Polystyrene Foam for Lightweight Road Embankment

Polystyrene Expansée dans Remblais Légèrs

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SYNOPSIS This paper deals with the use of expanded polystyrene in road embankments. Expanded polystyrene is extremely light, initial density 20 kg/m^3, and may represent the only feasible solution in projects with exceptional soft subsoil other than supporting the embankment on piles or constructing a bridge.

Examples of how polystyrene foam is used are described in the following 3 case records:

- repair of a road across a bog
- construction of a new road on bog/clay
- road embankment adjoining bridge abutment

Expanded polystyrene blocks, size 0,5 x 1,0 x 3,0 m, are generally used. A reinforced slab of lean concrete is cast on the polystyrene for protection and a flexible pavement is constructed on top of it.

Our experience with 25 polystyrene foam fills is so far good in all cases. These embankments give a satisfactory design, often at a much lower cost than alternative methods.

INTRODUCTION

The load exerted by road embankments on soft, fine-grained subsoils often leads to problems of bearing capacity and settlement. Slides may occur as a result of shear failure in underlying clay- and peat soils. Such subsoils often yield unacceptable settlements. This is especially the case in transitions between embankments and bridges or other structures founded on piles on bedrock, where differential settlements are a problem.

The way in which the road embankments are to be protected against unstability and troublesome settlements will depend on local conditions. Among current methods which can solve these problems, can be mentioned:

- counterberms
- lightweight fill materials
- vertical drains
- replacement of soil masses
- embankment on piles
- bridge construction

At each site the special problems and conditions will have to be analyzed. The method giving satisfactory protection of the construction at lowest costs is the one to be chosen.

Fig. 1: A 4,2 m high fill of expanded polystyrene in Oslo. The use of polystyrene blocks reduced the bridge by one span. (Photo: Ulf Winther)

Lightweight fill materials will often be the best solution from a technical-economical judgement. Figure 2 shows the lightweight materials used in Norway and their densities to be used in stability analysis. For comparison, ordinary fill materials usually have a density of about 2000 kg/m^3.

Material	Density kg/m^3 for calculation
Bark	1000-1100
Sawdust	1000
Cellular concrete waste	1000
Light expanded clay (Leca)	800-1000
Waste bricks of Leca	1000
Expanded polystyrene	100

Fig. 2: Density of lightweight materials being used in Norway

Expanded polystyrene is extremely light even compared with other lightweight materials. Therefore it can be used where the conditions are so difficult that ordinary lightweight materials will not give a satisfactory design. The alternative to the polystyrene embankment is often more expensive constructions, e.g. supporting the embankment on piles. Since the first experimental fill was constructed in 1972, polystyrene foam has been used as lightweight material in 25 projects in Norway (until August 1980).

MATERIAL PROPERTIES OF POLYSTYRENE FOAM

The material being used in the fills is blocks of expanded polystyrene with a density of 20 kg/m^3. The size of the blocks is usually 0,5 x 1,0 x 3,0 m which gives a mass not greater than 30 kg. This can be easily handled by one man and a fill of polystyrene is therefore easy to build, see fig. 3.

Fig. 3: Building with blocks of expanded polystyrene. The blocks are interlocked by using a staggered joint pattern. Double sided timber fasteners (e.g. Bulldog Ø 117 mm) shall prevent sliding on the underlying layer. (Photo: Refsdal)

Expanded polystyrene is chosen only because of its favourable price compared with other products (e.g. extruded polystyrene, polyurethane foam, etc.).

The compressive strength (average) should be 100 kN/m^2 (1 kp/cm^2) at max. 5% deformation. In quality control single test results as low as 90 kN/m^2 will be accepted. The common expanded polystyrene with a density of 20 kg/m^3 will usually meet these requirements.

The question is whether this material is suited for road construction when it weighs only 1% of ordinary road construction materials and you can easily make a hole in it with your finger. Our experience is positive without exception. Testing of sampled specimen from two fills, 4 and 7 years old, does not show any decay of the polystyrene (Aabøe, 1979). This leads to two conclusions:

- The material can stand up to the traffic loads
- The aging of the polystyrene is slow (if any)

The sampled specimen also showed a limited moisture content in the polystyrene, though not negligible. One specimen taken below groundwater level had 8% by volume moisture content (wet density: 100 kg/m^3), but the average moisture content was less than 4% (Aabøe, 1979).

The good material properties or advantages of expanded polystyrene can be summarized to be (Dahlberg and Refsdal 1979):

- Low mass. The initial density is only 20 kg/m^3 which is 1% of ordinary fill materials. A density of 100 kg/m^3 is used in stability calculations in order to allow for future increase in moisture content.
- Durability. Research and experience so far show no change in material properties.
- Ease of handling. The material is clean, easily handled and inspected on the construction site.
- Availability. 16 producers all over Norway and low transportation costs.

On the other hand expanded polystyrene has some undesirable properties when used in road embankments (Dahlberg and Refsdal, 1979):

- Inflammability. It is possible to set the polystyrene on fire during construction period or when stockpiled.
- Dissolving by chemicals. Polystyrene is not resistant to petroleum-based liquids, several dissolvents etc., and an accident with a lorry carrying these liquids could be serious. It is advisable to protect the polystyrene by a membrane. Some protection is gained from the concrete slab mentioned in the next paragraph.

- Icing. The insulation effect of the foam increases the tendency of icing on the road surface. A minimum pavement thickness is required.

DESIGN OF ROAD PAVEMENT

Expanded polystyrene is very soft compared to subgrade materials, and even today the design of road pavment is a matter of discussion. Most of the polystyrene foam fills in Norway are protected by a 0,1 - 0,15 m thick reinforced concrete slab. The slab adds considerably to the strength of the pavment and will also give some protection against liquids which can dissolve the polystyrene. A normal flexible pavement is constructed on top of the concrete slab. The thickness of the layers is found from the Norwegian design manual assuming that polystyrene is equal to clay with average moisture content.

The lean concrete slab makes it possible to build a thin pavment, minimum 0,5 m thick, on the polystyrene, which is strong enough for roads with high traffic volume. Bearing capacity measurements on pavments, consisting of 0,1 m concrete, 0,3 m granular materials and 0,1 m asphaltic materials, show a Dynaflect Maximum Deflection of 0,06 mm and a Surface Curvature Index of 0,007 mm. This is satisfactory for most roads in Norway.

The cost of the concrete slab is high and its use may be questioned. To omit the slab a much thicker pavement would have to be constructed. A polystyrene foam embankment on road E6 near Sarpsborg is one of the few without concrete slab. The road pavement consists of 0,15 m light expanded clay (Leca), 0,63 m crushed rock, 0,1 m bitumen penetration macadam and 0,1 m asphaltic surfacing. Bearing capacity measurement shows a Dynaflect Maximum Deflection of 0,13 mm and a Surface Curvature Index of 0,007 mm. The maximum deflection is about 3 times higher than normal for an important highway and it would have been completely unacceptable if the Surface Curvature Index had not been very small (large radius of curvature). The permitted axle load is 100 kN but according to the Norwegian interpretation of the measurements, including curvature, the recommended maximum load is 80 kN. The annual daily traffic is 7000 vehicles. The importance of the radius of curvature is a matter of international discussion and only the coming years will tell us if the service life of the surfacing is too short.

From computer programs calculating stresses and strains in pavements and subgrade (Modified Chevron) we have found that the height of the fill will not influence the pavement design. Practical experience so far is confirming these calculations.

Expanded polystyrene is an insulating material and it will drastically reduce the heat flow between the subgrade and the road surface. The result is that the road surface will have a temperature which is different from the adjacent part of the road. On clear nights in late autumn the temperature of the road surface may drop below 0°C while the adjacent sections, with heat transfer from the subgrade, are above 0°C. This causes a difference in tendency of icing on the road surface which reduces the traffic safety.

A layer of gravel keeps some moisture and will provide a heat supply above the polystyrene and therefore reduces the tendency of icing, but the problem is not completely eliminated. In our specifications for polystyrene fills a minimum thickness of the pavement is required. The minimum thickness is dependant on the traffic volume and tendency of icing on the adjacent parts of the road.

CASE RECORDS

In the following three case records, the construction and experience of using lightweight fills will be described in more detail. In each case, the lightweight material was chosen in order to ensure stability and reduce settlement.

a) Repair of a road across a bog (1975)

At Solbotmoan, road no 154 crosses a boggy area. Over the years there has been a significant settlement, and the road was flooded about twice each year. Each addition of new materials to compensate for settlement would cause a further settlement, untill finally the subgrade level had subsided 1,7 m. The rate of settlement has been large and increasing. The increasing occurence of cracks in the road surface could be interpreted as an imminent danger of structural collapse.

The subgrade conditions can be seen in Fig. 4. Below a road embankment of 1-2 m thickness, there is peat to a depth of 7 m. Below the peat, there is a rather soft silty clay extending down to bedrock which is at a depth of 20 m. The clay has a water content of 20-30% by weight, the undrained shear strength being 10-20 kN/m^2.

In repairing the road, the intention was to elevate it above the floodlevel. Using convential materials, however, would lead to accelerated settlement and cause collapse.

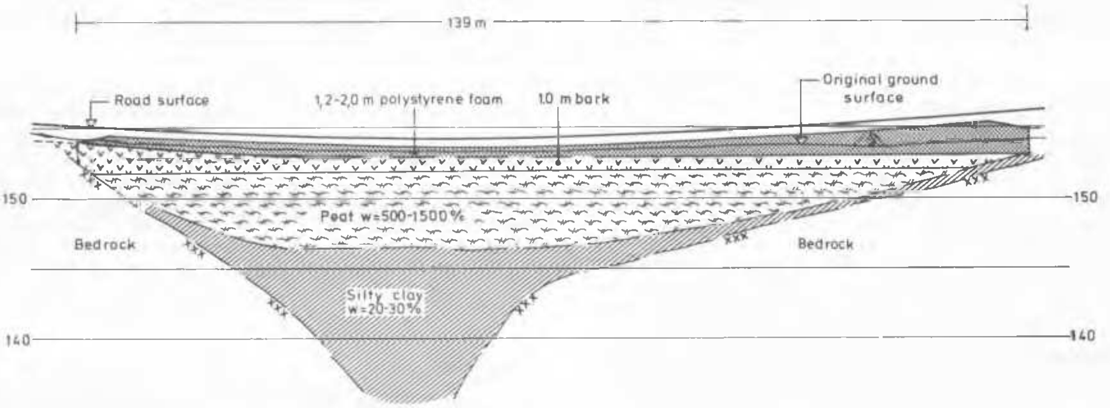

Fig. 4: Longitudinal road profile, Solbotmoan

The only practical solution would be to reduce the load from the road embankment and thus try to stop or reduce the existing settlement. To accomplish this, the road embankment was excavated and replaced by lightweight materials as shown in Fig. 5.

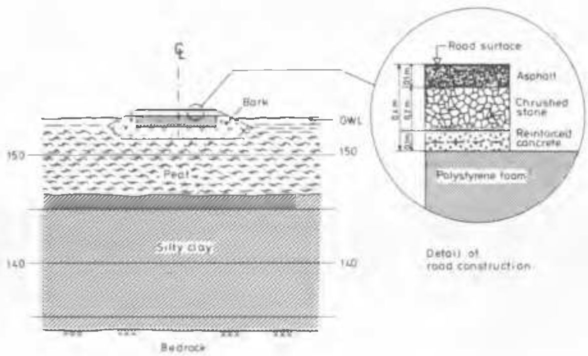

Fig. 5: Cross-section profile of road embankment, Solbotmoan

The road embankment was excavated to a depth of 1 m. Then bark was added up to the ground water level. After compacting and levelling the bark layer, a layer of expanded polystyrene was used (Figs. 4 & 5).

The road has been subjected to traffic for 5 years since the repair. The total settlement varies between 0 and 80 mm with a reduced rate of settlement.

b) Construction of a new road on bog/clay (1976)

When changing the alignment of the Sloraroad, it was required to put a new length of road across an easily compressed and exceptionally soft subgrade. To avoid flooding, the road surface was to be elevated 1-2 m above the bog surface.

The subgrade conditons are shown in Fig. 6. The whole area is boggy. There are peaty materials to a depth of 3-4 m, then a normally consolidated clay down to bedrock. The bed-rock level increases from both sides to a depth of 30 m.

The water content of the clay is 50-60% by dry weight, sensitivity varies from 8 to 60 and undrained shear strength 5-10 kN/m^2, though the latter may be slightly higher in places.

A road embankment comprising conventional materials would undoubtedly lead to unaccept-able and differential settlement. Furthermore the load caused by the embankment might cause collapse in the peat or a clay slide. To build a bridge or to support the road embankment on piles was regarded as too costly.

The road embankment comprises expanded clay and expanded polystyrene as shown in Figs. 6 & 7. Pellets of expanded clay were used up to a level of 1 m below the road surface. Then there is a 0,6 to 0,9 m thick layer of expanded polystyrene and finally 0,45 m of conventional pavement materials.

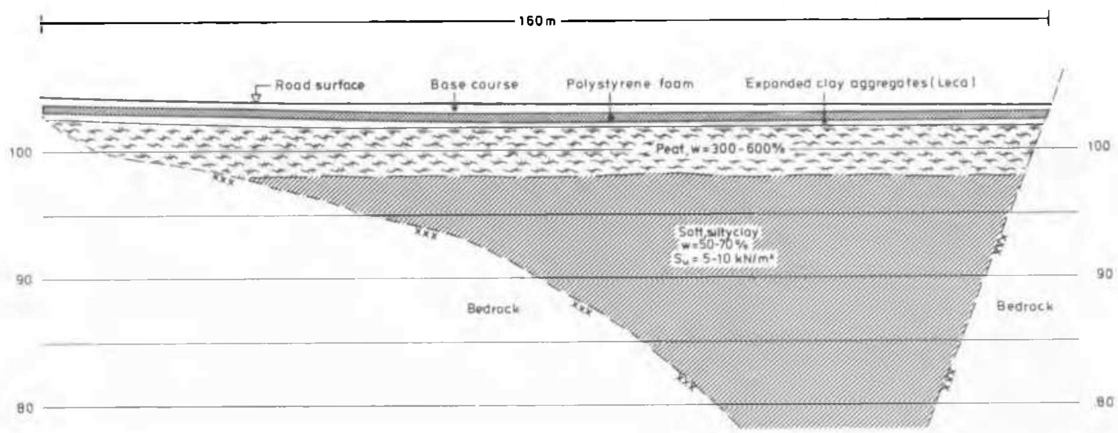

Fig. 6. Longitudinal profile, the Sloraroad

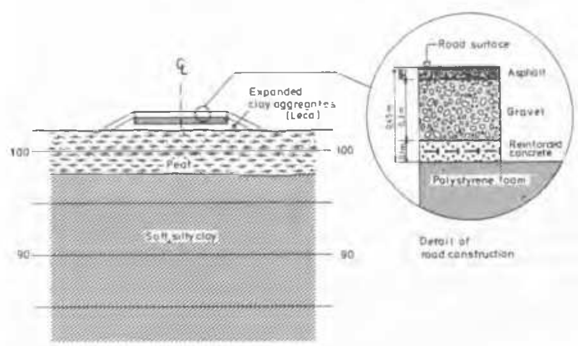

Fig. 7. Cross-sectional profile of the Sloraroad

The weight of the road embankment will cause a stress of 10-15 kN/m^2 on the subsoil ignoring traffic loads. Settlements of magnitude 300 mm were expected, primarily due to consolidation of the peat. The level of the road surface has been increased to allow for future settlement by increasing the thickness of the expanded polystyrene.

The road has been subjected to traffic for 4 years, and settlement has been less than calculated.

c) Road embankment adjoining bridge abutment (1978)

Road embankment on the western side of the Lenken bridge is constructed on subgrade giving large settlements when subjected to loading. Embankment height increases up to 3,5 m at the bridge abutment which is constructed on drilled piles down to bedrock.

The subgrade materials (Fig. 8) comprise topmost a 2 m thick layer of stones, and sand and clay which were dumped some decades ago. Then there is silt/sand with a large proportion of organic materials to a depth of 12 m. Water content is 60-80% by dry weight, and the degree of packing is relatively low. Below there is a layer of normally consolidated silty clay with a water content of 30-40%. The bedrock level falls off to 30 m at the abutment.

Calculations showed unacceptable settlements of the embankment adjoining the abutment if conventional embankment materials were used. From a technical and economical point of view, the best way of reducing settlement would be to use expanded polystyrene (Fig. 8). The thickness of the polystyrene increases from zero to 3 m over a length of 40 m. At the transition between embankment and abutment, a hinged concrete slab was used to even out settlement.

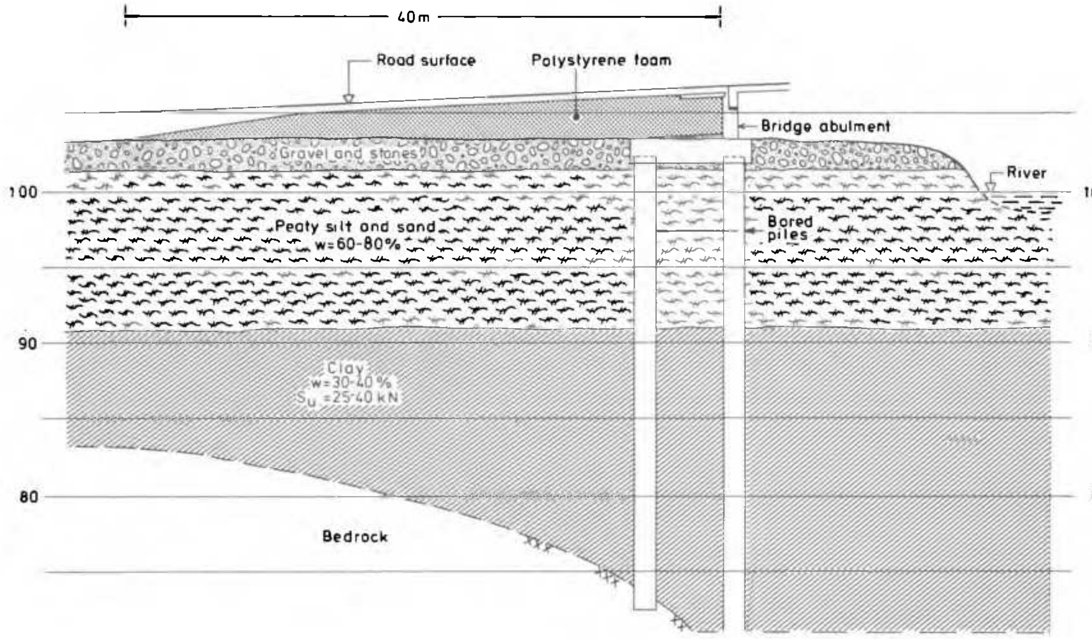

Fig. 8: Longitudinal profile, Lenken bridge

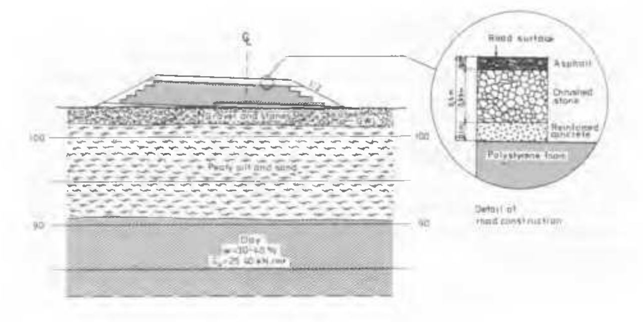

Fig. 9: Cross-sectional profile of road embankment at Lenken bridge

The embankment has experienced a settlement of 25-40 mm in one year, and ignoring traffic, the additional stress on the subgrade is approximately 10 kN/m^2.

CONCLUSIONS

Fills of expanded polystyrene have been used under extremely difficult subsoil conditions where other lightweight materials, which are relatively much heavier, could not do the job. However, the choice may also be for economical reasons. Expanded polystyrene is not a cheap material, but it is usually cheaper than employing alternative methods, like bridge construction, embankment on piles etc.

The practical experience is good so far Settlements have been brought under control, the moisture absorption is limites and there seems to be no aging or decay of the material. The polystyrene foam can stand up to the traffic loads, though a special care should be taken in the design of the road pavement.

REFERENCES

Dahlberg, R.G. and Refsdal, G. (1979). Polystyrene foam for lightweight road embankments PIARC, World Road Congress, Vienna.

Aabøe, R. (1979). The use of lightweight materials in road construction. Thesis, Norwegian University of Technology. Not published.