CURRENT DUTCH DEVELOPMENTS REGARDING EPS GEOFOAM CONSTRUCTION METHOD

M. Duškov[1], A.A.A. Molenaar[2],

and

L.J.M. Houben[3]

ABSTRACT

Considerable large areas of the western and northern parts of the Netherlands consist of subsoil with poor to very poor civil engineering characteristics. The building of embankments for roads on such soft saturated subsoils in the traditional way is time consuming. Therefore EPS geofoam has been applied to a still increasing extent in the last two decades for light-weight building purposes. Since a few years the EPS geofoam method has been even used for reconstruction and widening of major Dutch motorways. Such developments would not be possible without fundamental knowledge about relevant EPS material characteristics and the extent to which the low stiffness of EPS affects the performance of the overlaying structure under representative Dutch conditions. Such a research program has been carried out at the Road and Railroad Research Laboratory of the Delft University of Technology. The paper gives an overview of current developments regarding the EPS geofoam construction method in the Netherlands. The recently revised Dutch design guidelines and related issues from Dutch road engineering practice will be discussed. In the second part two significant Dutch projects are described which are currently under construction. The accent in the case study lies on specific characteristics of the Dutch design approach.

KEY WORDS: light-weight road structures, design guidelines, case study

[1] Infrastructural Engineering Delft BV, Delft, The Netherlands
[2] Faculty of Civil Engineering and GeoSciences, Laboratory for Road and Railroad Research, Delft University of Technology, Delft, The Netherlands
[3] Faculty of Civil Engineering and GeoSciences, Laboratory for Road and Railroad Research, Delft University of Technology, Delft, The Netherlands

1 INTRODUCTION

Since 1980's EPS geofam has been increasingly applied in Dutch road engineering practice. Difficult soil conditions in the western part of the country, characterised by extremely poor load bearing capacity and high groundwater level, force Dutch civil engineers to look for modern solutions. Ever growing traffic intensity and loading in combination with lack of time for proper treatment of the soil to improve its stability and limit the settlements stimulate the use of light-weight materials. Being able not only to minimise the structure total deadweight and thus resulting settlements but also the required construction time, the EPS geofoam approach keeps winning more popularity. Up to 1996 in the Netherlands 400,000 m^3 of EPS-blocks [Van Dorp, 1996] was built-in in approach roads and bridge abutments or used in the scope of road widening/reconstructions, site preparations, load reduction of utility pipes and drainage of sportfields. The growth in the use of EPS is still increasing, supported by positive experiences and practical and fundamental studies resulting in the new Dutch design manual for this type of structures [Duškov and Houben, 2000]. Over the last five years the average annual amount extends 100,000 m^3. Anno 2001 more than 1.1 million m^3 of EPS-blocks lie below the surface in the western part of the country.

Increased confidence and improved design procedure have enabled applications of EPS in Dutch motorways during the last years. The very heavily trafficked motorway, A4, between Amsterdam and The Hague was the first such project. Realisation of motorway A15, an important connection between Rotterdam's harbour and Germany, is going on and new projects, such as a new part of motorway A11 are in preparation. This new trend means except dealing with heavier traffic loading also implementation of much bigger quantities of EPS, for instance in the A15 reconstruction an amount of 105,000 m^3 is planned. Obviously, not only the total quantity but also the applied quantities per project increase rapidly.

2 DEVELOPMENT IN DESIGN METHOD

The structural design of road pavements with EPS essentially is the same as that for more standard pavement structures. There are however some special aspects related to the application of EPS in the pavement structure that require special consideration. These aspects are the thickness of the EPS-package, the material properties of the EPS and the interaction between the EPS and the other pavement layers, and the buoyancy force control for the total pavement structure with EPS. These issues are addressed in the next paragraphs.

2.1 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.

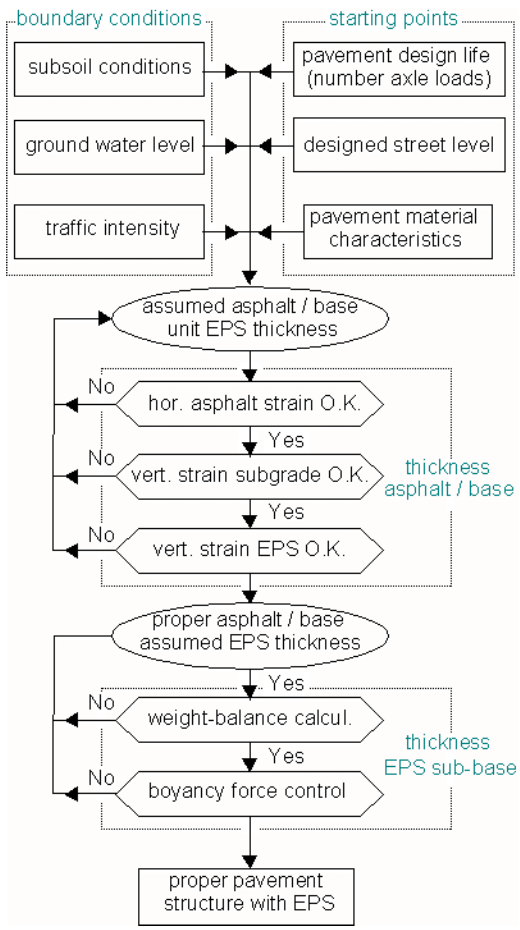

Figure 1 - Flowchart of the revised Dutch design procedure (incl. EPS strain criterion) for flexible pavement structures with an EPS sub-base

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 [Shell 1989]. 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'.

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 uniaxial 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, 1991] 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 1.

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.

2.2 Relevant EPS material properties

Except the already mentioned design criterion for the EPS layer (max. dynamic strain = 0.4%), for the design of pavement structures with EPS geofoam especially the following EPS material properties are important:

a) immediate deformation and creep of EPS due to the deadweight of the overlying pavement layers
b) (dynamic) modulus of elasticity
c) Poisson's ratio

Re a) Due to the construction of the overlying pavement layers not only an immediate permanent deformation of the EPS occurs but also a creep process starts, where creep is the time-dependent development of permanent deformation. Figure 1 shows the range of creep curves that were measured for the two most widely applied EPS-types EPS15 and EPS20. The light pavement structure represents a vertical stress of 10 kPa (i.e. a pavement structure with a thickness of 0.4 to 0.5 m), the heavy pavement structure represents 20 kPa vertical stress (i.e. a 0.8 to 1.0 m thick pavement structure). Figure 1 shows that the total permanent deformation is not only small but also that the greater part of it occurs in the first hours after loading. For practice this means that the small EPS permanent deformations mainly occur during the construction phase and that the creep of the EPS does not affect the condition (evenness) of the in-service pavement with EPS.

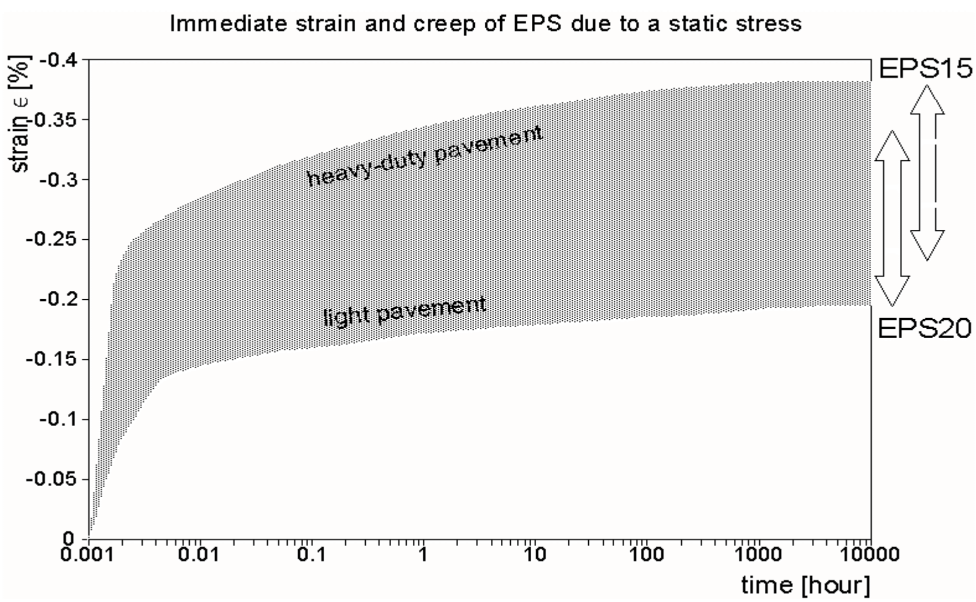

Figure 2 - Immediate deformation and creep of EPS15- and EPS20-blocks under vertical stresses representing light and heavy pavement structures

Re b) The dynamic elastic modulus of EPS is directly related to its dry volume weight. The average dynamic modulus of elasticity E (MPa) can be calculated by the equation (which is valid for a dry volume weight ρ between 15 and 60 kg/m³):

$$E = 0.1284\ \rho^{1.368}$$

For practice the following minimum E-values for the EPS-types EPS15, EPS20, EPS25 and EPS30 can be used: 4, 6, 8 and 10 MPa respectively.

It is remarked that these EPS modulus values are low compared to those of 'weak' subgrades such as peat (E = 20 to 30 MPa) and clay (E = 40 to 80 MPa).

The type of EPS has hardly any effect on the stresses and strains that occur in an overlying asphalt or concrete layer. For the in-service road therefore the lightest type of EPS (EPS15) normally is sufficient. However, the construction phase is more critical and for that reason it may be necessary to apply a heavier, and thus stiffer type of EPS in the upper part of the EPS package as in all cases the EPS design criterion (dynamic strain smaller than 0.4%) should be fulfilled.

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.

Re c) The Poisson's ratio of EPS is about 0.1, which is rather small compared to that of cement-bound materials (0.15 to 0.25) and that of granular and bitumen-bound materials (0.25 to 0.5).

The low EPS Poisson's ratio implies that due to vertical stresses only very small horizontal deformations occur or that, when these horizontal deformations are obstructed, only small horizontal stresses occur. This property makes EPS very suitable, for instance, to be used as backfill at retaining walls.

It appeared from extensive material testing that low temperatures, water absorption and exposure to freeze-thaw cycles, separately or combined, have no negative effect on the above-mentioned properties of EPS.

2.3 Buoyancy force control

The main reason for the application of EPS in a pavement structure is always to strongly reduce, or even eliminate the (unequal) settlements of weak clay- and (especially) peat-subgrades At least in The Netherlands, in those subgrades the groundwater table always is very high, say 0.5 m below the ground surface. By consequence, the bottom of the EPS-package is close to or even below the groundwater table.

As the volume weight of EPS is very much smaller than that of water, always a boyance force control has to be done to ensure that the pavement structure with EPS will not float upward at the highest possible groundwater level. Floating is a failure mechanism for such pavement structures.

It has to be checked whether at the bottom of the EPS-package the total weight of the pavement structure including the EPS is greater than the total upward water pressure, which means a check whether the grain stresses below the EPS still are compressive. The boyancy force control in fact is a strength-criterion from a soil mechanics point of view and therefore, according to the Dutch standard NEN 6740, estimated values for both the material properties (volume weight of pavement materials) and the external loadings (water pressure) have to be used. These estimated values are obtained by using partial safety factors and safety margins.

The pavement structure with EPS has to be such that the risk for floating upward of the total pavement structure is acceptably low, where a distinction can be made between the construction phase and the in-service phase of the pavement structure.

In the case of excavations below the groundwater table, during construction of the pavement structure with EPS the water table has to be lowered to prevent the pavement under construction from floating upward. Of course the most critical phase is the placement of the EPS-blocks when there still is not any surcharge

Also in the in-service phase of the pavement structure with EPS the vertical weight balance must be guaranteed. The pavement structure itself needs enough weight to exclude floating upward.

In buoyancy force safety calculations estimated values are used. The dry volume weight of the materials of the pavement structure with EPS is reduced in the calculations by the application of partial material factors (γ-m;g). The upward water pressure at the bottom of the EPS-package is calculated by increasing the normal groundwater table with a partial loading factor (Δh).

In the buoyancy force control furthermore a distinction is made in three functional classes of pavement structures with EPS. This division in functional classes is based on the kind, the extent and the (economic) relevance of the pavement structure. The three functional classes of pavement structures with EPS are:

Class 1: pavement structures of limited extent and of local relevance, such as footways and bicycle tracks

Class 2: pavement structures of greater extent and of local or regional relevance, such as municipal roads and (minor) rural roads

Class 3: pavement structures of great extent and of regional or national importance, and maybe part of evacuation routes (in the case of floodings), such as (important) rural roads and motorways.

For each functional class a high groundwater level (groundwater table plus a partial loading factor (Δh)) and a partial material factor γ-m;g (for reduction of the dry volume weight of the materials applied in the pavement structure) are chosen. These factors are:

Class 1: groundwater level at least equal to the ground level and a partial material factor γ-m;g = 1.1;

Class 2: groundwater level at least equal to the ground level and a partial material factor γ-m;g = 1.2;

Class 3: groundwater level at least equal to the ground level and a partial material factor γ-m;g = 1.3.

In all functional classes special cases, such as application of a pavement structure with EPS in a potential flooding area, require special attention.

3 SIGNIFICANT RECENT PROJECTS

3.1 General

The projects described below are selected for study as the two largest applications of EPS geofoam blocks up to now in Dutch road engineering practice. After completion of all still ongoing activities in total approximately 150,000 m^3 of blocks will be bult-in. Except significant quantities of EPS also employed design philosophy is typical for current Dutch large scale projects with geofoam. During the time available up to the start of construction, namely, preloads (high sand embankments) have been put on. Stimulation of the consolidation process of the peat-subsoil improves the bearing capacity and results at the end into less relatively costly EPS geofoam.

The first case considers the project “viaduct number 29” where a light-weight approach is chosen for two approaching embankments to a crossover structure over the new heavily haul railway between Rotterdam’s hrabour and Germany. The second project is the already mentioned reconstruction of motorway A15. Both projects are located close to a small town Sliedrecht near Rotterdam. As one could suppose, local peat-subsoil is extremely compressible, even for Dutch conditions. Representative thickness of peat layers amounts about 10 m. The saturation degree of peat is approximately 600% and there was no doubt about the unacceptability of future (differential) settlements if the embankments consist of (heavy) sand. Since the preloads are applied in the preparation stage of both projects the monitoring already confirmed the former statement in practice.

3.2 Reconstruction of Motorway A15 near Rotterdam

Confronted with the fact that regular maintenance measures do not provide adequate improvement of traffic conditions on motorway A15 near Sliedrecht, the Dutch authorities decided on a total reconstruction. High traffic intensity, approximately 90,000 vehicles including 8,000 heavy trucks per day, makes it clear why frequent maintenance was an undesirable option. Particularly settlement problems and need for extra traffic capacity strongly influenced the decision process. Project realisation started in 1998 and the accomplishment of most of the activities is planed in 2004. During that period four existing junctions around Sliedrecht will be radically rearranged. Looking from Rotterdam the first junction is Wijngaarden (future Sliedrecht-West), second one Sliedrecht-Centrum (will be dismantled), third one Zwijnskade (future Sliedrecht-East) and the last junction is called Hardinxveld-Giessendam. The total motorway length to be reconstructed amounts about 8 km. The long list of reconstruction activities includes not only new approach roads and widening of existing roadways but also dismantling of all existing and building of new viaducts and crossovers. A lot of attention is also spent on improvement of noise protection of surrounding districts resulting in arising new noise barriers over almost the entire length of the motorway between above-mentioned junctions. Continuously growing traffic on this important road connection may not be hindered by either insufficient head-room or road capacity in the future.

This paragraph deals with the reconstruction activities on locations Sliedrecht-East (Zwijnskade) and Sliedrecht-West (Wijngaarde). On these locations significant quantities of EPS geofoam blocks of totally planned 105,000 m^3 have already been or will be used in coming months. Understandably, the light-weight embankments are exclusively planned on the most critical locations.

Future look-out of the junction Sliedrecht-East is illustrated in Figure 3. The entire junction is redesigned. All approach roads on both sides of the motorway are rearranged. The future viaduct over A15 is located 15 m south from the existing one. This explains the necessity for radical situational changes. New abutments have to overcome a difference in height of about 5 m between the upper counter line of the future viaduct and the local ground level. Such demands in combination with established extreme compressibility of the subsoil and relatively limited available time explain why the light-weight approach with EPS was necessarily chosen for the both southern and northern side of A15.

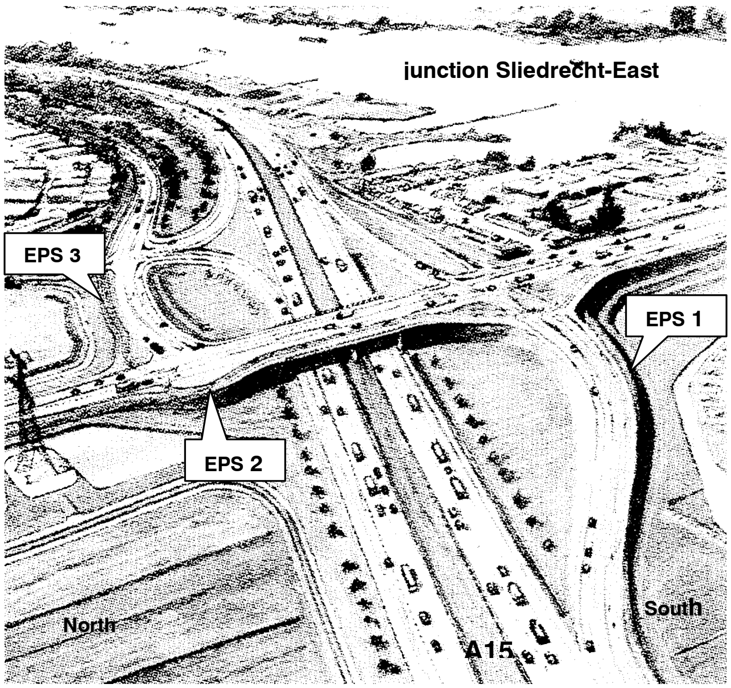

Figure 3

Future look-out of the junction Sliedrecht-East including new viaduct over motorway A15 and approach roads with light-weight embankments of EPS geofoam

EPS-1 light-weight embankment constructed on the southern side, is 200 m long (see Figure 4). The geofoam layer thickness reaches a maximum of 5.0 m. Characteristic for the site are block dimensions, pile foundation of the noise barrier, additional lowering of groundwater, upper pavement layers and preloading.. These characteristics are more or less valid for the remaining locations with EPS as well and as such will be explained.

Figure 4 – Partly covered EPS-blocks belonging to EPS-1 approach road on the southern part of junction Sliedrecht-East

Most blocks used have dimensions 6.0×1.2×1.0 m. Such huge blocks are not easy to handle and demand from mechanisation. However, stacking up is very efficient plus the EPS package consists of only few layers.

The piles belonging to the foundation of the noise barriers were prematurely driven before constructing the embankment. Consequently the blocks were stacked around the piles as can be seen in Figure 4. Expanded clay is used for filling the gaps. As shown in the new Dutch design guidelines [Duškov and Houben, 2001] a more logical approach would be foundation on EPS itself. The blocks possess sufficient bearing capacity to support properly designed concrete plates. A similar solution with concrete plates instead of a pile foundation for a noise protection wall is applied along Hamburg-Fuhlsbüttel bypass in Germany [Beinbrech, 1996].

Third characteristic is control of groundwater during construction. To enable the placement of the lower EPS layer in dry, the local groundwater level has been additionally lowered. Due to the relatively large difference to be overcome and considerable deadweight of the upper pavement layers it was, namely, necessary to start with EPS below the groundwater level. (By carrying out excavation to a certain depth necessary extra reduction of the total dead weight is achieved.)

The cross section of the road structure belonging to embankment EPS-2 on the northern side is shown in Figure 5. The EPS package is up to 4.5 m high and consists of 1.0 thick blocks. The light-weight part of the approach road reaches 175 m from the viaduct. Therefore the section EPS-3 is about 100 m long. The upper pavement layers, identically to another two approach roads, consist of 1 to 1.3 m sand sub-base, 0.25 m thick roadbase of unbound material and asphalt package. No concrete capping is applied; the sub-base lies directly on the EPS blocks. Besides the price the advantage from the point of view of Dutch contractors seems to be the possibility to build-in road furniture directly in sand, in the way they are used to do. However, such a thick sand layer does not contribute to a higher bearing capacity and a longer lifetime of the pavement structure.

Regarding the total deadweight, implementation of the sand sub-base does not mean any extra weight. Excavating and removing an equal thickness of sand belonging to the preload, compensates that weight.

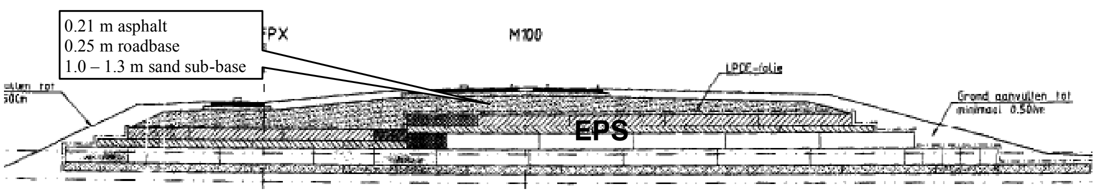

Figure 5 - Cross section of the embankment EPS-2 on the northern part of junction Sliedrecht-East near future crossover

On all locations along motorway A15 where light-weight solutions are applied a preload was placed before construction. Actually, preloading and creation of balance through partly replacement of sand by EPS may be considered as the standard procedure for the entire project. Stimulation of the consolidation process leads to a gradual increase of the bearing capacity of the subsoil and consequently decrease of the settlements occurring under deadweight. As already mentioned, the major motivation for preloading was to use less EPS blocks. Sand costs significantly less and for contractors transport of sand yields a higher profit than placing the blocks.

Consolidation is time consuming, a few years is no exception. In the case of road structures EPS-2 and EPS-3 the available time was shorter, about 6 months. Original deadlines in the time planning were postponed, however, creating extra time for the consolidation process. In fact, the preload stayed about a year long on the locations. During that period about 50% or 3 m of preload disappears as a consequence of the settlement process. The impact of extra preloading time and the deadweight of a more than 6 m high temporary embankment resulted even in revision of the design. Based on additional soil mechanical analyses it was decided to reduce the EPS thickness for 1.5 m on the northern side (EPS-2 and EPS-3). In practice 1.5 m less sand is removed before stocking up of the blocks. As additional bonus, the higher sand level of the lower EPS layer on the northern side of the junction Sliedrecht-East made it possible laying geofoam blocks in dry without extra measures in spite of high groundwater level.

Whether an application of the light-weight approach after partly consolidation of the subsoil by preloading will lead to sufficient reduction of settlements is basically a matter of timing. The consolidation process should have proceeded enough so that the subsoil can bear the total load equal to remaining preload (total preload minus removed part before building-in of EPS-blocks starts) and deadweight of the light-weight road structure. Such an approach is not without risk. Already a slightly incorrect interpretation of the consolidation process could result in unacceptable settlements. Keeping in mind that on piles founded viaducts are settlement free it is obvious that the margin is narrow, in particular for the abutments. In order to create a better insight into structural behaviour in practice and to control whether the predictions are realised, a monitoring program is being carried out.

How the junction Sliedrecht-West will look out after accomplishment of reconstruction is illustrated in Figure 6. The old railway crossover is replaced with a new much wider viaduct. It was necessary to create space for widening of the motorwayA15 from 2×2 to 2×3 traffic lanes. The widening is realised on the southern side where the sections with EPS-blocks are in total 535 m long and 15 to 25 m wide. Such dimensions mean for Dutch engineering practice actually a big step forward in large-scale applications of road structures with on light-weight EPS geofoam.

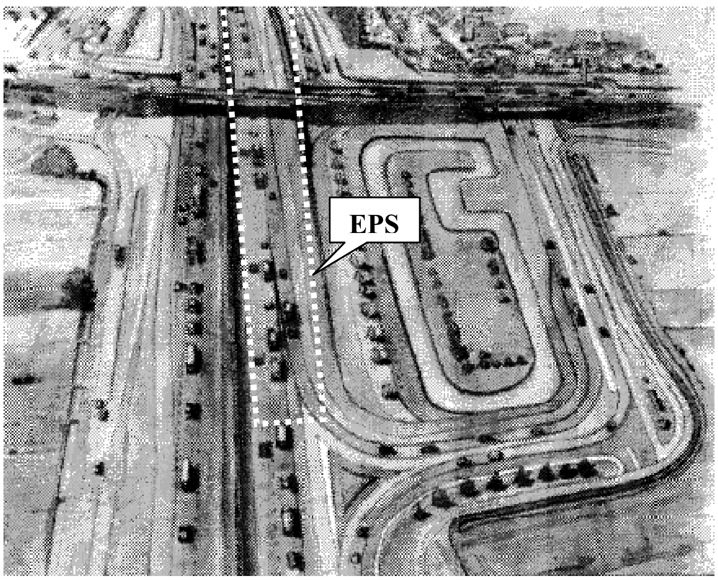

Figure 6

Future look-out of the junction Sliedrecht-West with a 535 m long and 15 to 25 m wide section founded on EPS geofoam blocks laid under the new southern traffic lanes

Figure 7 shows the cross section of the light-weight structure of the new southern traffic lanes of motorway A15. The upper pavement layers differ only with respect to the asphalt thickness (310 mm) with respect to above discussed pavement structures of approach roads.

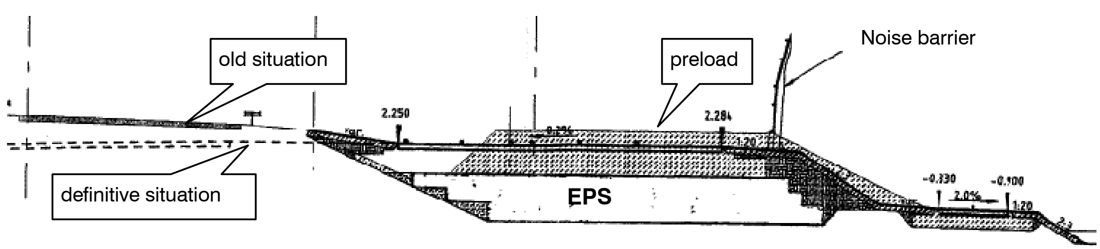

Figure 7 - Cross section of the additional traffic lanes for the widening of motorway A15 from 2×2 to 2×3 lanes

3.3 Crossover "Betuweroute" near Sliedrecht

The Dutch mega project "Betuweroute" is a new heavy haul railway connection between Rotterdam and Germany exclusively for freight transport. Identical to the motorway A15 the Betuweroute crosses a large peat area around Sliedrecht. Actually, these two major transport routes lie parallel to each in that section. As a consequence the construction of belonging crossovers share common problems related to settlements. In this paragraph the light-weight structure located near the railway station Sliedrecht is discussed. It belongs to the crossover number 29. Actually, the eastern and western approaches that create access to the viaduct, contain light-weight EPS geofoam. A site drawing is presented in Figure 8.

The project is interesting for a few reasons. Firstly, a significant quantity of 44,000 m^3 EPS geofoam is applied. Secondly, road structures constructed according various design approaches lie next or close to each other. Thirdly, similar to the previous case preloading contributed to a certain improvement of the subsoil conditions before laying EPS.

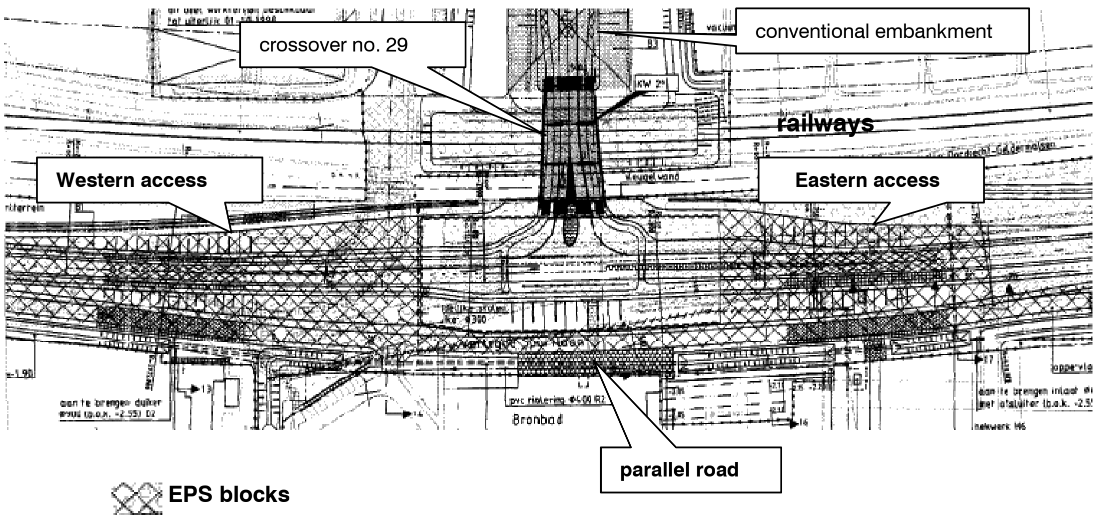

Figure 8 –Situation drawing of approach roads to the viaduct (structural work number 29) over the Betuweroute railway

On site three light-weight structures ca be distinguished. The western access is 200 m long, 10 to 40 wide at the base and the EPS package reaches a height of 7.5 m. The opposite access on the eastern side is identically high but the light-weight structure is not longer than 100 m. The dead weight a new parallel road is also reduced by applying a 1.0 thick EPS package over a length of 600 and a width of 9.5 m.

Interesting aspect is the middle part of the access, including the abutment to the viaduct. There a sand embankment is applied and to prevent horizontal deformations in the subsoil and to protect the railway structure expansive sheet piling was driven around. Furthermore, on the railway side, a 7 m high and wide L-shaped wall serves for horizontal support of the abutment. Why such principally different design approaches are selected for neighbouring sections is not clear. In any case, from the interviews with the supervisory staff serious problems with conventional embankments on the northern railway side are indicated. Vacuum consolidation failed and the sideways pressure due to settlements caused by the 8 m high sand embankment resulted in horizontal deformations of anchored sheet piling. The consequences on the southern side will be known after finishing of construction works. Up to august 2001 only the eastern part is completed.

The cross section of the western access road 110 m from the western end is illustrated in Figure 9. In the same figure also the parallel road is drawn. The upper pavement layers are the same as those for the approach roads in the previous paragraph. EPS blocks are covered by a at least 1 m thick sand sub-base, 0.25 m thick roadbase of unbound material and asphalt layers. In the case of the parallel road a concrete block pavement is chosen. Directly above the EPS geofoam layer lies a 0.5 m thick sand sub-base and a 0.5 m roadbase of mix granulate (mixture crushed masonry and crushed concrete).

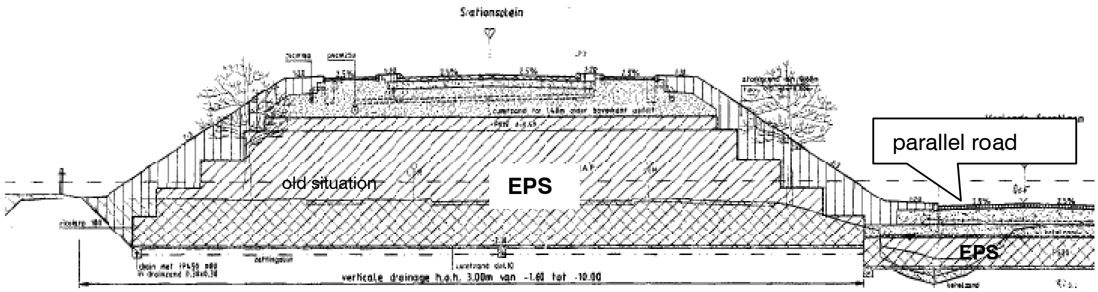

Figure 9 - Cross section of the western access and parallel road near the crossover number 29

4 ACKNOWLEDGMENTS

Stybenex is gratefully acknowledged for sponsoring the research into EPS geofoam.

5 REFERENCES

Beinbrech, G. (1996), Current Status of Geofoam Construction Method in Germany, Proc. Int. Symp. on EPS Construction Method, EPS Tokyo '96, Tokyo, Japan, pp. 118-127.

Dorp, T. van (1996), Building on EPS Geofoam in the "Low-Lands" Experience in The Netherlands, Proc. Int. Symp. on EPS Construction Method, EPS Tokyo '96, Tokyo, Japan, pp. 59-69.

Duškov, M. (1991), Use of Expanded Polystyrene Foam (EPS) in Flexible Pavements on Poor Subgrades, Proc. Vol. 1, Int. Conf. on Geotechnical Engineering for Coastal Developments, Yokohama, Japan, pp. 783-788.

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

Duškov, M. and Houben, L.J.M. (2000), Design Guidelines for Light-weight Pavement Structures with EPS Geofoam, CROW, Ede, The Netherlands, p. 85.

Shell International Petroleum Company Ltd., 1983, Shell Pavement Design Manual, London, UK.