årum-Hauge	10	0	85	2,5
Hønefoss	10	0	180	2,0

Fig. 12 Bearing capacity of EPS fills.

Dynamic loads

NRRL has been testing EPS insulation boards to find their behaviour under dynamic loads. These tests show that for loads up to 80 % of the compressive strength, the material can take an "unlimited" number of repeated loads.

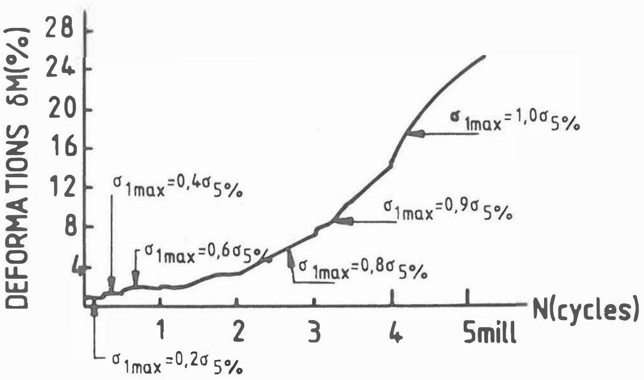


Fig. 13 Dynamic loads on EPS with quality 40 kg/m³ (Isopor 40), $\sigma_{5\%}$ = 245 kN/m².

Practical experiences during 20 years show that the strength of insulation boards covered with a pavement of 40-50 cm is not reduced. Our conclusion is that there is nothing to fear from dynamic loading for EPS embankments.

Horizontal pressure

The horizontal pressure is significantly reduced by using EPS instead of conventional materials. Knowledge of EPS material can be very useful when designing high bridge abutments and retaining structures. An example is Lambertseterveien bridge (see case histories) where the abutment, which is 1,5 meter thick and piled to rock, was built in a traditional way able to take care of earth pressure as if the embankment was made of heavy materials. During the construction, a gap was made between the EPS fill and the abutment wall, which theoretically should indicate no earth pressure on the abutment wall under the concrete slab. The compressive stiffeners in the formwork were hollow pipes, leaving holes through the front wall. Through these holes the distance between the EPS fill and the abutment has been measured 7 years later and there is still a gap to be observed except for a small area. The conclusion is that there is almost zero earth pressure against the abutment wall.

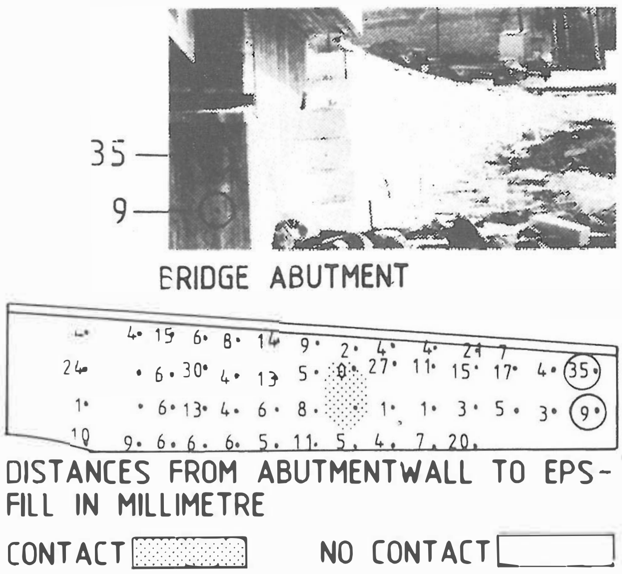


Fig. 14 Earth pressure on Lambertseterveien bridge abutment.

At present, the normal design procedure is to design the earth pressure against the wall with an evenly distributed load of 10 kN/m² against the abutment a very conservative design. This is probably one of the main areas where EPS can be utilized on a larger scale in the future.

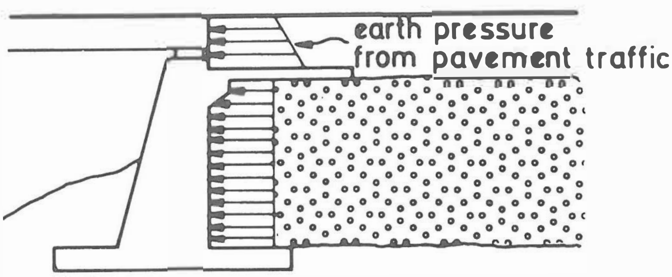


Fig. 15 Earth pressure on abutment - design.

Economy

For each project, when the question of using EPS material arise, the technical and economical consequences should be compared to those of alternative solutions. When the only alternative solution are too costly, for instances prolonging a bridge, low bridges over peat or soft areas or vertical walls in urban areas, the use of EPS foam often prove to be competetiv in Norway. In many cases the material will compete favourably economically with the more traditional lightweight material as Light Expanded Clay (Leca) and gaseous concrete (Siporex Ytong) waste. This is mainly due to the lower transportation costs of EPS.

Drawbacks

Icing problems

Icing problems have appeared at a couple of constructions, mainly due to a pavement with too little heat supply. This has led to different icing from adjacent road sections, especially in clear nights in late autumn when the temperature has dropped below 0 °C because the EPS has stopped the heat transfer from the subgrade.

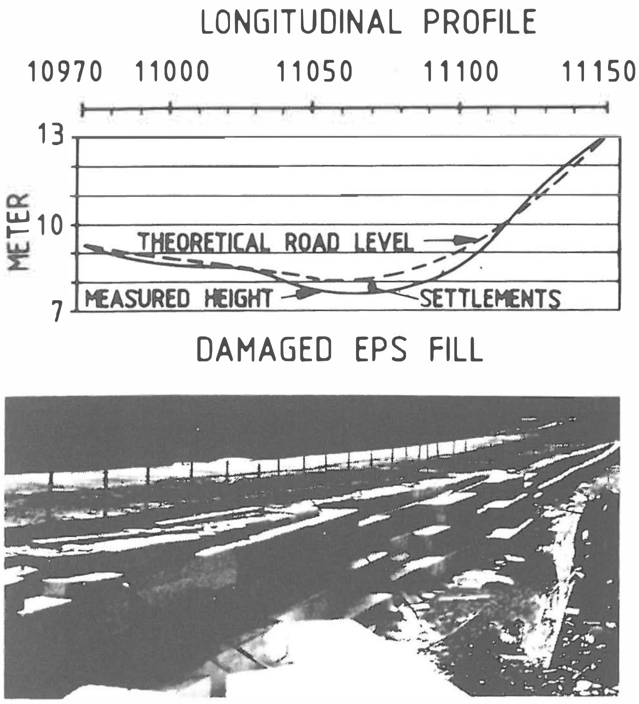


Fig. 16 Unacceptable settlements - longitudinal profile.

Projects that failed

It is very important that the local contractor/planner understand the method. On one occasion a local road was built back in 1975 with EPS crossing a peat area. The job was completed during the summer and 1,5 m sand/gravel were placed below the EPS fill to get enough bearing capacity during the construction period. This could only lead to one result - very large settlements immediately and of course large settlements over a long period. Today it is almost 1 metre of settlements. In 1980 someone got the brilliant idea that they should stop the settlements by taking away the pavement, replace it with additional EPS and have a new pavement of 20 cm on top. With another obvious result: the black top broke down in less than one year. And finally, because of these settlements the EPS material has been pressed down into the water with another obvious result: the blocks on the slopes have been pushed up by the buoyancy.

Another not very successful construction was Fergestadveien, a bridge abutment, with a pavement of 35 cm and no concrete slab. Much heavier traffic than expected passed the bridge. The asphalt layer broke down after a few months, new layers of asphalt were added. Measurements indicate that the embankment today has a bearing capacity less than 5 tons.

These are only two embankments out of 70. It is perhaps a good experience to learn more about the method by doing these initial mistakes. Too many not very successfully constructions will however give the method a bad reputation very soon.

In summing up our experience with EPS, two conclusions are apparent:

- EPS material has no problem in standing up to traffic loads
- The aging of EPS is slow (if any) and outside the interest of a road engineer

FUTURE TRENDS FOR EPS USE

by Geir Refsdal, Senior Engineer, NRRL

1. It started with frost protection

The use of expanded polystyrene (EPS) in the road sector started in the mid 60-ies for frost protection purposes. This market is today rather limited and especially so for EPS. The material now generally used for frost protection of roads is extruded polystyrene (XPS).

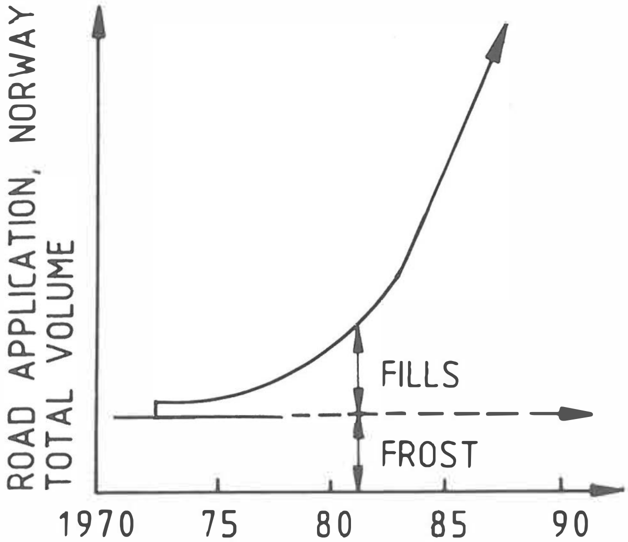


Figure 1. Relative use of XPS (for frost protection) and EPS (for embankments) in the road sector.

The use of EPS as a lightweight fill material in Norway, which started in 1972, has steadily increased. The major breakthrough came however in the 80-ies, with a volume of 35000 m³ used in 1984, i.e. about 10 % of the total EPS production in Norway. A guess is that the double of this volume is reached within another 5-7 years, provided the EPS price does not take off from the general price trend.

Today the projects can typically be classified as follows:

Small projects	:	250	-	500 m³
Medium projects	:	1000	-	2000 m³
Large projects	:	5000	-	15 000 m³

The largest projects carried out or under planning today are in the order of 12-15 000 m³. It is expected that the project size for "large projects" will increase, and single projects in the order of 20-30 000 m³ may not be far away.

EPS has been used in Sweden for several projects as well as in France, Holland and Canada (and other countries?). It is clear that the potential in these countries, and particularly maybe in other countries with still more severe settlement and stability problems, is (not to exaggerate) great. Probably we have yet only seen a fraction of its use, the main reason simply being that the method is not generally known. The other reason may be that the method is too fancy to satisfy a respectable consultant or road engineer. In the bottom of his heart the engineer thinks that there must be some snags attached which he will be blamed for afterwards. So far however, and strangely enough one could say, there seems not to be any major drawbacks to this method.

One could expect, if engineers were logic-minded creatures, that the use of EPS should follow this trend in the countries where it was introduced:

First stage: use in projects where traditional lightweight materials would not solve the problem, the weight still being too high. The alternative is then not use of other lightweight materials, but for instance a bridge constructon.

Second stage: use as a lightweight material in competition pricewise with other lightweight materials.

Third stage: use in constructions where settlements or stability is not a problem, but where EPS, due to is low weight, the simple and rapid construction technique and self supporting ability, may compete favourably with other and very different techniques.

2. EPS - A producer specified material

For the majority of EPS applications the customer accepts the product without mechanical properties specified. As long as the material sticks together the producer and the customer is happy. The only quality parameter of concern for the producer is the density, a parameter which at least for road fill applications is of no interest as long as it is still a "lightweight material".

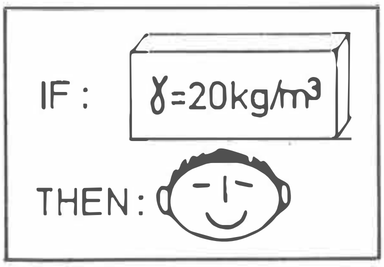


Figure 2. The customer often has very primitive requirements regarding EPS quality.

2.1 Compressive strength - the important quality parameter

Dealing with EPS for road embankments or similar use, the important characteristics are:

1. compressive strength

and

2. a good bonding structure

There is no good correlation between the bonding structure and compressive strength. A very good bonding actually seems to be followed by a slight drop in compressive strength. No requirement on bonding structure is specified today, but it is likely that this will come in order to prevent blocks with loose single beads.

In order to keep moisture pickup as low as possible the bonding structure is essential, but the design value of 100 kg/m³ for block density is reached only for blocks with rather poor bonding, and then mainly due to capillary rise.

2.2 Can EPS be tailored better to road use?

The main parameter will be the compressive strength, and here it should be possible - may a road engineer be allowed to think - to utilize the material better than what is the case today. A compression test on EPS generally shows that when the 5 % deformation limit is passed, the material still gains in strength. For the future it should be a task for EPS producers to come up with a 100 kN/m² material with less than 19-20 kg/m³ input. But then obviously some modifications in the present process will be required.

Also, if the EPS producers are able to come up with a material which has a lower deformation at the same strength level, it could be possible to reduce the compressive strength requirement from todays 100 kN/m² to say, 60-80 kN/m². It is also suggested that the EPS producers should look into this. With raw material prices (1985) at approx. $ 1.00/kg, EPS may today generally be the preferred light weight material. But if the price should suddenly increase, and with the raw materials making up 80 % of the production cost, it would be good to be able to reduce the material input and still meet specifications.

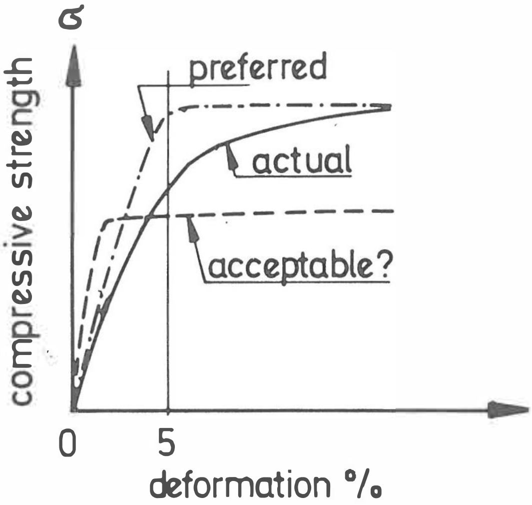


Figure 3. The EPS material could have better characteristics regarding road application.

Today a design density of 100 kg/m³ is used. In order to obtain a material with a lower design density, say 40 kg/m³, the moisture pickup resistance must be improved. Even if this technically is possible, this improvement can be paid by the user with only approx. 1 $/m³, and little emphasis ought to be put on this for embankment use, even if it may be essential for increased use for other purpose, like frost insulation.

3. Looking for EPS rivals

Even from the best viewpoint, it is difficult today to see the EPS competitors clearly, at least when the requirement is a material with a design density below 200 kg/m³. For design densities around 1000 kg/m³ or somewhat below, other materials may, however, also in the future be economically feasible. Most probably there will still be projects where expanded clay ("Leca") and gaseous concrete waste will be used simply because they in the particular case offer better economy.

In the low density group it seems difficult to beat the economy of EPS.

3.1 Extruded polystyrene

Extruded polystyrene (XPS) has, for many years, been produced with densities from 30 kg/m³ and up. XPS therefore has properties which are far better than required for a road fill, which also is reflected in the price. Lately XPS of 100 kN/m³ has been produced, but even if this is superior to EPS in respect of moisture pickup, the drawback is that it can be produced in boards only, and not blocks. Probably XPS will be able to compete only if the deformation characteristics are significantly better than those of EPS. XPS can therefore not totally be looked away from as a fill material.

3.2 Honeycomb materials

Other plastic foam materials seems not to be in the picture, but plastic materials with honeycomb- structures are available and may be technically and economically a possible competitor. The advantage in the honeycomb structure lies of the superior compressive strength in relation to density.

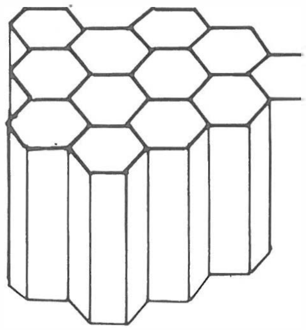


Figure 4. Honeycomb materials have good strength and buoyancy characteristics.

3.3 Gypsum waste

Gypsum is a waste material produced in enormous quantities in many countries. At a laboratory scale, and for a few tenths of a second, it has been possible to produce foamed gypsum at very low densities. That day this process works at full scale,EPS could experience difficulties in keeping the road embankment market for itself. One extra advantage will be that gypsum could be foamed in situ. However, it seems to be a difficult process to put this into practice.

4. Future EPS road applications

Today the main EPS use is for 1-4 m high road embankments where stability or settlement is a problem. Most likely this will also be the main application for many years, but it is possible to point out areas where a growth in EPS use may be expected and also new application areas for the material.

Up to now EPS fills have stopped at 4 to 5 m height. This is definitely no limit and we may soon see fills up to 10-20 m high or even higher.

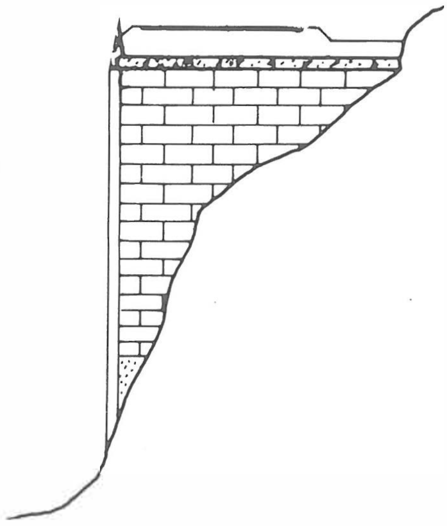


Figure 5. EPS fills of 10-20 m heigth may come.

EPS is a material which quickly can be placed and removed. It should therefore have a high potential for use as temporary road constructions, an area where EPS has not been utilized up to now. In combination with the reinforced earth concept new solutions could also emerge combining the good effects of the two methods. Pedestrian or culvert underpasses may be constructed, with the EPS forming the sidewalls and with a concrete slab bridging the two sides. This is an example where EPS has advantages without solving stability or settlement problems.

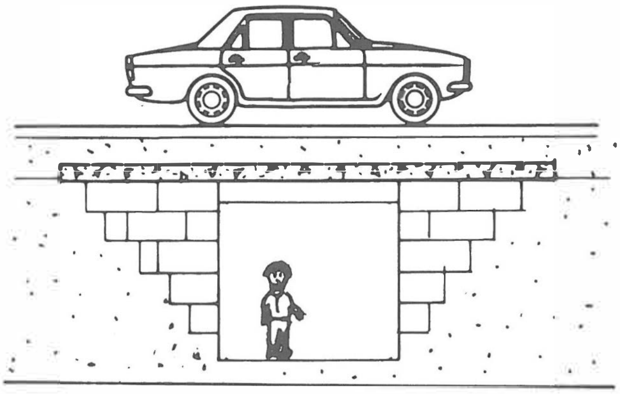


Figure 6. Underpasses in EPS – why not?

Plans for road E18 in Vestfold District and E6 in Sør-Trøndelag District, Norway, also suggest the use of EPS where the soil mechanics aspect is not the major issue, but where the length of a culvert under a road fill can be dramatically reduced by incorporating EPS in the structure. Instead of building a conventional embankment of considerable height and width, it has been suggested to build a relatively narrow embankment of conventional design, topped by a “vertical wall” EPS fill to reach the necessary height. The economy here lies in the reduced culvert length.

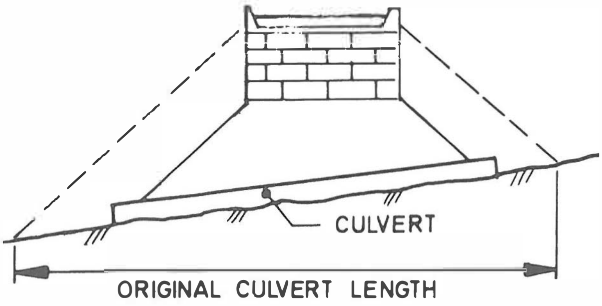


Figure 7. Reduction of culvert length with EPS.

The principle used at Sande, Sogn og Fjordane District, Norway (1983) where the EPS created the formworks for concrete beams, may be used also for other constructions where uneven settlements are expected or where it is of importance that the EPS fill acts as one monolithie structure.

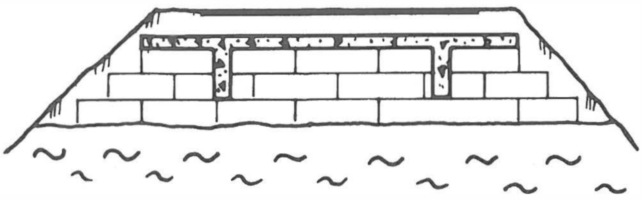


Figure 8. The principle of utilising the EPS also as formwork may be applied in many types of constructions.

And why should not EPS be used as floating bridges in order to cross Norwegian fjords? With the many slides occurring along the steep sides of Norwegian fjords, it may even be an idea to have a stock of EPS floating bridge elements in order to connect such broken road sections until a permanent repair has been established.

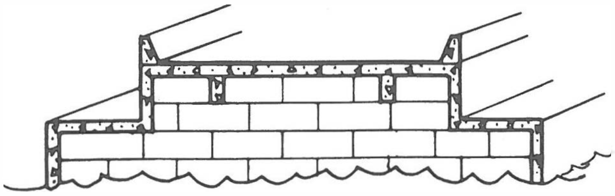


Figure 9. EPS may bring down the costs of a floating bridge.

What is mentioned above is only a fraction of the new applications we will see for EPS in the future. So far, after 13 years of use, what we have seen is fascinating and interesting, but a guess is that we still are at the very beginning of this type of EPS use, both in terms of volume and in applications.

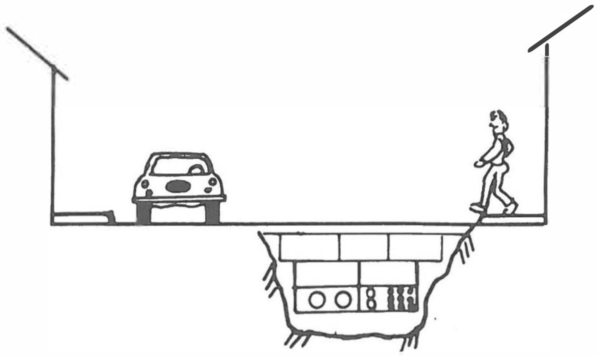


Figure 10. And what about "street blocks" for utilities etc.

APPENDIX - CASE HISTORIES

CONTENTS

CASE HISTORY 1

SITE: **FLOM** (The first EPS road)

Road no./section:	159		
Vehicles per day:	15 000		
Allowable axle load:	10 tons	Year of construction:	1972/1973
Embankment length:	170 m	Built by:	District Road Adm. of Akershus
Embankment height:	Max. 1,5 m	Built for:	Public Road Adm.
EPS volume:	1700 m^3		

SITUATION:

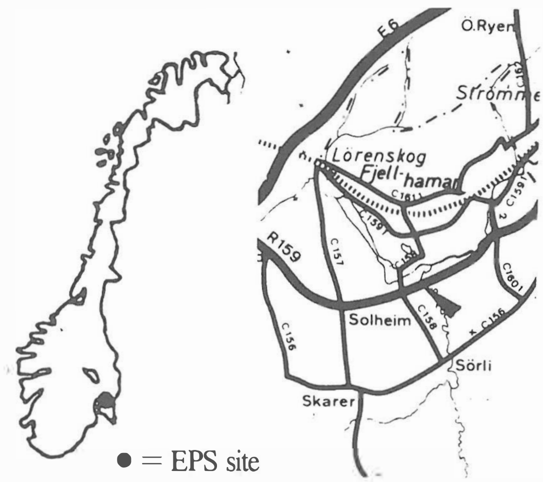


PHOTO FROM SITE:

Background

At Flom, about 15 km from Oslo, Road no 159 crosses a bog. Figure 1. This highway is one of the main roads from east to the capital Oslo, and therefore has very heavy traffic, about 15 000 vehicles a day.

In the middle of the bog is a small stream over which the road crosses on a bridge founded on concrete piles to bedrock.

The subsoil consists of a 3 m thick layer of peat overlaying 10 m thick, soft, sensitive silty clay to firm bottom.

The weight of the road construction caused settlement ecspesially in the peat layer. As the road level was re-established several times in about 30 years, the settlement increased in intensity and was 20-30 cm a year in 1971-1972. The road was than about 60 cm below the bridge level and the situation was very dangerous for the traffic.

Various solutions were considered, such as piles to firm bottom and ordinary light weight materials combined with excavation of the existing road materials. Extremely light weight materials were also evaluated, and so plastic foam, the EPS solution, came into consideration. After numerous discussions a construction of EPS covered with polyurethan (PUR) was proposed. The project was accepted by the District Road Administration of Akershus to be built in 1972 and 1973.

The EPS solution

The aim was to reduce the weight on the ground with at least 10 kN/m^2 while the road level was lifted up to the bridge level. The project was complicated by possible uplift of the EPS materials caused by high water level during flood periods in the spring and autumn seasons.

Additional information

The final design adopted was a 1,1 m thick layer of EPS and PUR covered by 50 cm of road base materials and asphalt pavement. Figure 2. This gave 5 kN/m² in reduction of weight on the subsoil, as 80 cm of the existing heavy road materials were excavated.

The work was successfully performed in 1972 and 1973. No particular construction problems were experienced except that the spraying of PUR was time-consuming due to technical difficulties with the spraying nozzles and weather conditions. In rainy weather the production of PUR stopped completely. Thus the use of PUR as a protecting layer was not particulary successful, and Flom is so far the only site where these PUR-materials have been used as a protective cover.

12 and 13 years after the construction of EPS roads at Flom it can be concluded that the EPS solution has been a success. Settlement observations show that in 12 years the road level has subsided 8 cm. During the last 3 years the settlement is approximately zero. Figure 3.

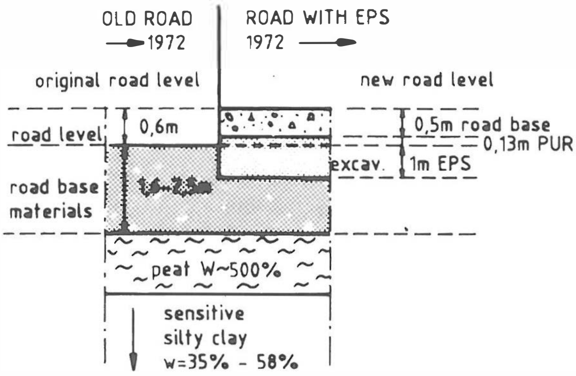


Fig. 2 Road construction.

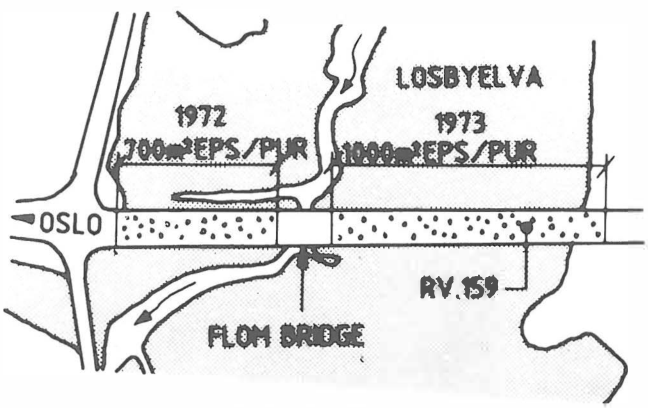


Fig. 1 The Flom site.

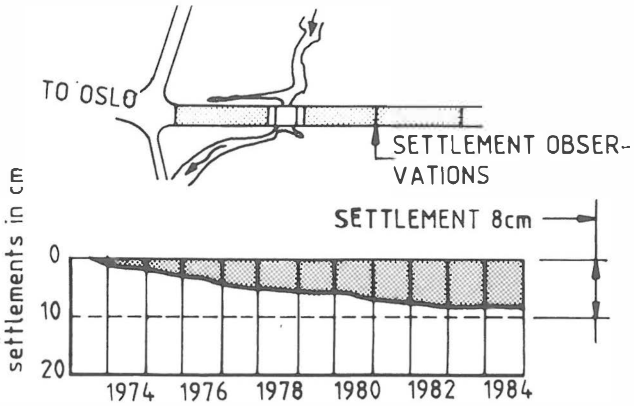


Fig. 3 Settlement observations.

CASE HISTORY 2

SITE: **TVERRELVDALEN IN ALTA**, County of Finnmark

Road no./section: County highway Y26
Vehicles per day: 300-400

Allowable axle load:	10 tons	Year of construction:	1983
Embankment length:	40 m	Built by:	District Road Adm. of Finnmark
Embankment height:	Max. 4 m	Built for:	District Road Adm. of Finnmark
EPS volume:	1500 m^3	EPS consultant:	NRRL

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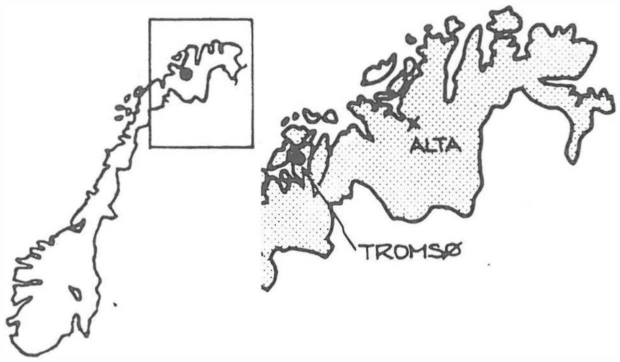


● = EPS site

PHOTO FROM SITE:

Slide crater

EXPANDED POLYSTYREN BLOCKS (EPS) USED TO RE-ESTABLISH ROAD ACROSS A QUICK-CLAY SLIDE CRATER

Introduction

The 18. of September 1982 an approximately 40 m long stretch of District highway Y26 in the valley of Tverrelvdalen in Alta, Finnmark, collapsed as the embankment slid into the river. The road ran along an embankment beside the river which was 11-12 m higher than the river bed.

Rainfall in the summer and autumn of 1982 was exceptionally heavy in Alta and this was probably the decisive factor that caused the slide, particularly because the drainage system was not functioning satisfactorily. Earlier minor slides along the edge of the river also indicate that erosion from the river may have been a contributory factor.

Investigations showed that the ground in the region of the slide consisted of soft quick-clay. Borings indicated soil deposit down to a depth of 40 m below the bottom of the slide crater. Stability calculations indicated that existing road also in adjacent areas upstream and downstream of the slide had a low factor of safety. Therefore measures were planned to improve the stability in these areas while re-establishing the road across the slide.

Description of road construction

The road was re-established by using blocks of expanded polystyren (EPS). Work was postponed until the summer of 1983 (8-10 month after the slide took place) due to difficult working conditions during the winter months. By then the clay in the crater had reconsolidated to a certain extent and the bottom was filled up 2-3 m by sand and gravel. This layer of gravel was compacted thoroughly and levelled before placing a 4-meter high fill of EPS blocks (8 x 0,5 m). A 10 cm thick reinforced concrete slab was placed on top of the

EPS blocks and finally an approximately 80 cm thick layer of gravel with an asphalt topping.

Embankments made of plastic foam have very limited ability to resist horizontal forces. Therefore it was important to ensure that the soil embankment behind the plastic foam sloped gently so that the EPS blocks were not subjected to any appreciable pressure from the soil. It was also important to prevent any water pressure against the EPS blocks. To reduce the flow of surface water a layer of clay was placed at the inner edge of the EPS fill and under the ditch along the inner side of the road. A layer of gravel was placed in the ditch to reduce erosion (figure 1). A culvert was placed at about the middle of the EPS fill. In connection with road improvement activities in recent years the road level had been raised. To capture as much water as possible, the culvert was located fairly deep, on a level with the old culvert that was there previously. For drainage purposes, there was also placed a blanket of gravel under and behind the EPS blocks. This layer was not carried right through, but was terminated against the clay ditch. Thus the inflow of water was reduced as much as possible, while ensuring that any water that penetrated from the rear of or from under the EPS fill could drain off, thus preventing water pressure from building up against the EPS blocks.

Description of counter-berm, stone scour protection etc.

While the slide area was being refilled, counter-berm was placed outside the slide crater and for some distance upstream and downstream of the crater. This counter-berm made it necessary to fill up a part of the original river bed. To avoid decreasing the river cross-section some excavation was recommended on the opposite side so that after the counter-berm was completed the river had approximately the same cross-section area as before the slide. This was recommended in order to make the least possible change in flow conditions, as the river bed is very sensitiv to erosion. In addition stone scour protection was placed along the front of the counter-berm and elsewhere along the river bed.

Experience - settlement of EPS fill

So far the method has proved to be a good solution. The level of bolts cast into the inner and outer edge of the concrete slab showed that some settlement (2-5 cm) took place during the first few months after the road was opened for traffic. However the settlements gradually decreased and in the past year they were less than 1 cm.

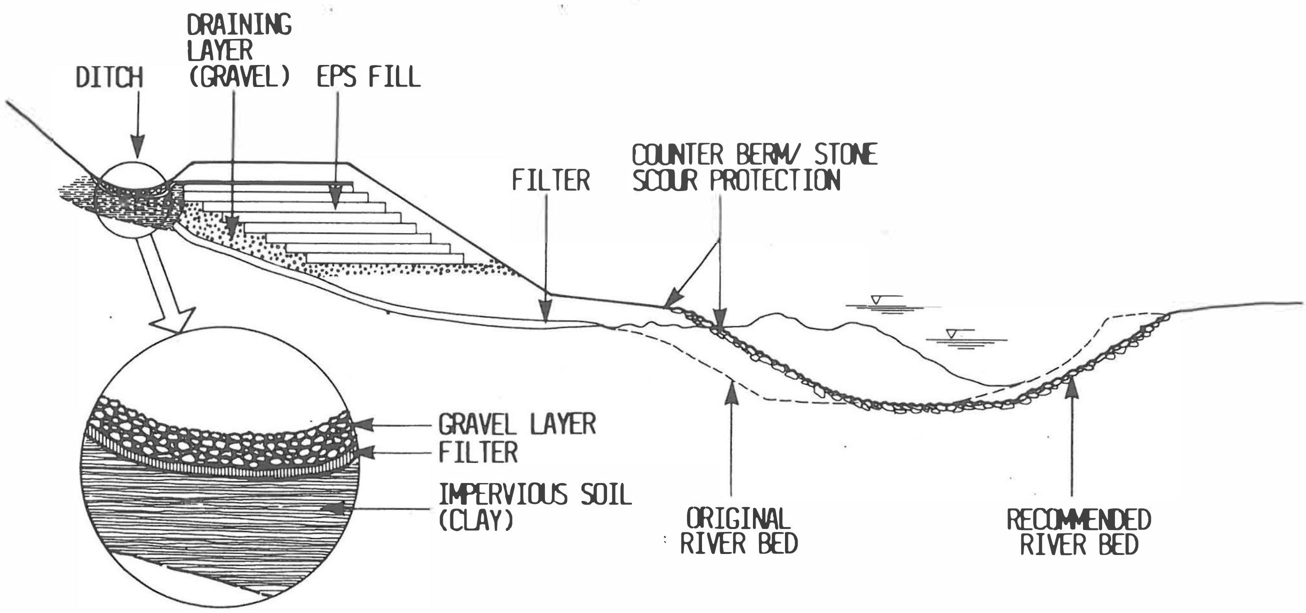


Fig. 1 Cross section - road embankment with counter berm and river bed

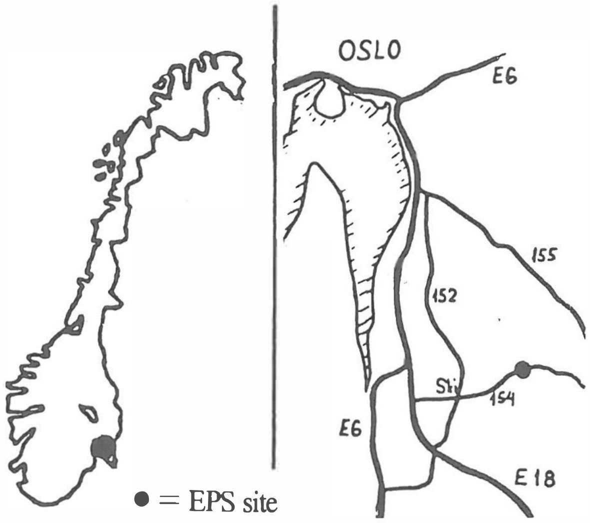
CASE HISTORY 3

SITE: **SOLBOTMOAN**, 30 km from Oslo in south-east direction

Road no./section: Road no 154
Vehicles per day: approx. 2000

Allowable axle load:	10 tons	Year of construction:	1975
Embankment length:	139 m	Built by:	Public Roads Adm.
Embankment height:	Max. 2,7 m	Built for:	Public Roads Adm.
EPS volume:	560 m³	EPS consultant:	NRRL

SITUATION:



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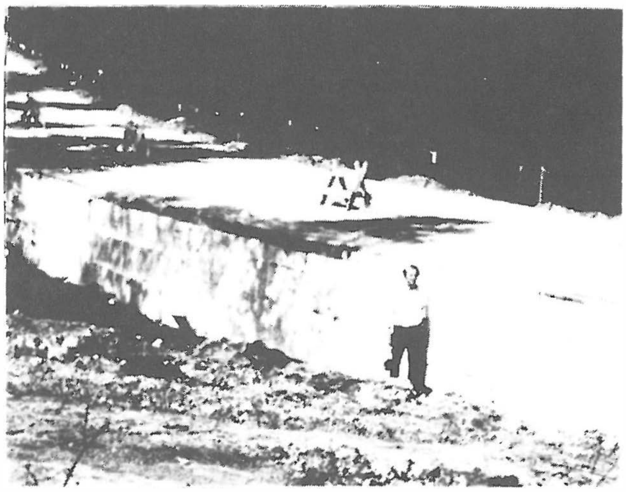


Description of problem

The road crosses a boggy area. During the years there has been a significant settlement, and the road was flooded about twice every year. Each addition of new materials to compensate for the settlement caused a further settlement until finally the subgrade level had subsided 1,7 m. The rate of settlement was increasing and occurence of cracks could be interpreted as an imminent danger of structural collaps. The subgrade conditions can be seen in figure 1.

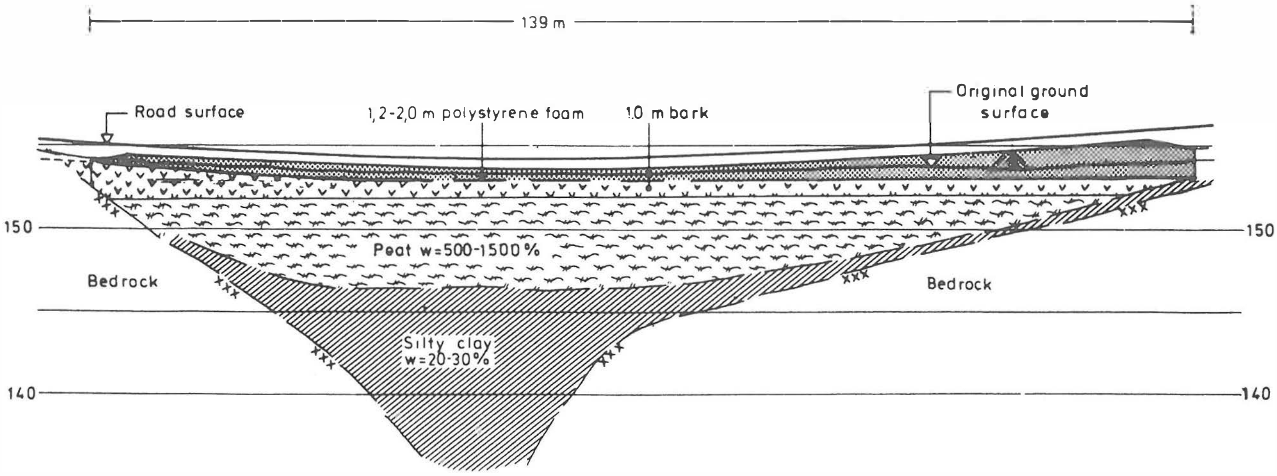


Fig. 1 Longitudinal road profile, Solbotmoan.

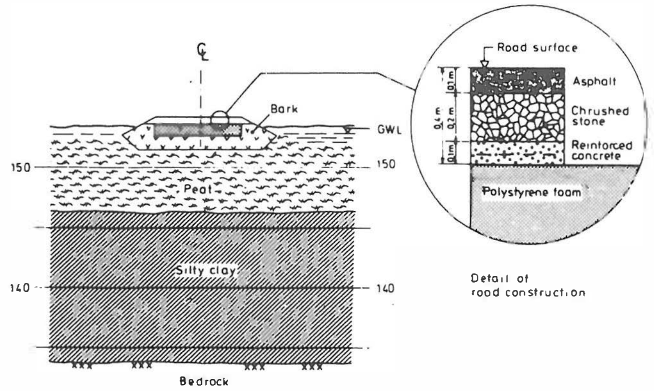


Fig. 2 Cross-section profile of road embankment, Solbotmoan

Description of job

In repairing the road, the intention was to elevate it above the floodlevel. Using conventional materials would lead to accelerated settlement and cause collapse. The only practical solution would be to reduce the load from the road embankment and thus try to stop or reduce the existing rate of settlement.

The road embankment was excavated to a depth of 1 m. Then bark was added up to the groundwater level. After compacting and leveling the bark layer, a layer of expanded polystyrene was used. The thickness of the layer varies from 0,5 to 2,7 m.

The average total settlement after 10 years is estimated to 60 mm (measurements stopped in 1981) with a reduced rate of settlement.

Road pavement

The road pavement above the EPS consists of asphalt 10 cm crushed stone 20 cm reinforced concrete 10 cm

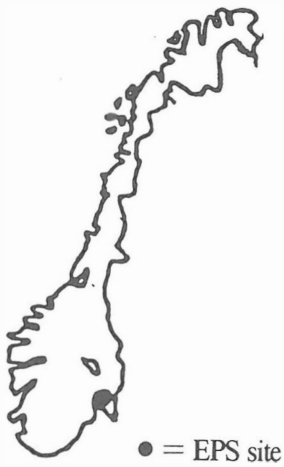
The road has been subjected to traffic for 10 years and the bearing capacity has proved to be satisfactory.

CASE HISTORY 4

SITE: **SOUTHERN ØSTFOLD**, by Skjelinveien south of Sarpsborg

Road no./section:	E6/Årum - Hauge		
Vehicles per day:	7800/950		
Allowable axle load:	10 tons	Year of construction:	1977
Embankment length:	70 m	Built by:	Public Roads Adm.
Embankment height:	Max. 2,5 m	Built for:	Public Roads Adm.
EPS volume:	1700 m³	EPS consultant:	NRRL

SITUATION:



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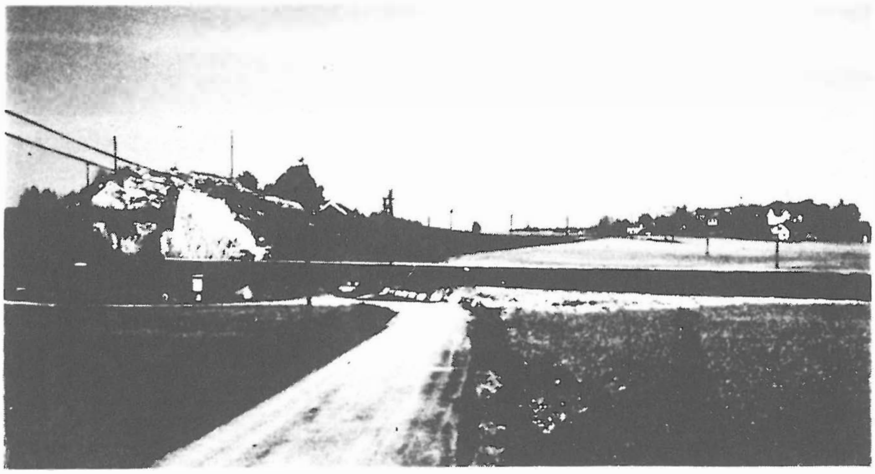

Description of problems

The new highway E6 was to be constructed on a 3 m high fill on very soft and compressive clay. In addition to stability and settlement problems with an ordinary fill there was an existing major water supply pipe crossing underneath. This was not allowed to get settlements at all.

Description of job

The fill was built about fully compensated by first removing about 1 m of the existing soil to compensate for the weight of the pavement cons truction. In connection to the EPS-fill there was built a fill of lightweight material (Leca) to reduce the difference settlements. In the other end the EPS-fill was built in connection to road in cut through rock.

Road pavement

Upon the EPS-fill the pavement construction consists of (from beneath): 2 layers of polyethylene membrane, 10 cm of Leca, 64 cm of crushed stone, 10 cm of bitumen penetrated macadam and at the top 12 cm of asphalt premix. Note that there was not built a lean concrete slab covering the EPS-blocks.

There is no special point in the use of Leca above the EPS-blocks, but due to the polyethylene membrane there ougth to be used a thin layer of fine-grained materials, for example gravel.

Experience

The EPS-fill has now been laying about 8 years, and there has appeared no settlements. The water supply pipe is behaving well.

In the highest part of the neighbour fill of leightweight material there are remarkable settlements, as expected.

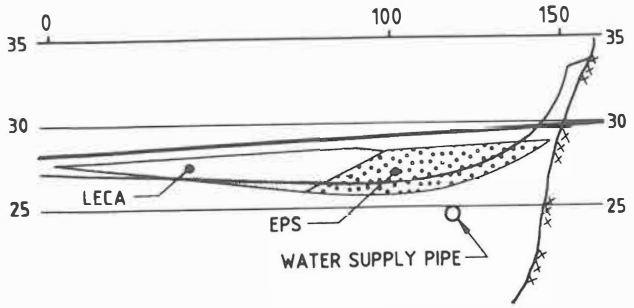

Fig. 1 Longitudinal profile.

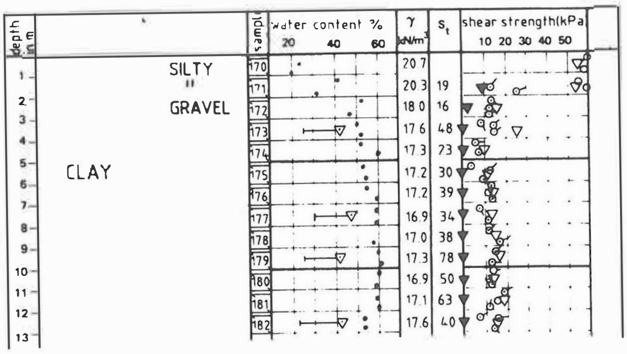

Fig. 2 Cross-section.

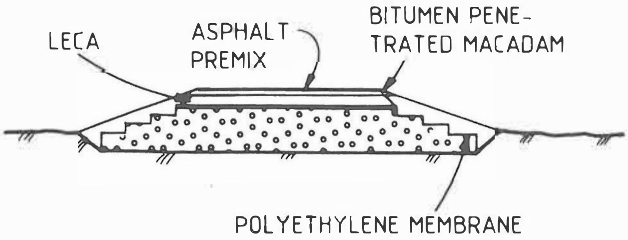

Fig. 3 Soil profile.

CASE HISTORY 5

SITE: **LAMBERTSETERVEIEN BRIDGE**, Oslo

Road no./section: Rv. 160
Vehicles per day: 5000

Allowable axle load:	10 tons	Year of construction:	1977
Embankment length:	110 m	Built by:	H. Eeg-Henriksen A/S
Embankment height:	Max. 4,2 m	Built for:	Oslo Municipality
EPS volume:	4000 m^3	EPS consultant:	NRRL

SITUATION:

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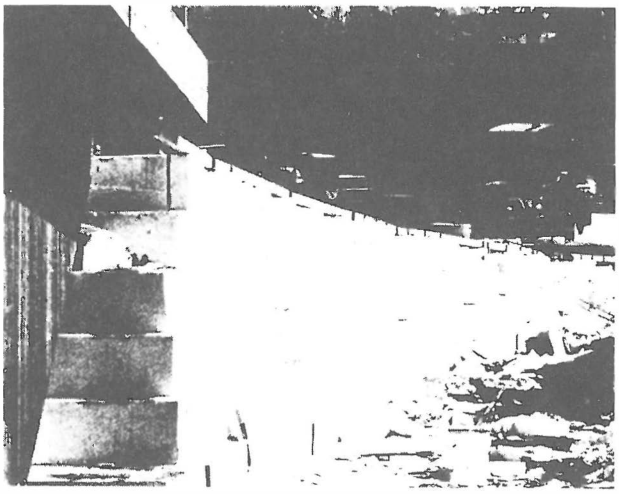


Description of problems

A bridge abutment was to rest on piles to bed rock. Depth to bed rock was 35 m. Upper 2,5 to 3,0 m was peat of Van Post 9. Remaining 32 m was quick to highly sensitive clay of unconfined shear strength S_u = 6 kN/m^2. For stability of the abutment as well as to avoid settlements EPS fill was chosen. The piles were battered to take up horisontal load from creep.

Description of job

In June 1976 1 m of pine-bark was laid as a base and weighted by 0,9 m of rock-fill. In August the fill was doubled to 1,8 m. In February 1977 the rock-fill was removed. The bark had now displaced the upper 1 m of peat. There was a subsequent swelling of the peat of approximately 35 cm in one month. Now 20 cm sand was placed on the bark and the EPS, capped by 10 cm reinforced concrete slab and gravel + pavement of 40 cm. By 1983 a settlement of about 40 cm neccessitated a repair. The slab was uncovered and 10 to 50 cm of styrofoam placed upon it. This was covered with a layer of 28 cm crushed stone plus asphalt-gravel and bitumen to a total of 12 cm. The styrofoam had a compressive strength of 180 kN/m^2 to be able to carry the traffic load. The pavement has performed well since then. The settlement thus compensated had probably for the most part been due to the swelling.

During construction, the front of the EPS-fill was not brought fully into contact with the abutment wall, leaving a gap between. Thus there would be no transfer of "earth-pressure" from the EPS to the abutment wall. The EPS was self supporting. The concrete slab acted also as a lid above the gap, preventing sand or other materials from seeping in. The compressive stiffeners in the formwork were hollow pipes, leaving holes through the front wall. Through these it is now possible to check whether the EPS has subsequently sagged to contact the wall. It appears that the original gap is still there, and little or no horizontal creep has occured. This is important, as it provides a means to avoid all lateral "earth pressure" by means of EPS-fill in bridge abutments, and opens the vision of EPS used as retaining structure.

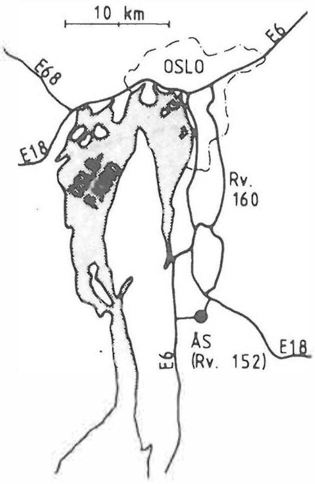
CASE HISTORY 6

SITE: **ÅS**

Road no./section: Rv. 152
Vehicles per day: 4000

Allowable axle load:	10 tons	Year of construction:	1985
Embankment length:	135 m	Built by:	District Road Adm. of Akershus
Embankment height:	Max. 2,5 m	Built for:	District Road Adm. of) Akershus
EPS volume:	2000 m^3	EPS consultant:	District Road Laboratory of Akershus in cooperation with Taugbøl & Øverland A/S
EPS height:	Max. 1,8 m		

SITUATION:



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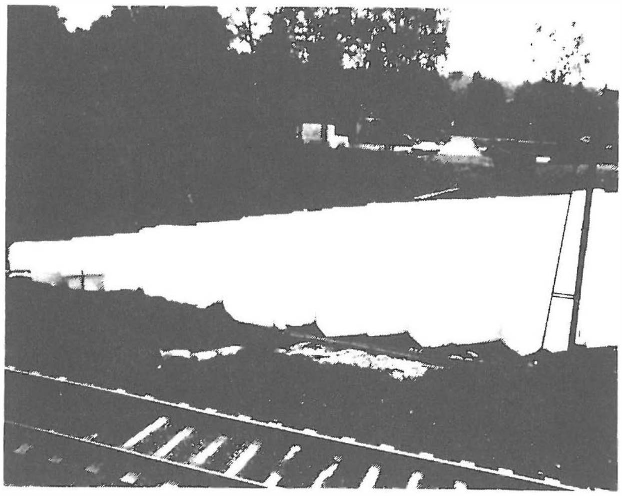


Description of problem

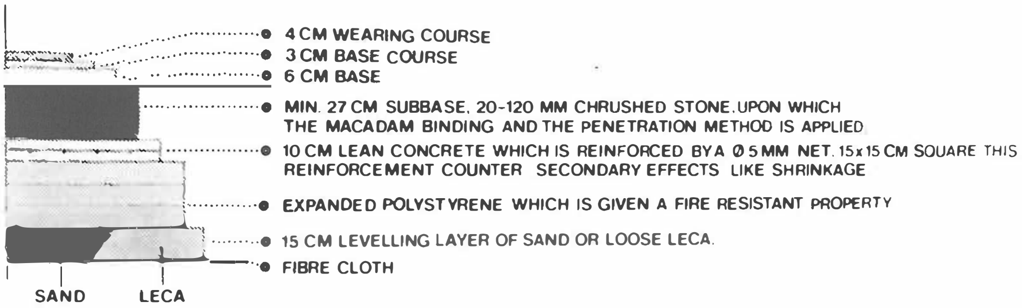
The national road no. 152 is to be permanently diverted around the centre of Ås by building a new leg locally. East of the railway-embankment which the new road crosses by a levelcrossing, the subground consists mainly of very soft silty-clay. An ordinary road embankment consisting of fill with weight of 2 t/m^3 is too heavy for the ground to be considered failure safe. The adjacent railway line complicates the picture as only marginal settlements are allowed. It was therefore necessary to construct the embankment as light as possible and EPS was therefore chosen.

Description of job

First the top soil of 30-40 cm was removed and a geotextile was rolled out covering the area. Then a fill of approximately 500 m^3 loose Leca ($\gamma_w = 0{,}8$) was deposited and levelled by doozer to a maximum depth of layer of 0,5 m. The higher parts of the ground was levelled by a minimum of 0,15 m layer of sand. The embankment was then built using EPS blocks mainly of the size 0,6 x 3,0 x 1,0 m. As a cover for the EPS there will be poured a 10 cm layer of concrete and finally a subbase and base like the adjacent road.

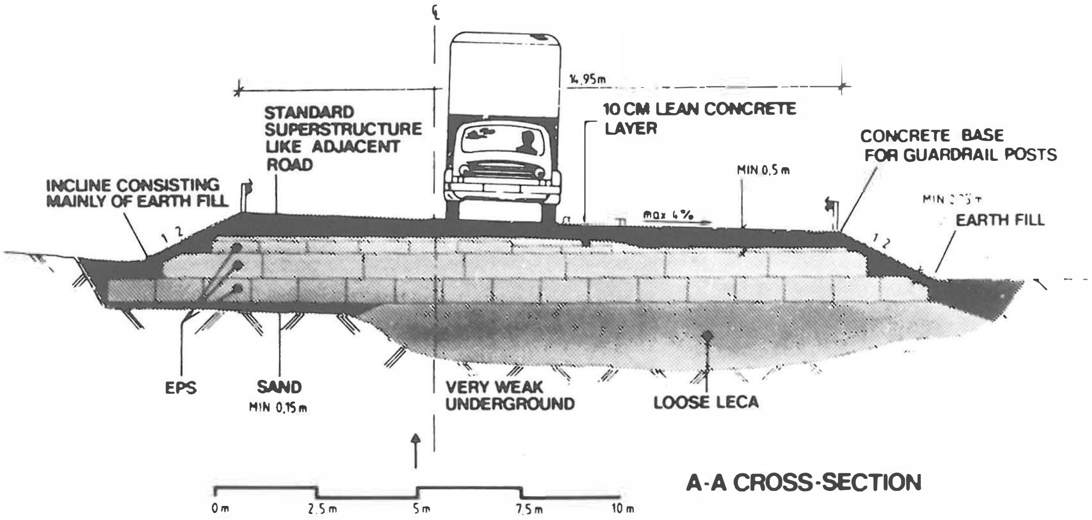
Road pavement

That part of the road pavement which is above the 10 cm concrete layer is equal to the adjacent road. A theoretical cross-section of the pavement is shown in the figures.



THEORETICAL CROSS-SECTION SHOWING POLYSTYRENE SUBSTRUCTURE AS A FOUNDATION FOR A STANDARD SUPERSTRUCTURE

Fig. 1 The quality of the EPS embankment is by large very dependant upon the correct and conscientious levelling and placing of the first layer of blocks.



A-A CROSS-SECTION

Fig. 2 The supplier of the EPS had some difficulties in complying to the demand for blocks without varying measures.

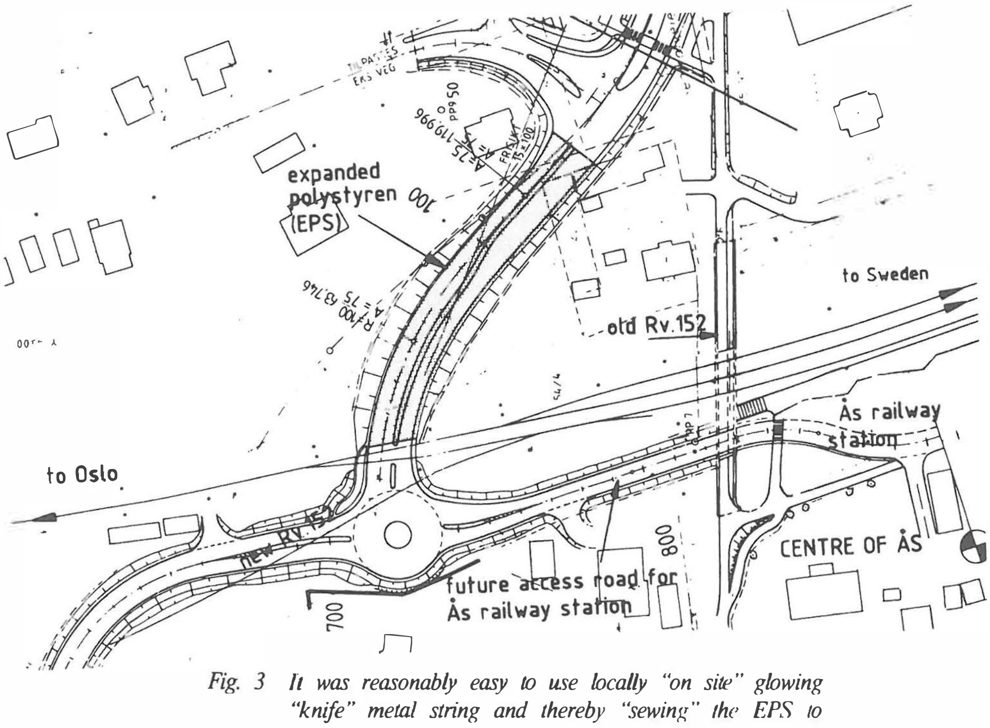


Fig. 3 It was reasonably easy to use locally "on site" glowing "knife" metal string and thereby "sewing" the EPS to measure.

CASE HISTORY 7

Site: **STATE ROAD No. 610**

Road no./section: Rv. 610, Steien - Osen bru
Vehicles per day:

Allowable axle load:	10 tons	Year of construction:	1983
Embankment length:	200 m	Built by:	District Road Adm. of Sogn og Fjordane
Embankment height:	Max. 1 m		
EPS volume:	500 m^3	Built for:	District Road Adm. of Sogn og Fjordane

EPS consultant: District Road Laboratory of Sogn og Fjordane and NRRL

SITUATION:

● = EPS site

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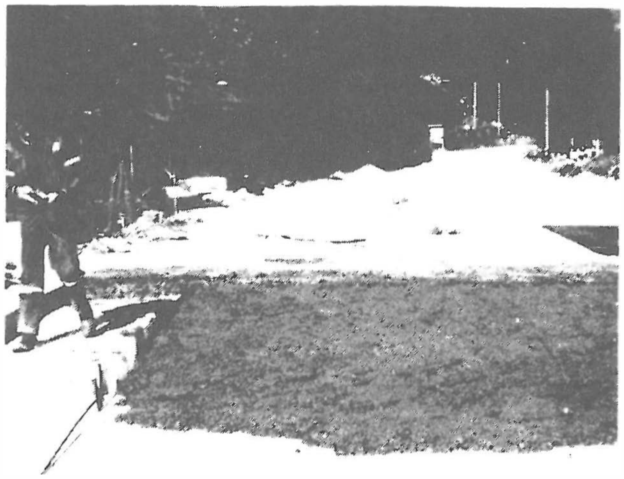


Description of problem

The State Road No 610 had experienced bearing capacity problems over long stretches for some time and in 1980 the District Road Laboratory prepared a plan for increasing the bearing capacity.

This generally involved the complete removal of unsuitable material like peat and other soft and difficult soil.

This work startet in 1982 and is still in progress.

On one of these stretches, a new alignment was prepared passing across a very difficult area where peat were overlaying very soft clays down to 10-12 meters depth.

Crossing this area was proposed in three different alternatives:

a) A wooden raft construction
b) Using EPS blocks
c) Combination of a) and b)

Sogn og Fjordane District road Office with NRRL as consultants decided to construct the 200 meter long road section using the EPS method.

Description of job

As the organic soil could not sustain any increase in effective stress without undergoing unacceptable settlements, the whole load had to be carried by the buoyancy of EPS blocks.

In practice this meant that the ground water level had to be maintained within reasonable limits, ± 20-30 cm.

The actual sequence of the road construction is presented briefly:

1) The excavation of the peat and organic material was done in sections varying from 5 to 35 meters length.

The width of excavation was about 9 meters, the depth being about 1,20 meters. The bottom of the excavation was somewhat uneven and was levelled off using various types of sawdust.

2) The first layer of EPS blocks was then placed directly on the levelled bottom of the excavation. Two sizes of EPS blocks were used 510 x 1000 x 5050 and 510 x 1000 x 2500 (mm). This bottom layer was made by placing the EPS blocks with their longest dimension along the road. The top layer and the next layer was placed at right angle to the bottom layer with steel connectors between the layers. These connectors will keep the blocks in position.
3) Formwork was completed and the 15 cm concrete slab was cast on top of the EPS blocks. Light reinforcement was used.
4) The road was then constructed on top of the slab. The construction had a total depth about 45 cm.

During construction work very heavy rain occurred almost continously, creating numerous problems with water in the excavation.

There were a number of other construction problems, but the work was finally finished and has to this day proved satisfactory.

As this was a new technique several points for measuring deformations and settlements were installed, these points will be followed for many years.

Road Pavement

45 cm total pavement thickness on top of EPS blocks.

Cost

The total cost of the 200 meter long section amounts to about 1,1 mill. NOK ($ 50 000). Considering the cost of the alternatives this is satisfactory.

Conclusions

The method used was new and to our knowledge not tried before. Except for the problems with heavy rain during construction, the method proved to be a good practical and economical proposition.

In future this method will be used and improved upon. A cost of about 5000 NOK per metre road the cost is considered to be satisfactory.

CASE HISTORY 8

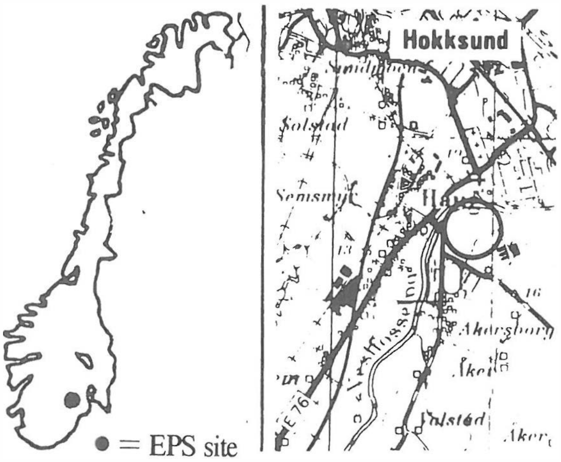
Site: **AKKA PRODUKTER A/S**, Hokksund, Norway

Year of construction: 1980/1985

Built by: F. Selmer   Built for: Buskerud Industriselskap A/S

EPS volum: 5000 m³

SITUATION:



Hokksund, Norway

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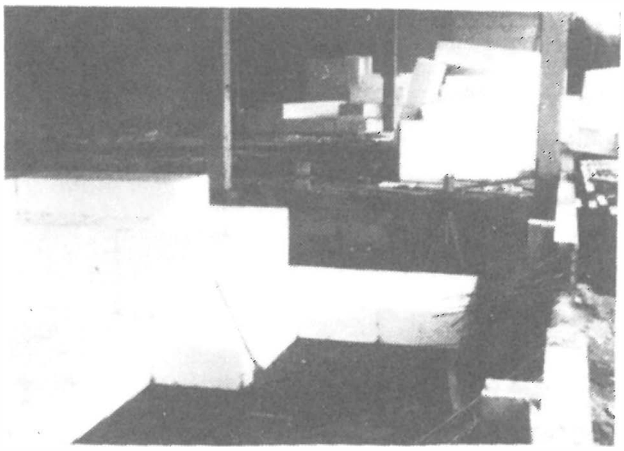


Placement of EPS

Description of problem

The factory building of Akka Produkter in Hokksund has, during its five years life, undergone settlements of as much as 350 mm, with a differential settlement of 250 mm. Maximum angular distortion is more than 1:50. The maximum rate of settlement is at present 40 mm per year. This situation is unacceptable. To reduce/stop the settlements, EPS will be used exchanging the existing foundation fill materials.

An extention to the main building has just been constructed. EPS was used underneath the floor to avoid added loads on the ground.

Description of job

The building was constructed during the year 1980. The dimensions are 50 x 55 m. The superstructure, supported by columns spaced 6 x 18 m, is founded on footings. The floor, elevated 1,50-1,80 m above the original terrain surface, is resting on a compacted gravel fill. A small section of the building has an excavated basement. Hence, the following loading situations exist underneath the building:

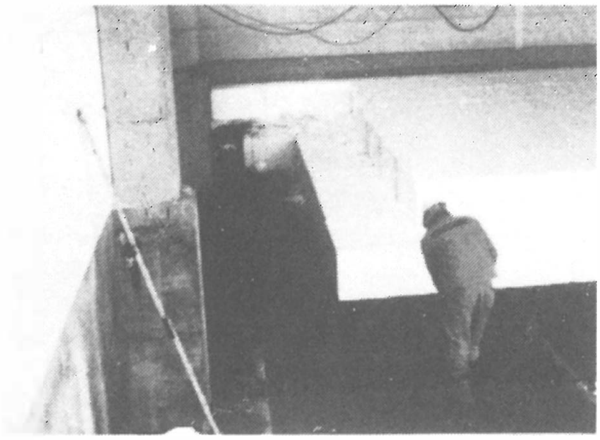
1) Compensated foundation under the excavated basement.
2) Additional load of 40-50 kPa (included live loads).
3) 60 kPa under column footings.

The soil consists of normally consolidated marine clay and silt with some sand lays, to more than 40 m depth. The water content varies between 20-40 % in the sand and silt, and between 40-50 % in the clay.

The settlement process mentioned above is due to consolidations in the marine sediment. Settlement observations and new calculations indicate that the total deformation will be between 500 and 700 mm.

Different solutions to reduce/eliminate the settlement problem have been considered. These are excavation for basement under the whole building, exchange the existing natural fill with lightweight fill of EPS. The use of EPS was chosen, both of economical and technical reasons. The new foundation under the elevated floor will consist of 1,6 m of EPS on top of which is placed a geotextile, 300 mm layer of compacted sand and finally 150 mm concrete slab reinforced in top and bottom. The sand layer will function as a load distributing stratum to reduce the effect of large concentraated life loads. The technical specifications for the EPS blocks and of the placement of the blocks are the same as used in road constructions. The work will be carried out during the months June, July and August 1985.

For the 18 x 55 m extention to the existing building (construction work was carried out in March, April and May), 2,1 m of EPS was used underneath the elevated floor. This allows for full compensation of the floor loads, included live loads. The building is at this time not taken into use, so no settlement data are available yet.



CASE HISTORY 9

Site: **LOENGA, OSLO**

Road no./section: E6 Mossevn. v/Loenga
Vehicles per day: 5000

Allowable axle load:	10 tons	Year of construction:	1983
Embankment length:	90 m	Built by:	Eeg-Henriksen A/S
Embankment height:	Max. 5,5 m	Built for:	Municipality of Oslo Road dept.
		EPS consultant:	Municipality of Oslo, Geotechnical dept. and Dr. Lars Aadnesen & CO A/S

SITUATION:

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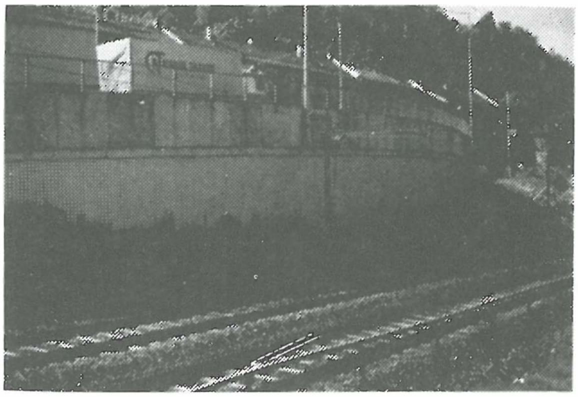

Vertical finish against the railway (Østfoldbanen)

Description of problem

In order to increase the traffic capacity the road department in the Municipality of Oslo has builу a ramp for a new exit from Mossevn., E6 at Loenga in Oslo. Figure 1.

The ground conditions in the area were not very good. The depths to dolid rock vary from approximately 10 m closest to E6 to approximately 25 m under Loenga bridge. the soil consists of 2-3 m fill over very sensitive soft clay which is partly quick.

The stability of the previous slope was satisfactory, but the factor of safety could not be reduced.

Several design methods were considered before it was decided to use plastic foam in the embankment. An ordinary retaining wall was out fo the question due to stability problems. The constructive alternatives were first valuated on an economic basis. A priority list follows with the cheapest design first:

Alt. 1) Embankment consisting of plastic foam
Alt. 2) Retaining wall supported on piles down to solid rock
Alt. 3) Permanent sheet pile wall to solid rock
Alt. 4) Bridge supported on piles down to solid rock.

Alternative 3 and 4 were rejected at once partly of great costs and partly because of technical reasons.

Alternative 2 was considered equal in price to Alt. 1 and by supporting the retaining wall on piles to solid rock sthe stability of the fill would be obtained. If the traffic lines were built in two levels, the retaining wall for the outer lane could be built on piles and support the inner lane which could be built as an ordinary retaining wall. However, the piling would have to be excuted very close to the railway with its overhead electric wires. It would be a problem to do this with railway in use.

Alternative 1 was estimated to cost the same as Alt. 2, but the plastic foam embankment was considered to have great advantages in the use of construction equipment. It was therefore assumed to be the solution that was most predictable, that is, that few unforseen difficulties would arise during construction. Short constructiontime was also of desicive sense.

Description of job

To obtain a stable fill, which was approximately 6 m high at the most, the previous slope was slacked to an angle of inclination of 1:3 (20°).

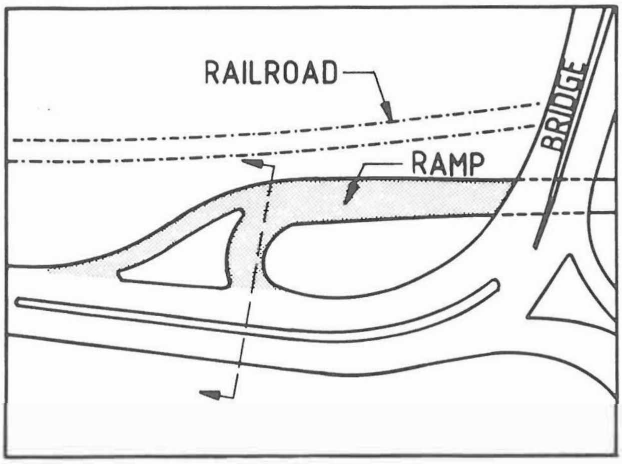

Fig. 1 Situation.

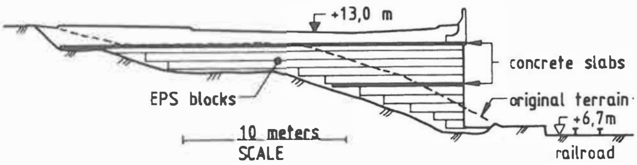

Fig. 2 Typical profile of fill.

All blocks, which measured (0,5 x 1,0 x 2,5) m, were placed in one direction (except from the first row) and horizontal. the ground underneath was adjusted with gravel to fit the blocks. The gravel would also take care of the drainage under the fill.

As the ramp curves it was provided that the blocks were adjusted to the curve at the vertical finish against the railway, so that no cutting of the blocks had to be done inside the fill.

As requirements to the material in the blocks and the construction of the fill, were used an instruction published by the Norwegian Road Research Laboratory (May 1980).

In case of the need to adjust the level in the middle of the fill it was designed a 12 cm thick concrete slab with light reinforcement. the construction showed that this was unnecessary as the level was pretty good due to equal size of the blocks.

At the top of the fill the blocks were cut exactly parallell to projected top of the road. The superstructure of the road consists of a 15 cm thick reinforced concrete

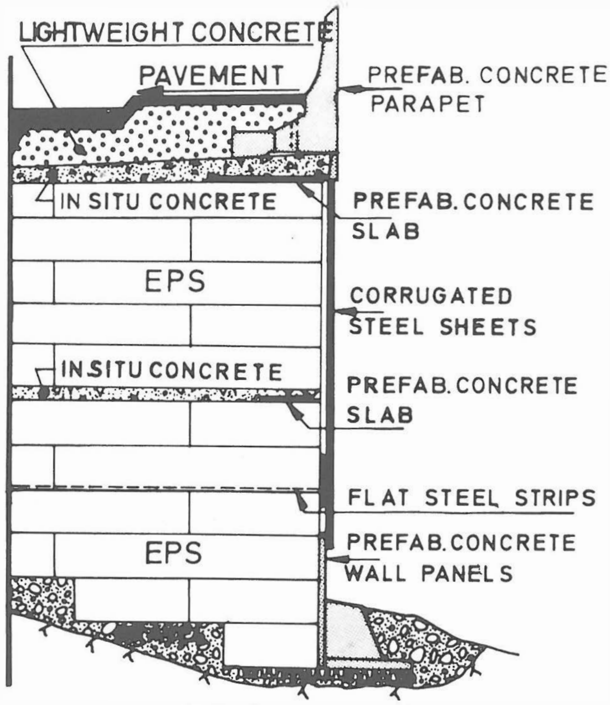

Fig. 3 Typical cross section.

slab on top of the plastic foam and on top of that 40-50 cm gravel and asphalt.

Because of the fill's unusual shape with its vertical finish against the railway, the construction had to be given special consideration. To prevent the vertical end of the fill from weathering, damage by fire etc., it was painted and protected with industrial corrugated steel sheets. These were fixed to the concrete slab at the top and to special brackets lower in the fill. The fastening arrangements had to allow the fill to creep without affecting the steel sheets.

The construction of the concrete parapet at the top of the fill also had to be given special consideration. There were mainly two problems which had to be taken care of:

a) It was not possible to cast the parapet in one piece and in situ. To solve this problem the parapet was built by precasted elements and put together at the edge of the fill.
b) The heavy construction at the edge of the fill could cause extra deflection in the plastic foam fill. To avoid this it was used light fill under the side walk and plastic foam with higher compression strength at the edge of the fill.

Furthermore the parapet had to be designed for greater loads than normal, because the ramp curved and this made it possible for the traffic to collied with the parapet at a right angle.

There has been made measurements to check the settlements on the fill. The measurements show that the parapet settled approximately 1 cm the first year. Further measurements show, however, that there has been no settlements the last six months, so it is presuméd that the settlements have stopped.

CASE HISTORY 10

THE EMBANKMENT AT HÄNDELÖ, NORRKÖPING, SWEDEN

A fast and easy reconstruction of an embankment with use of EPS

Background

In the early sixties a new bridge for road and railway traffic was built across the Motala stream at Händelö near the city of Norrköping. Within the south approach area of the bridge the subsoil consists of more than 20 m of very soft, partly organic, clay resting on non-cohesive soil. As for the bridge abutment end-bearing piles were used for a supporting concrete deck for some 40 m length of the approach embankment, the height of which was about 3 m at the end of the deck. In front of the concrete deck the embankment was built directly on the soft subsoil, stabilized only by loading berms. Except installing of three rows of wooden piles (with a length of 15 m and without concrete caps) no measures were undertaken to reduce the consolidation settlements in the subsoil.

After only a few years the settlements in boundary zone to the concrete deck caused a bumpy road surface. The settlements continued over the years with increasing traffic problems and a frequent need of maintenance measures.

In the autumn of 1980 the rate of the settlements was 50/70 mm/year and a serviceability failure was feared due to the increased loads of the piles beneath the concrete deck. Therefore, Swedish Geotechnical Institute (SGI) in Linköping was commissioned to carry out a geotechnical investigation and, if necessary, to design a reconstruction of the embankment.

Investigation results

The field investigations showed that the settlement next to the piled deck was about 1,4 m. The analysis of the degree of consolidation of the clay and the other investigation results proved that so large settlements remained, that a complete reconstruction of the embankment was necessary.

To obtain total elimination of the settlement problems the embankment should have had to be excavated and

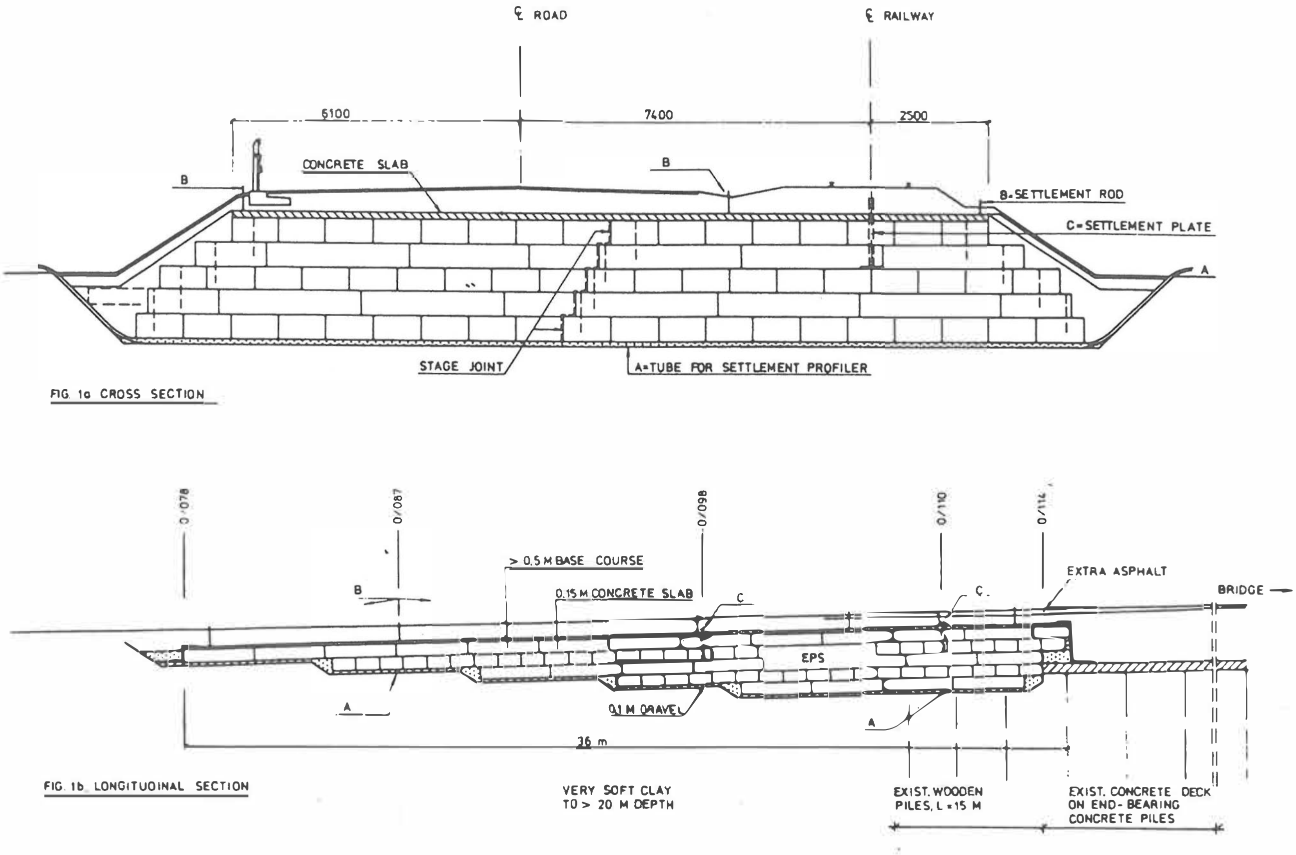

Fig. 1 Embankment design details and follow up instrumentation.

replaced on a new piledeck. Regarding the high costs for that solution and the demand for motor traffic over the bridge and maximum 2 weeks of break in the railway traffic a more simple method had to be chosen.

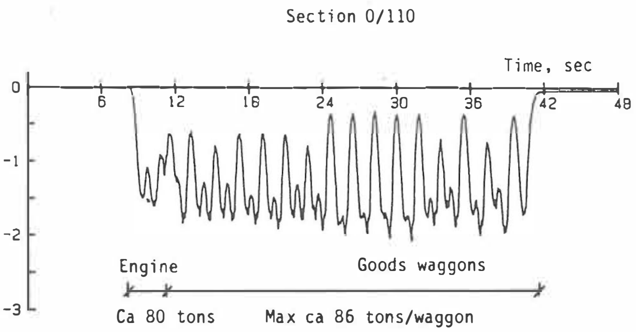

Fig. 2 The elastic deformation of the EPS fill under the train load (measured on one metre thickness beneath the concrete slab).

As shown in figure 2 the deformation of the EPS fill under the train load is very small and quite elastic. The diagram is representative for measurements at 5 occasions during the period August 1982 to June 1985.

SGI proposed and designed a combination of a lower profile for the road and railway and a partial exchange of the gravel fill to lightweight fill (expanded clay or EPS). The proposal was accepted by the client and finally the EPS alternative proved to be the most suitable one regarding cost and quality aspects. By the designed measures the future settlements were calculated to an acceptable amount of maximum 10 mm/year next to the piled deck.

The reconstruction

The reconstruction was carried out in the summer of 1982. The embankment design and follow up instrumentation are shown in figure 1. About 1000 m^3 of EPS-blocks with a unit weight of 20 kilograms per cubic metre was built in. The thickness of the EPS-fill varied from 0,5 to 2,5 m. The EPS-fill was covered with a reinforced concrete slab 0,15 m thick.

The embankment was instrumented (figure 1) in order to make long term follow up measurements possible. The total settlements of the embankment as well as the deformation of the EPS-fill under railway traffic load will be studied.

Conclusions

The experiences of this project are good in all respects, both technically and pratically. Due to the easy handling of the EPS-blocks the embankment for the railway could be reconstructed very fast within the schedule. The EPS block also made it possible to carry out the work operations within the original width of the embankment for the railway could be reconstructred very fast within the schedule. The EPS-blocks also made it possible to carry out the work operations withing the original width of the embankment, wicth was the available area.

So far (June, 1985) the reconstructed embankment has performed quite satisfactorily. The settlements next to the concrete deck during the period 1982-08 to 1985-06 have been measured to 20 mm. The calculated 3-year deformation is some 30 mm.

CASE HISTORY 11

ROAD 588 AT FITTJA, STOCKHOLM, SWEDEN

"Active design" with Lime Columns and Plastic Foam

Background

Road 588 at Fittja had to be constructed close to the shore line of a lake, where the soil layers consists of 1-2 m of silt over 8-10 m very soft clay resting on loose silt and sand to a depth of more than 50 m. Depending on the low factor of safety (F = 1,2) for the strip of shore it was impossible to construct the 3-4 m high embankment on the subsoil without previous improvement of the soil or transferring the load to a large depth in the sand by means of friction piles.

When planning the project a combination of embankment piling and a piled concrete deck (next to the lake) was found to be the best method and also economic with an estimated length of the piles of 25-28 m. From different reasons full scale pile tests could not be realized until the start of the construction work. These tests proved that the necessary length of the piles ought to be about 40 m. The test results caused a drastic cost increase and severe technical problems were also foreseen due to the increased piling activities. Therefore, the possibility to improve the strength of the soil was reconsidered.

Design and construction

A combination of soil improvement by lime columns and a partial use of plastic foam as embankment fill was studied from technical and economical aspects. It was proved that this alternative could be expected to work satisfactorily and as the cost calculations were favourable compared to piling, lime columns and plastic foam fill finally were chosen.

The designed measures are shown in Figure 1. The main function of the stabilization of the soil with lime columns was to increase the stability of the road area towards the lake. For this reason the lime columns next to the lake were arranged as panels. For the rest of the area the spacing of the lime columns was adjusted to the load of an estimated (calculated) thickness of the EPS-fill plus the base course and the gravel fill, so that the consolidation settlements would be eliminated or reduced to acceptable amounts. The final decision of the thickness of the EPS-fill within different parts of the road area was based on quality tests of the lime columns about 6 months after installation ("active design").

The construction work was carried out according to the design. The volume of the EPS-fill was estimated on the safe side in the cost accountings, i.e. corresponding to the total embankment height minus 0,6 m (0,1 m concrete + 0,5 m gravel and asphalt, which is the minimum thickness of the base course on plastic foam in Swedish road building). Due to the results of the lime column tests the volume of the EPS-fill could be cut down to about 2/3 of the initial calculated volume.

Conclusions

This project has shown that use of superlight fill, type EPS, often can offer a good and economic solution of

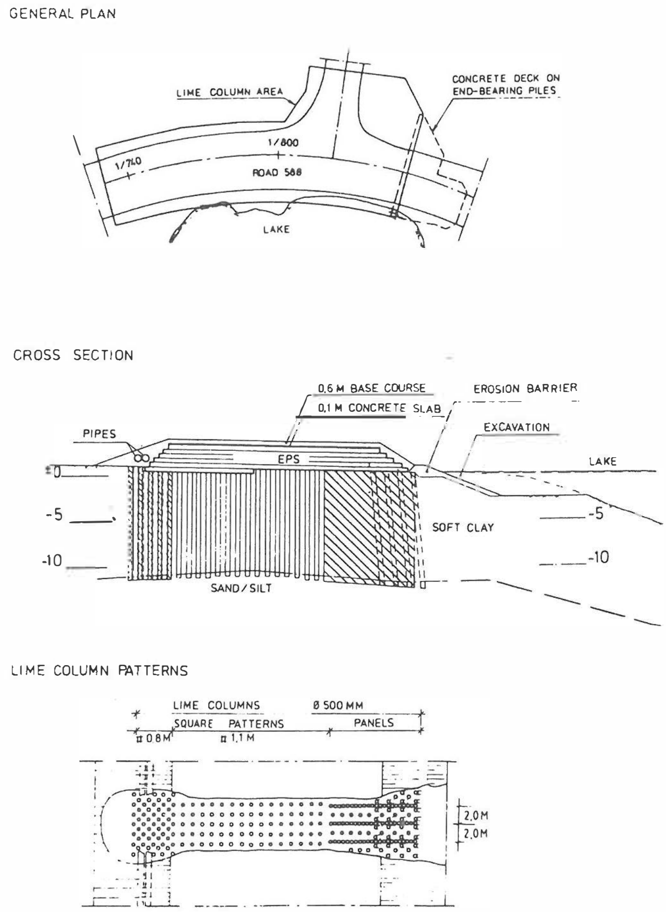

Fig. 1 Layout of the lime column installation and the preliminary volume of EPS fill.

stability and settlement problems for road embankments constructed in soft soil areas. A special advantage with the method is the possibility to easy adjusting of the thickness and shape of the EPS-fill according to different geotechnical conditions at different parts of the embankemnt. Due to the flexibility the EPS fill methods is very suitable for use on sites like Fittja where the final solution and design is best decided during the construction period.

CASE HISTORY 12

ROAD NO. E6 AT THE VISKAN RIVER (1980) AND AT HOLMAGÄRDE (1984), SWEDEN

(Swedish National Road Administration)

Viskan River (1980)

During the late seventies the design work for road no. E6 Malmö-Gothenburg between Åskloster and Frillesås was being completed. This part included a bridge crossing of the Viskan River (about 60 km south of Gothenburg).

The soil conditions at the river crossing are rather bad with clay to 50 m below ground level. The soft clay has a natural water content of 60-70 % and an undrained shear strength (cone and vane) 10-20 kPa.

Extensive soil investigations including numerous test pilings and static test loadings resulted in a design with foundation on piles of the connecting road embankments. The design asked for totally 15 000 m piles with length varying between 30 and 41 m. The piles to be both timber piles and piles with combined concrete and timber elements. For the "combination" piles a 10 months reconsolidation time was necessary before loading.

Just in time before the tender documents to be sent out an alternative design was made with embankments mainly of polystyrene foam. This design needed only 2000 m of shaft-bearing piles (close to the bridge abutments) and 1700 m³ of polystyrene foam.

The maximum height of the plastic foam was 2,0 m.

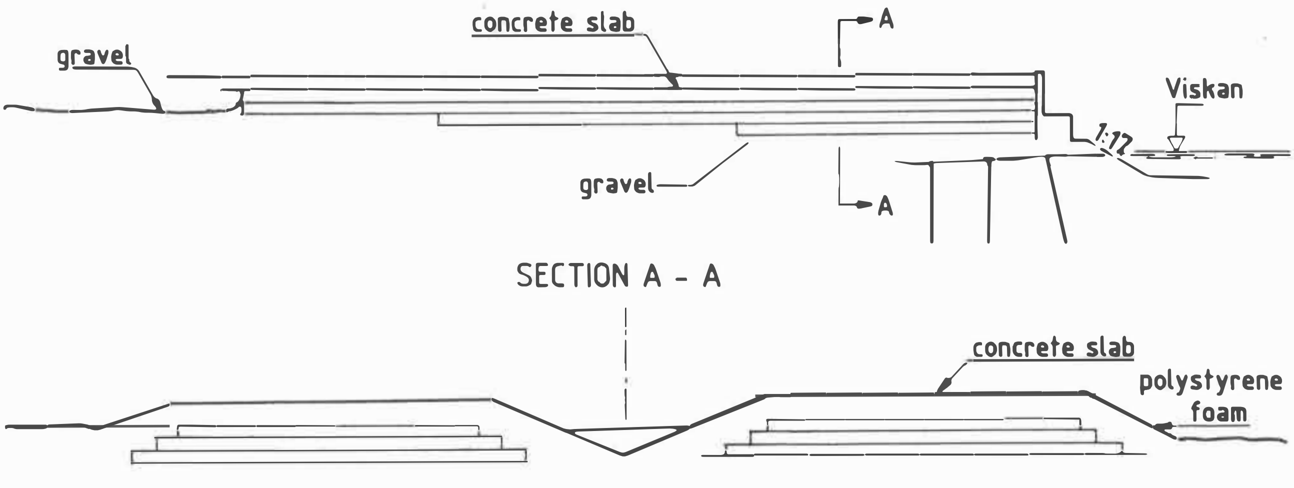

Fig. 1 E6 at the Viskan River - embankment on polystyrene foam.

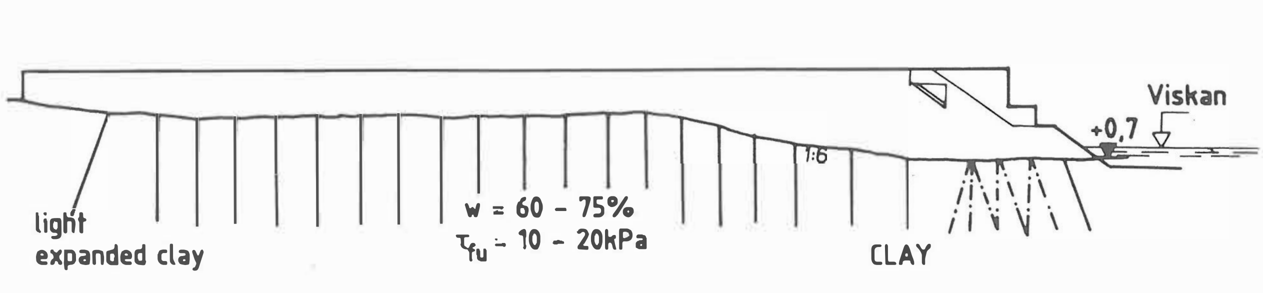

Fig. 2 E6 at the Viskan River - embankment on piles.

The surface of the plastic foam to be covered with a 100 mm case-in-situ concrete slab. The concrete (K 300) to be reinforced with a net ø 6 mm c 100 mm.

Preliminary cost estimates of the two alternatives clearly showed the advantage of the plastic foam embankments. The tender documents thus only gave the plastic foam alternative. From the contractor's prices it was estimated that the total cost of the constructed plastic foam alternative was at least 0,5 million SEK less than that of the original design with embankments on long shaft-bearing piles.

Holmagärde (1984)

At the future interchange between roads no. E6 and 153 at Holmagärde (near Varberg) the embankments for the road no. 153 over the E6 were designed with both embankment piles (close to the bridge abutments) and plastic foam with a total height of 4,0-4,5 m. The estimated pile length were 10-15 m.

Due to the market situation at that time - rising prices of polystyrene foam and a decreasing demand for concrete pile - the tender documents gave alternatives. There was a possibility to increase the area with embankment on piles thus decreasing the embankment of plastic foam.

The contractor chosen for this job offered to increase the embankment on piles with 35 m + 30 m road length on the two sides of the bridge. This meant additional 4100 m of end-bearing concrete piles (average length 12 m) instead of about 5000 m^3 of polystyrene foam (average height 4,5 m). The contractor's alternative offer gave us a price reduction of 0,25 million SEK compared to the original design.

The two examples show the benefit of free competition between alterantive earth strengthening measures under certain given presumptions.

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2. I. TH. ROSENQUIST. Petrografi og vegbygging (Petrography and road construction). 6 s. 1943. Utsolgt (out of print, copies aviable).

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Appendix: Case histories 1-12. 60 s. 1987.

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Some of the NRRL Internal Reports (in Norwegian) are aviable for distribution outside the Public Roads Administration. List of publications on request.

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Organisasjon:
Statens Veglaboratorium ble etablert i 1938 og er administrativt en avdeling i Vegdirektoratet.

Veglaboratoriet er internt organisert i 5 seksjoner som knytter seg til fagområdene **asfalt og kjemi, betong, bærelag, geologi** og **geoteknikk**, samt sekretariat og felles verksted.

Oppgaver:
Hovedoppgavene er å drive forsknings- og utviklingsarbeide på det vegtekniske område samt å virke som rådgiver innenfor de fagområder laboratoriet dekker. I dette arbeidet inngår kurs og opplæringsvirksomhet.

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NORWEGIAN ROAD RESEARCH LABORATORY

Organization:
The Norwegian Road Research Laboratory was established in 1938 and is a sub-division of the Public Road Administration.

The N.R.R.L. is internally organized in five technical sections, Bituminous materials and Chemistry, Concrete, Pavement design, Geology and Soil mechanics, together with a secretariat and a workshop.

Field of Operation:
The main object of the N.R.R.L. is research and development in the area of highway construction and consulting within the technical fields of operation. This work includes offering courses and training programs.

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