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Expanded polystyrene – A superlight fill material

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When road embankments are constructed across deposits of soft clay or peat, both bearing capacity and settlement problems may be solved using blocks of expanded polystyrene (EPS) as a fill material. Also when constructing roads on steep slopes, EPS may be used to solve stability problems. The unit density of polystyrene is about 100 times lighter than ordinary fill material, and the material properties match the load conditions in a road structure. In Norway more than 100 road projects involving the use of polystyrene blocks have been successfully completed with volumes varying from a few hundred to several thousand cubic metres of EPS.

1 SOFT GROUND PROBLEMS

In construction projects involving structures resting on soil, satisfying answers must be found to at least two main questions: is the soil strength sufficient to support design loads, and will deformations within the soil layers be of permissible magnitude? If the answer is no to either of these questions, special design solutions will have to be considered depending on the local site conditions and the availability and cost of suitable construction materials. The most obvious solution to load problems is, of course, to reduce the load if possible, but other methods like soil improvement, soil replacement, load transfer to firm ground etc. should also be considered technically and economically if applicable.

2 LIGHT FILL MATERIAL

Traditionally, wastes from the timber industry like sawdust and bark have been used as a light fill material in road construction in Norway. Wastes from the production of cellular concrete elements and building blocks with light expanded clay aggregate (Leca) as well as Leca-grains as such have also been employed.

The weight reduction obtained by using such materials is of the order of half the weight of ordinary fill material. When the idea of using blocks of EPS as a light fill material emerged, the incentive was to cut weights more dramatically.

Since 1965, various sorts of insulation material have been tested for road frost protection purposes in Norway. An extensive programme was carried out on polystyrene materials, both expanded and extruded to investigate compressive strength under repeated loads, and water absorbtion properties in particular. Frost protected pavements were constructed using 5-10 cm thick polystyrene boards mainly of the extruded type, but also boards of expanded polystyrene were tested. No strength problems were detected with pavement covers of 30-50 cm thickness above the boards. Based on this experience, it was

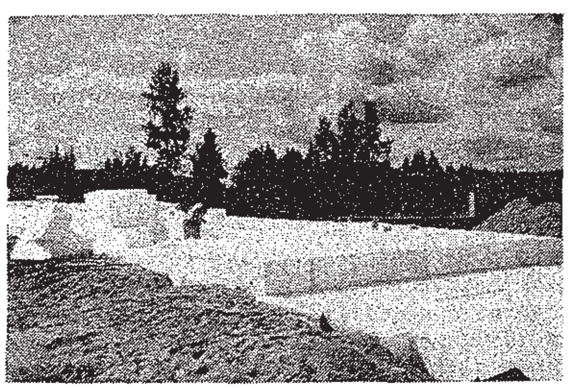

Fig 1. EPS blocks in roadfill.

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 500 cm.

In 1972, the use of polystyrene in greater thicknesses than the insulation boards was investigated at the Norwegian Road Research Laboratory for the first time. Excess settlements of road embankments adjoining a bridge were then successfully halted by replacing a one metre layer of ordinary fill material with EPS. Since then, the use of polystyrene blocks as a light fill material has become standard practice in road construction in Norway. Today more than 100 projects have so far been carried out with polystyrene fills totalling a volume in the range of 200.000 m^3.

3 ADVANTAGES

The major advantage of using EPS is, of course, the low unit density, 20 kg/m^3 when delivered from the producer. 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, EPS is by far much lighter than any other light fill material commonly used in road construction.

The low unit density also makes EPS easy to handle on site. One EPS block of normal size (.5x1x3 m) can easily be handled by one man, since it only requires a lifting force of 300 N. Furthermore, cranes on site can handle whole truckloads in one unit, placing the blocks on the required spot. The material is also easily formed and adjustments to block shapes can be made by hand- or chainsaw or even with a knife if necessary to shape details when EPS fills join on to other structures like bridge abutments, drainage systems and so on.

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

4 DURABILITY

To prevent the polystyrene from being dissolved by petrol or other chemicals in case of a spill from an overturned tanker on the road, a 100-150 mm reinforced concrete slab is cast on top of the EPS blocks. The concrete slab also contributes

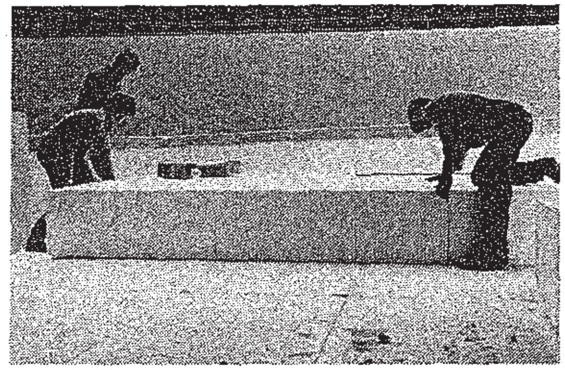

Fig. 2. EPS blocks are placed so that continuous joints are avoided.

to the strength of the pavement structure and reduces the total thickness of pavement material above the EPS blocks. The chances of a petrol tanker overturning just on an EPS fill are, of course, extremely small, and even if this should happen, only the outer part of the fill is likely to be affected. Necessary repair should also be easy to perform.

Otherwise, no decay of the EPS material is expected as polystyrene is a very stable compound chemically. Samples retrieved from existing fills show no sign of strength reduction. On the contrary, a slight increase in compressive strength is observed in some fills. From load cycling tests, it has been shown that the material will stand up to an unlimited number of load cycles as long as the repetitive loads are kept below 80 % of the compressive strength.

EPS is also resistant to biological destruction from bacteria and enzymes. Major attacks by animals are not likely as EPS does not represent a source of nourishment. The blocks could, however, easily be excavated to satisfy personal housing needs for smaller animals, but this is unlikely to affect the technical behaviour of the fill and has not been observed.

Ordinary EPS is not fire resistant and may be ignited by a fire when freely exposed to air. When covered by the concrete slab and soil on the embankment slopes, oxygen will not be available in sufficient quantities to allow a fire to develop. However, when EPS is placed in large quantities and/or will be exposed to open air for a long period during construction, and when nearby structures may be damaged by a fire, the selfextinguishing quality of EPS should be specified to a cost of 5-10 % above the standard quality.

5 MATERIAL REQUIREMENTS

For road construction purposes the following material requirements have been specified:

* The unconfined compressive strength measured on 5x5x5 cm cubes should have a mean value not less than 100 kN/m^2 and single measurements should not be below 80 kn/m^2.

These values are not selected to protect the EPS itself, but to limit pavement deflections.

* The EPS blocks should be cut with sides at right angles and with a thickness not less than 0.5 m unless otherwise specified. Deviations from specified dimensions should be within 1 %, and the evenness of the block surface measured with a 3 m straightedge should be within 5 mm.

As the material continues to expand for some time after production, these requirements will normally only be met if the producers cuts the blocks prior to delivery and not earlier than 24 hours after being taken out of the form. A new vacuum process is, however, now making it easier to meet dimension requirements.

6 PAVEMENT DESIGN

Normally, a 100-150 mm slab of lean reinforced concrete is cast on top of the EPS fill. The quality of the concrete should at least correspond to quality C 15 (15 N/mm^2 or 2100 psi, 28 days). The reinforcing net is placed in the middle of the slab.

For design purposes, EPS with a compressive strength of 100 kN/m^2 is considered as equivalent to a subgrade soil within bearing capacity class VI (similar to clay or silt). According to Norwegian specifications, the required pavement thicknesses are as listed in table 1.

Table 1. Minimum pavement thicknesses for 10-ton axle loads in Norway.

Annual average daily traffic	Pavement thickness, including concrete slab
0 to 1000	40 cm
1000 to 10.000	50 cm
over 10.000	60 cm

In some cases, at least in a country with a climate similar to that of Norway, the EPS may create unfavourable icing conditions. The pavement thickness is therefore sometimes increased depending on conditions at the adjacent road section. In general, road icing is reduced by using pavement materials with a high heat storage capacity. A gravel subbase will normally provide satisfactory conditions.

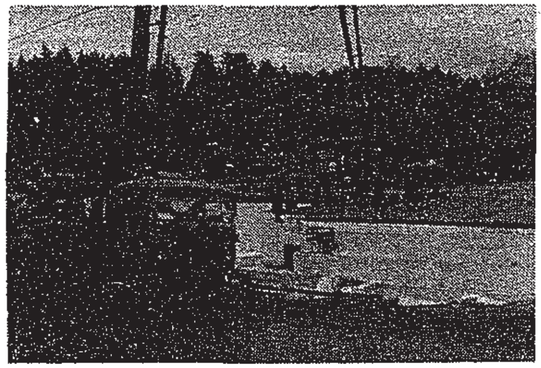

Fig 3. A layer of lean concrete is cast on top of the EPS fill.

7 ECONOMY

When considering the cost of EPS blocks, the present rates quoted in Norway are of the order of 30-35 US $\$/m^3$ from the producer. This is only half the price paid in 1972 when related to the present price level. With low transportation costs, even a long haul will not affect project cost too much.

When comparing the cost of different light fill materials, however, one should bear in mind that it is the cost per unit load reduction related to ordinary fill material that should be considered, since weight reduction is the aim. Assuming an average unit density of 2000 kg/m^3 for ordinary road fill materials, a cost comparison as shown is achieved for light fill materials in Norway with varying transport distances. Apart from material costs, volume reduction and cost of placing and compaction 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 represents the only choice if a certain weight reduction is to be achieved. In Norway, EPS will also compete favourably with soil improvement methods like salt wells and lime columns as well as vertical drains and piling. Depending on local conditions, soil replacement and counter weights will often provide a cheaper solution if applicable, but EPS may still be preferred for technical reasons.

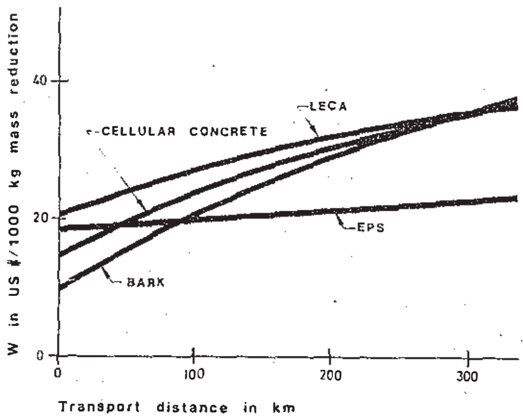

Fig 4. Cost comparison of various light fill materials.

8 PRESENT USE OF EPS FILLS

Typical projects where EPS is used today are in road embankments crossing clay deposits and peat bogs and for reconstructing slide areas. Special applications of EPS have been to reduce the horizontal pressure against bridge abutments. At the same time, the problem of differential settlements between the bridge and adjacent fills is reduced. Solutions involving the termination of the EPS fill in a vertical wall, covered with some protective material like steel sheets have also been adopted. Furthermore, designs utilizing the buoyancy effect of EPS when submerged have been successfully completed. In this case it is essential to control or predict the highest ground water level likely to occur in order to balance the buoyancy forces. Some examples from the present use of EPS are given below.

8.1 Road on very soft, sensitive clay

Most ramps in a major road intersection at Lysaker near the City of Oslo airport rest on bedrock or on foundations to firm ground. Two ramps 1 and 2 are founded on a very soft, sensitive normally consolidated clay layer of 15-25 m thickness. The ramps have an elevation of 1-1.5 m above the ground level and a marked cross slope since both are lying in a sharp curve.

To satisfy both bearing capacity and settlement conditions, it was decided to apply a design with EPS blocks and Leca grains in order to prevent stress increases in the ground. The design adopted is shown on the cross section in fig 5. The weight balance obtained from excavating

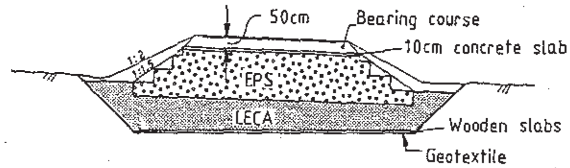

Fig 5. Typical cross section at Lysaker.

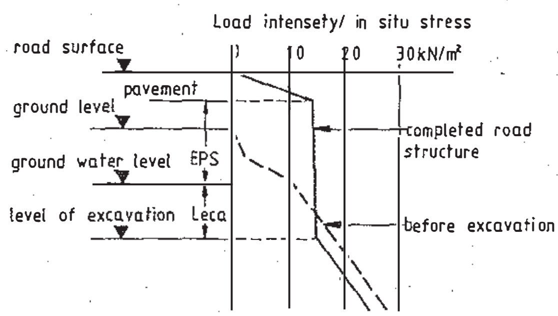

Fig 6. Load conditions at Lysaker.

1,5-2 m of the top soil and replacing it with light fill material is shown in fig. 6. The total volume of EPS used is somewhat above 8000 m^3.

The ramps were completed during the first half of 1986. Observations show settlements of the order of 4-5 cm during the first year and decreasing with time. No adverse effects have been observed since the ramps were opened for traffic towards the end of 1987.

8.2 Bridge abutment

EPS was used as backfill material for a bridge abutment on road E 18 in the county of Vestfold, Norway. The bridge was completed in spring 1987. The EPS fill was placed in contact with the abutment wall. To monitor possible stress transfer from the EPS fill to the vertical concrete wall, 6 Gløtzl cells were installed at three different levels on the wall. Load tests were carried out during autumn 1987 using a lorry weighing 31 tons and containers applying a total force of 30 kN/m^2 over an area of 25 m^2. The resulting horisontal stress increase was of the order of 0.1-0.2 times the applied load intensity by the containers on the road surface.

On another bridge built in 1977, EPS blocks were used behind one of the abutments, but a small gap was left between the EPS and the concrete wall. Measurements performed in 1984 and 1987 show that the gap is maintained unaltered indicating

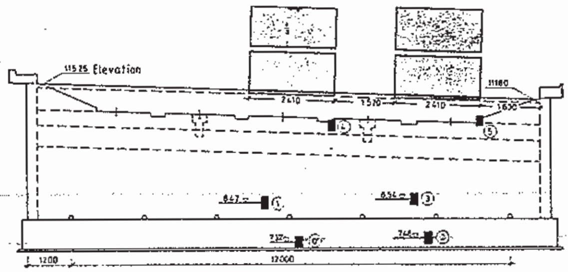

Fig 7. Location of load cells.

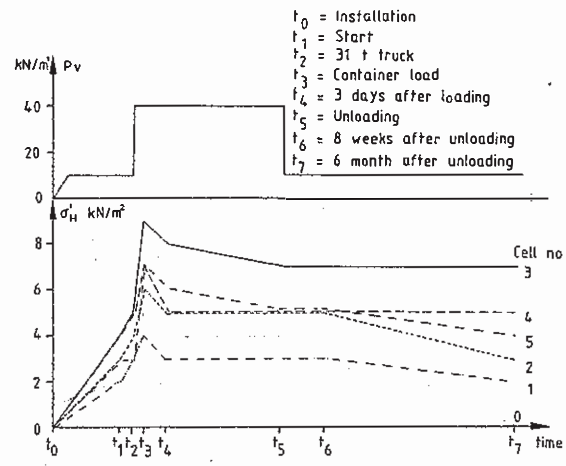

Fig 8. Results from loading test.

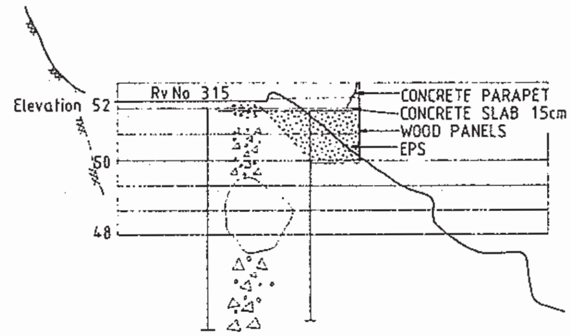

Fig 9. Vertical EPS wall on steep slope.

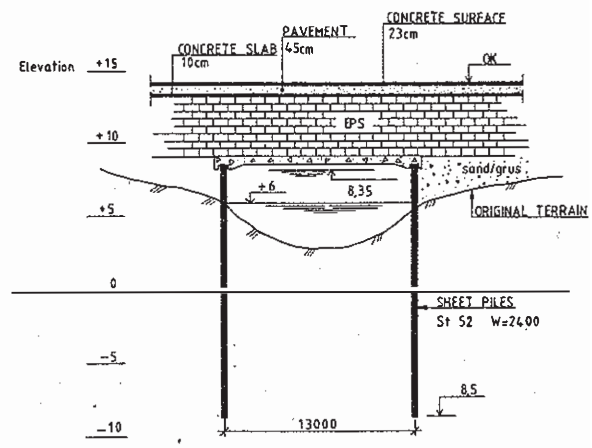

Fig 10. Reduced load on culvert.

that the EPS fill is stablle, and that there is no force transfer between the blocks and the concrete wall.

8.3 Vertical EPS wall

In the county of Vestfold close to the City of Holmestrand, a widening of road no. 315 was planned to allow for the construction of a separate pedestrian/cycle path. The road passes through a rock scree with a steep slope (~1:1). A conventional retaining wall founded in the rock scree could not be accomodated due to bearing capacity problems. Two alternative solutions were considered, one involving a huge retaining wall at the bottom of the scree, the other consisting of an EPS fill terminated in a vertical wall.

The latter solution was adopted both for technical and economic reasons. Approximately 800 m³ of EPS was used with a vertical wall height up to 2.5 m. A 15 cm reinforced concrete slab was cast on top of the EPS blocks and continued 3 m horizontally into the existing road for anchorage. A concrete parapet was erected as an outside barrier and connected to the concrete slab. To protect the EPS blocks the verical wall was covered with wood panels. The wall as shown in fig 9 was completed in 1985. Prior to this case EPS fills with vertical walls up to 5.5 m have been constructed.

8.4 Simplified bridge design

Road E 18 trough the county of Vestfold is presently being realigned to bypass urban areas. At Sem the new road is passing over a small erosion valley with a river at the bottom. Site investigations indicate more than 30 m of medium stiff clay of shear strength 25-30 kN/m². Alternative designs considered were a conventional bridge, a concrete culvert and a steel sheet pile culvert with a concrete deck and EPS blocks on top. The steel sheet pile solution was selected and will be completed during spring 1988. The EPS layer will be 4 m high with a pavement of 78 cm on top. This will reduce the weight to be carried by the sheet piles dramatically and also reduce the length of the

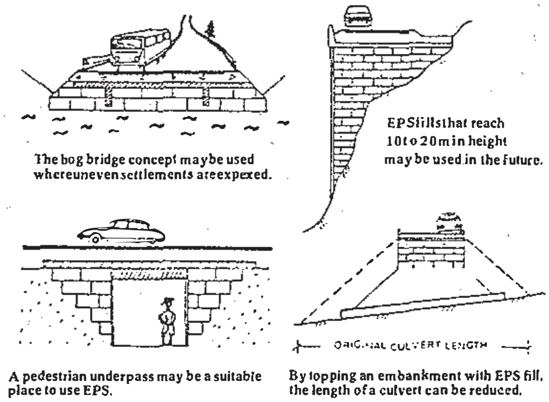

Fig 11. Possible applications of EPS.

culvert since the EPS will be terminated in vertical walls along the road edges.

9 FUTURE POSSIBILITIES

The superlight fill material with the highest potentials seems still to be EPS both based on material quality and cost. A new superlight material with a honeycomb structure has recently been developed making it possible to accommodate changes in water level without introducing buoyancy forces. For certain uses this material may be superior, but future use will in the end depend on technical properties and price in relation to other materials available.

Superlight materials have mainly been used to reduce loads and settlements on soft ground. This approach allows fairly high fills to be constructed with an adequate factor of safety and tolerable settlements. The many uses for this purpose will probably develop further as more ingenious details are worked out.

It has been established that it is possible to reduce or prevent transfer of pressure on a retaining wall or bridge abutment by using EPS as a backfill. This fact must be taken advantage of when designing such wall in the future. The same approach may probably be persued for the design of sheet pile walls.

The application of EPS blocks as a structural element will certainly increase and probably lead to the use of higher vertical walls. Combined with the reinforced earth concept, new solutions based on the merits of both are likely to emerge. This will permit various types of structures on hillsides without creating stability problems.

A highway crossing deep ravines with normal soil embankments will result in long and expensive culverts. The use of an EPS fill with vertical walls or combined with a conventional fill in the lower part, may considerably reduce the culvert length and fill volume.

EPS used as building blocks could be applied for rapid construction of pedestrian underpasses and have certain advantages on soft ground. The future may also bring increased use of EPS for floating structures, whether it is on extremely soft ground or in water. Prefabrication of certain elements can insure quality and reduce construction time.

There are still room for more ideas when it comes to the use of superlight fill materials in road building and other construction activities. Many of the old soil mechanics problems may have new and surprising solutions. A satisfactory solution and cost advantage will depend on the solution of many small details of which we have only seen the beginning. The new materials required are available.

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