New Dutch Design Manual for Light-Weight Road Structures with EPS Geofoam

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Keywords: Geofoam, Lightweight products, Design method, Pavement systems, Embankments

ABSTRACT: The use of Expanded PolyStyrene (EPS) Geofoam instead of traditional "heavy" sand for pavement sub-base can reduce or even eliminate the additional load on the subsoil, thus decrease or eliminate the settlement of pavement structures on a compressible subsoil. The experiences with EPS Geofoam are very positive but a uniform design procedure does not yet exist for this type of structure. Optimisation of the existing EPS pavement design guidelines and their improvement has demanded materials research on EPS, the use of three dimensional finite element pavement models and measurement on test pavements and in-service roads. Extensive materials research provided data for the stress-strain response of EPS under representative loading and environmental conditions. 3-D modelling (verified by in-situ measurements) enabled critical evaluation of existing design methodologies. Furthermore, evaluation and monitoring of Dutch projects with EPS Geofoam has been carried out to define problematic aspects from a practical point of view. Based on the research findings the current Dutch design guidelines have been revised and optimised. In order to make this knowledge easily accessible an official Dutch Design Manual for Light-weight Pavements with EPS Geofoam has been composed. The outlines of the manual are presented.

1 INTRODUCTION

Through a substantial reduction of the total road structure weight, EPS as a sub-base material offers a major new solution for reduction of the settlements of new road structures and roads to be widened in areas with soils of poor load-bearing capacity. Such areas are present in the western and northern parts of the Netherlands. The application of EPS however affects the performance of the overlaying structure. To investigate, on one hand, to which extent the EPS characteristics influence the overall pavement behaviour and, on the other hand, the long term durability of EPS in relation to varying environmental conditions, materials research on EPS, in- situ measurements and numerical analyses of the structural behaviour of pavements with an EPS sub-base have been carried out. Based on the research findings the current Dutch design guidelines have been revised and optimised. This paper deals with the functions of EPS in road structures, the technical and economic feasibility, pavement design guidelines and evaluation of Dutch projects in the view of the application of EPS.

2 FUNCTIONS OF EPS IN ROAD STRUCTURES

In road structures EPS may have the following function(s):
a) reduce or nearly eliminate settlement
b) increase the stability c.q. limit the space required by slopes

c) reduce the construction time
d) reduce the horizontal pressure on adjacent structures
e) reduce the influence on the existing road parts in case of widening of the road

Re a) *Settlement* – A road structure on a weak and compressible subsoil (peat, clay) leads to settlement of the subsoil. As a result of varying soil profiles longitudinal unevenness of the road will occur because of residual settlements. In addition, differences in level will occur between the road structure and 'rigid' objects included in the road (bridges founded on piles, fly-overs, underpasses, culverts, etc.) or situated near the road (buildings). Therefore, residual settlements will require maintenance to preserve the longitudinal profile and/or level of the road.

Application of EPS is primarily meant to limit the weight of the road structure and consequently to reduce or even eliminate settlements. When (practically) no settlements occur there is the question of a balanced structure. By definition a balanced structure leads to the excavation of a trench followed by the application of a relatively thick layer of EPS.

When this is not feasible for technical reasons (for instance instability of the existing road in case of widening of the road) or economical reasons, a structure with EPS can be installed after temporary preloading, which will settle very little after the road is in service. However, principally it remains a heavy-weight structure, although the settlement entirely occurs during the construction phase.

Re b) *Stability* – A road structure on a weak and compressible subsoil may cause instability of the slopes. By reducing the weight of the road structure, the danger of instability can be reduced. The same slope will be safer with regard to sliding and the construction time will be shorter. On the other hand it will also be possible, while maintaining the safety against instability, to make the slope steeper so that less space will be required.

Re c) *Reduction of construction time* - When taking into consideration the technical preconditions as described under b) and c) it will take less time to construct roads on compressible subsoils with light-weight materials compared to roads constructed with traditional embankment materials. As a result the additional road capacity will become available within a shorter period of time.

Re d) *Horizontal pressure* - The Poisson's ratio of EPS is rather small, namely about 0.1. This means that in case of a vertical load on EPS only a slight horizontal displacement will take place or only a slight horizontal pressure when the displacement is hindered. Therefore, EPS can be used to reduce the horizontal pressure on earth-retaining constructions, foundation piles, sheet pilings, etc.

Re e) *Widening of roads* - In case of widening of roads the subsoil will not only be loaded just below the widened construction but also below the adjacent part of the existing road construction. In case of a weak, compressible subsoil this will not only lead to settlements below the widened construction but also to additional settlements below the adjacent part of the existing construction, which is in fact pulled down by the widened construction. As a result the transverse slope (crossfall) of the existing road will change and longitudinal cracks may occur. By limiting the weight of the widened construction these effects will be reduced and less damage to the existing road structure will take place.

3 TECHNICAL AND ECONOMIC FEASIBILITY

A design of a light-weight road structure is technically feasible when requirements with regard to safety, stability and durability are met. The most important safety requirement is the protection against buoyancy of the light-weight structure. As far as stability and structural durability is concerned, a light-weight structure will be feasible from a technical point of view provided that the road structure has been correctly designed. Generally speaking the design process for a road structure with an EPS-layer consists of a soil mechanical and a pavement structure design which of course are inter-related.

From a soil mechanical point of view a structure with EPS minimally affects the stability of the soil, because such a structure hardly causes any increased pressure on the subsoil, especially when part of the subsoil is excavated. Of course the stability of the slope is guaranteed on the basis of a slope stability analysis. Stability of the entire structure and the slopes should not only be guaranteed during the post-construction period, but during the construction phase as well, if necessary by means of an adjusted rate of loading.

Assuming that the stability design is correct, the risks with regard to a pavement structure containing EPS are mainly found in the raising of the structure and possibly the slipping of (high) slopes in case of extremely high water levels. Therefore, testing of the vertical stability of light-weight road structures with EPS consists of checks with regard to buoyancy. In practice, a partial safety factor of ≥ 1.1 for all materials is applied to check the maximum boundary conditions. At the request of the client, a higher value can be chosen. Furthermore, a phased construction and a minimum (dry) density of EPS are taken into account.

A pavement structure with an EPS-layer is mainly applied when this light-weight structure is feasible from an economical point of view, taking into account the settlement and/or construction time to be expected. In other words, the design of the structure must meet the program requirements from not only a technical point of view but from an economical point of view as well. In most cases the least expensive pavement structure is chosen. In this context the costs of the road structure include the following items:

a) initial construction or reconstruction/widening costs
b) maintenance costs during the design life of the pavement (usually 20 years)

Re a) Initial costs are the construction or reconstruction/widening costs including the costs related to the construction time. The costs of a road structure with an EPS-layer depend on the materials chosen and the thickness of the layers. The costs of EPS-blocks are substantial since per volume-unit the price of EPS is considerably higher than the price of traditional filling material (sand).

Re b) The reduction of the settlements is a decisive advantage compared to road construction with traditional heavy filling material; for the latter, the residual settlement and maintenance costs are relatively high unless a long construction period is accepted and/or special measures (such as vertical drainage) are taken to speed up the settlement process. Based on this the costs involved have to be considered integrally to allow for an objective assessment of the economic feasibility of an EPS-solution. When the initial costs and the maintenance costs are capitalised over a lifetime of say 20 years, calculations may be in favour of a light-weight pavement structure with EPS, despite the higher initial costs, as illustrated in Figure 1.

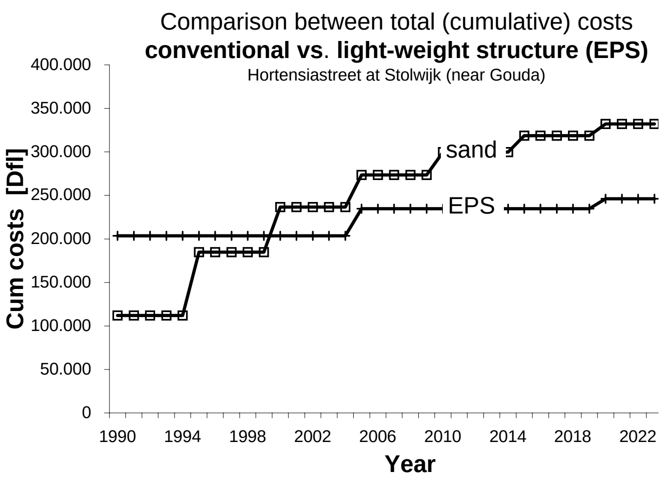

Figure 1. An example of a comparison between the total costs (incl. maintenance) of conventional and light-weight alternatives of a block pavement structure; 1 Dfl (Dutch guilder) ≈ 0.42 US$

4 PAVEMENT DESIGN

The design of the road structures with an EPS sub-base (materials and thickness of layers) is based on a technical program of requirements.

4.1 *Technical program of requirements*

The following aspects are of importance for the preparation of the technical program of requirements:
- available construction time and available budget
- traffic load (intensity and composition of the traffic)
- design life of the pavement structure
- dimensions of the cross section, like paving width and width of the road embankment
- road furnishings (lighting masts, beam barriers, acoustic baffles, columns, etc.)
- fluctuations of the groundwater table
- necessity to avoid cracking of the trench floor as a result of a high groundwater pressure in the deeper soil layers
- acceptable settlement and differences in settlement at connections with engineering structures
- acceptable settlements and differences in settlement at the location of underground infrastructure (cables and pipelines) and at the location of former ditches (both in longitudinal and transverse direction)
- specific requirements with regard to the position of underground infrastructure (cables and pipelines) in the transverse section and with regard to the position of pipe sleeves
- connection of the road section to existing pavement structures (both in longitudinal and transverse direction)
- construction of the existing road structure (in case of widening)
- presence of a pre-load and period of time required for this

The design parameters for each specific situation are determined based on these aspects.

4.2 *Relevant material properties of EPS*

The material parameters to be used as input data for the design of the pavement structure have to be representative for the material behaviour under representative stress conditions inside a road structure. EPS, in a sub-base, is exposed to static loads (dead weight of the overlaying layers) and to dynamic loads (traffic loads). All this takes place in surroundings where the moisture content and the temperature vary daily and seasonally. The following material properties of EPS are of importance for the use of EPS as a light-weight filling material in road structures:

a) immediate deformation and creep of EPS due to the dead weight of the upper pavement layers
b) (dynamic) modulus of elasticity
c) maximum stress and strain values within the linear elastic region
d) Poisson’s ratio
e) fatigue behaviour

Re a) The additional settlement of the road structure due to creep in the EPS sub-base is rather limited, only a few tenth of a percent. About half of the expected maximum creep occurs already within the first day (thus during the construction phase). Therefore this deformation increase is of no practical importance for pavement design.

Re b) A clear relationship appears between the elasticity modulus and the density of EPS.

Re c) Cyclic loading test results (see Figure 2. - Duškov 1997) point out that EPS20 does not accumulate permanent deformations under combined static and cyclic stress of 15 kPa and 20 kPa respectively. It may be stated that as long as the elastic deformation in the EPS sub-base due to cyclic (traffic) loading is limited to 0.4%, then permanent deformation of the EPS blocks is negligible and will have no influence on the pavement behaviour. Therefore, the design criterion for the EPS layer should be a maximum cyclic strain value of 0.4%.

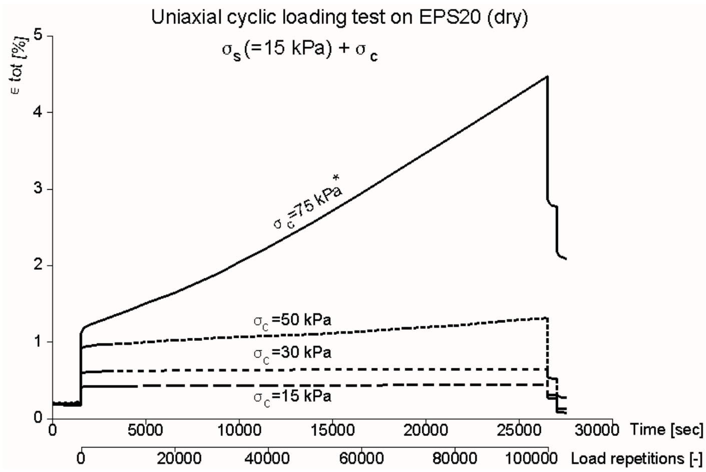

Figure 2. Evolution of strains in dry EPS20 samples under combined static and cyclic stresses

Re d) EPS has a low value of the Poisson's ratio with respect to traditional pavement materials. The Poisson's ratio value of EPS of 0.1 seems to be appropriate for design purposes.

Re e) Extensive testing of EPS15 and EPS20 (Duškov 1997) has shown that low temperatures, water absorption level and exposure to freeze-thaw cycles, separately or combined, have no negative influence on the mechanical behaviour of EPS. The modulus of elasticity for the EPS Geofoam will not be lower than in dry state at normal temperature.

4.3 *Design guidelines*

The design procedure for pavement structures with EPS differs to a certain extent from the Dutch design procedure that is followed in the case of application of a traditional sand sub-base. The differences concern the weight-balance and the buoyancy calculations. Both calculations serve the purpose of determining the proper thickness of the EPS sub-base. "Proper EPS sub-base thickness" refers to such a pre-determined thickness that subsoil settlements are eliminated, or reduced to an acceptable amount. Considering the buoyancy forces, the highest possible groundwater level may restrict the excavation depth for the EPS material.

Once the proper EPS layer thickness has been determined the design procedure continues with calculation of the pavement design life based on the Shell Pavement Design Manual (1983). This mechanistic procedure is the main pavement design method used in the Netherlands. The Shell Pavement Design Manual considers the maximum horizontal tensile strain at the bottom of the asphalt layer and the maximum vertical compressive strain at the top of the subgrade to be of critical importance for the design. The asphalt strain value has to be limited to prevent asphalt fatigue cracking; while the limitation of the vertical strain serves to prevent excessive permanent deformation in the subgrade. In the Manual, strain values are given as a function of the allowable number of load applications. So, by knowing the strain values, one is able to determine the pavement design life expressed as 'allowable number of equivalent 100 kN axle load repetitions'.

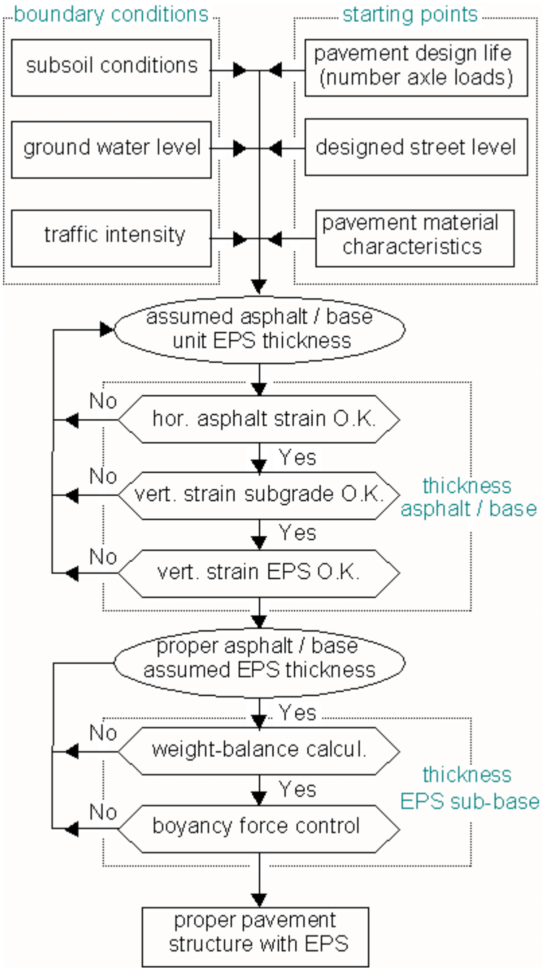

Figure 3. Flowchart of the revised Dutch design procedure (incl. EPS strain criterion) for flexible pavement structures with an EPS sub-base

The missing part in the above design procedure for pavement structures with an EPS sub-base is a design criterion regarding the EPS material. As mentioned before, based on the results of the uni-axial cyclic loading tests it may be stated that the design criterion for the EPS layer should be a maximum strain value of 0.4%.

Pavement analyses by means of both multi-layer (Duškov 1996) and finite element models (Duškov 1997) pointed out a negligible influence of the EPS thickness on the structural pavement behaviour. Because of the low elasticity modulus the EPS block layer, it simply does not contribute to the load distribution and functions only as a fill material. Since the stress and strain values in the pavement layers are independent of the thickness of the EPS sub-base it is possible to determine the pavement design life before carrying out settlement and buoyancy calculations. As an input value a unit EPS thickness, e.g. 0.5 m, could be applied. The advantage of such an approach is that the upper pavement layers can be designed first and their total weight thus is known before carrying out the weight-balance calculation and determining the thickness of the EPS layer. The revised design procedure, including the ε_{EPS} criterion, is shown in Figure 3.

During the construction phase, which is the most critical phase, special measures (such as steel planking) should or could be taken to ensure that the maximum allowable EPS strain value of 0.4% is not exceeded. Overloading EPS results in a lower modulus of elasticity, a higher water absorption and permanent deformations.

The presence of an EPS sub-base in a pavement structure has a significant influence on the stress and strain development in the pavement. *If granular materials are placed immediately on top of the EPS layer* then the stiffness of such a layer is low and in fact much lower than is normally expected. Consequently, unbound material modulus values reduced up to 50% should be used as input data for design purposes.

Application of a cement treated capping layer on top of the EPS sub-base has a tremendously beneficial effect on the performance of the pavement. Such a capping layer neutralizes the effects of open joints between the EPS blocks, guarantees sufficient support to overlaying unbound base material even under high traffic intensity and eliminates any restriction for use of less-expensive, low-density EPS types. A cement treated capping layer is therefore strongly recommended for heavy-duty roads.

4.4 *Working details*

1) Gradient and construction of slope with blocks

Where normally the gradient of the slopes varies between 1:1.5 and 1:3 it will be possible to achieve a block slope of 1.5:1 or more with a fill of EPS-blocks. This increased stability is the result of the weight reduction of the road structure and sliding can be prevented more easily. In Japan and Norway vertical light-weight fillings have been regularly applied in situations with a lack of space. As illustrated in figure 4., from a constructional point of view vertically stacked EPS-blocks do not need to be supported, though they have to be covered for the purpose of mechanical and (if necessary) chemical protection.

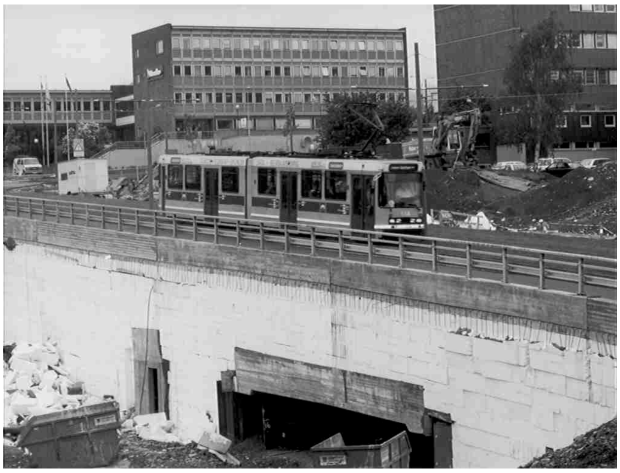

Figure 4. Tramway track in Oslo on a vertical filling of EPS-blocks with a height of about 5 m, still to be covered at the sides

2) Plastic sheet

EPS is not chemically resistant to oil derivatives. However, since the introduction of EPS some 30 years ago no cases have been reported in which the protective cover actually had an inhibiting function. The conclusion is clear when weighing the risk against possible savings: the protection of EPS-blocks with an oil-resistant plastic sheet or another protective layer will only be necessary in specific situations. In principle an EPS-layer in a road structure does not need to be protected against chemical influences. In general the actual chance of damage is nil.

3) Transitional construction

In the longitudinal profile between the road sections with a light-weight and a conventional road structure the thickness of the EPS-layer has to be reduced gradually to avoid differences in settlement. It is typical that the lengths of the longitudinal transitional structures at both ends of the light-weight road part can be different, The required lengths depend on the local variations in settlement sensitivity of the subsoil. The designers need to pay due attention to this aspect. Only a design based on the balance calculations tailored to the specific subsoil conditions may prevent the creation of ‘bumps’ between the light-weight and conventional road sections.

5 EVALUATION OF DUTCH PROJECTS

Evaluation and monitoring of four projects carried out in the Netherlands has revealed a number of problematic and even conceptually incorrect aspects. Such findings are actually a matter of course in view of the large-scale application of EPS as a light-weight filling material. Moreover, an extensive research programme has been carried out during the last few years.

Summarising, the following aspects are problematis or not optimal and can be improved:

- The application of a cement-stabilised sand layer directly above the EPS-layer entails a high risk of (local) overload during the construction phase. The spreading of the cement, the spraying of water and the mixing is carried out with heavy trucks and machinery; besides, it will take some time before the stabilised layer will be sufficiently stiff to carry building traffic. Therefore it is essential that building traffic makes use of the boards during the stiffening period.
- Regularly, the available financial means influence the final choice of the pavement structure in an advanced stage and the thickness of the (relatively expensive) layer of light-weight material in particular. Often the timing is critical to outline all consequences for maintenance and integral costs of the selected (heavier) alternative. As a result unforeseen, additional maintenance costs (and thus integral costs) may be higher than the savings on the initial costs.
- It is incorrect from a conceptual point of view to fill up road structures in residential areas with light-weight material and the adjacent sidewalks and front yards with conventional material. In this case differences in settlement occur which often are disastrous for sewer systems including the house service connections (although the consequences are less than in case of purely conventional pavements). The application of relatively light-weight expanded clay grains below the sidewalks along the houses and on top of cables and pipelines may be a solution for problems related to excavation works in an EPS layer in case of maintenance of the pipelines and growth of plants in the filled up front yards.
- A discontinuity in the EPS-layer, for instance around cesspits will locally lead to additional settlement caused by a locally higher weight. EPS needs to be installed below the gully holes as well.
- Installation of a sand layer on top of a (cement)bound layer that is on top of the EPS-blocks (see Figure 5) is incorrect from a conceptual point of view. Such a sand layer does not contribute to a higher bearing capacity and a longer lifetime of the pavement structure, but does considerably increase its dead weight.

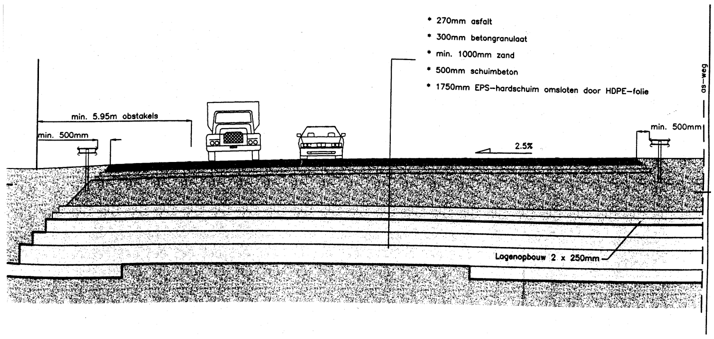

Figure 5. Cross-section of the light-weight road structure of the A4 motorway near Leiden with the pavement structure consisting of 0.27 m asphalt, 0.3 m thick unbound roadbase and a 1.0 m thick sand layer on top of a foamed concrete layer (0.5 m) and an EPS layer (1.75 m)

- A foil for the protection of EPS against chemical damage will not be necessary on the upper side when a cement bound layer (concrete or foamed concrete) is poured on top of the EPS-layer. Both concrete and foamed concrete will be sufficiently impermeable.

ACKNOWLEDGEMENTS

Stybenex BV, the Road and Hydraulic Engineering Division of the Ministry of Traffic, Public Works and Water Management (DWW-RWS), and the Center for Research and Contract Standardization in Civil and Traffic Engineering (C.R.O.W) are gratefully acknowledged for sponsoring the research into EPS Geofoam.

REFERENCES

1983. *Shell Pavement Design Manual*, Shell International Petroleum Company Limited, London

Duškov, M. 1996. 3-D Finite Element Analyses of Pavement Structures with an EPS Geofoam Sub-base, *Proc. Int. Symp. on EPS Construction Method*, EPS Tokyo '96, Tokyo, pp. 48-57.

Duškov, M. 1997. *EPS as a Light-Weight Sub-base Material in Pavement Structures*, Ph.D. Thesis, Delft University of Technology, Delft, p. 251.