EPS Foamblocks as Lightweight Construction Material in Road Embankments

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1. General

The conventional techniques of subsoil improvement by soil replacement, reinforced embankments, supporting the embankments on piles etc., are often time-consuming and costly.
By employing lightweight materials, the weight of the road embankment - and with it the load on the subsoil - is reduced considerably.

A largely settlement-free method of construction is thus obtained when practically no additional loads are brought to bear, ie, by using extremely lightweight materials in the embankment such as blocks of EPS-foam, known as the "GEOFOAM" System.

2. Styropor® Rigid EPS

EPS is the standard abbreviation for Expandable PolyStyrene. Styropor EPS foam has been produced worldwide for over 40 years, and is mainly used in the construction and packaging industries.

The price of rigid EPS foam is much lower than that of other foam materials, but compared with conventional materials used in road substructures, it is considerably more expansive. However, a simple cost comparison is not enough.

® = Styropor is the BASF trademark for EPS

Alternative construction methods must also be considered. Depending on the local conditions, construction with EPS Geofoam offers a definite technical and economically interesting solution - mostly for structures (eg, bridges, supporting walls, pipe ducts) where settling is to be avoided.

Experience from abroad has shown that in certain cases a cost reduction of 50 % can be achieved over conventional building techniques. EPS also offers obvious advantages if, for instance, material has to be transported to the construction site over long distances or special environmental requirements have to be met.

3. Experience to Date

The experience with Styropor (EPS) foam boards used as frost protection for roads and railways provides the basis for the development of this construction technique. This method of construction has been applied since the middle of the 1960s, mainly in countries with severe winters (eg, alpine regions, Canada, and the Scandinavian countries) where deep frost makes it necessary to prevent frost-heave of road pavement. With EPS boards as a frost-protection layer, it is possible to save costly frost-proof subbases.

From 1964 onwards, as part of the BASF program of practical tests, experimental stretches of road in Germany and other European countries were laid with Styropor EPS foam sheets in the substructure, and monitored by means of instruments.

Methods of construction and the long-term performance of EPS boards as frost protection in roads and railways under traffic load were studied.
Test samples of EPS boards, which have been taken from rebuilt road sections after 25 years, have shown that there is no damage to the foam or deterioration of the foam properties.

On the basis of these practical tests, the German Road and Transport Research Association published in 1984 a "Technical Data Sheet on Pavement Consolidation Using Frost-Insulation Layers of Rigid Foamed Plastics".
The publication of this data sheet by the Research Association established the antifrost construction method of using EPS foam insulating layers as the "regular system", meaning that it can be used in publicly funded building projects as an officially accepted system.

An essential requirement for this, of course, was that the long-term performance of EPS rigid foam in substructures gave favorable results. After more than 30 years of practical experience, the question of the aging performance of Styropor foams in road building and civil engineering no longer arises!

The favorable experience of the EPS "antifrost system" forms the basis for the EPS "Geofoam system" using EPS rigid foam blocks as a load-distributing substructure for embankments and bridge ramps.
The Geofoam system relies on the fact that EPS foams combine very light weight with high bending and shear strength and are much more efficient than conventional construction methods in distributing traffic loads on poor load-bearing foundations.
The fact that the installation of frost-insulating EPS foam blocks also provides a long-lasting, frost-proof method of construction is a secondary consideration in this context.

The first large stretch of road to use rigid EPS foam as a substructure was built in Norway in 1972. This development was initiated by the Norwegian Road Research Laboratory in Oslo which - as I mentioned - has evaluated the use of rigid EPS foam board as an antifrost layer in road and railway construction for many years.

Although positive results about this method of embankment construction were published, interest was initially confined to Scandinavia. It was in 1985, at an international road building conference in Oslo, that this construction method first caught the attention of experts from countries in which difficult soil conditions are common, and where significant economic advantages were to be gained by the use of EPS foam, rather than conventional materials (eg, in the polder areas of Holland, in southern France, USA, Canada and in Japan).

4. Engineering Properties

In the meantime, numerous data are available from research institutes in different countries on the theory and practical use of EPS as Geofoam.

Because of the limited time, I don't want to go too much in detail, but should say a few words about the mechanical performance of EPS, which are of greatest interest in geotechnical engineering applications:

EPS foam is a thermoplastic which exhibits visco-elastic behaviour when under load.

The compressive stress/compressive strain curves in this figure show that stress increases linearly, until the limit of the elasticity is reached at 1,5 % to 2 % of strain, according to the density of the material. As permanent material deformation begins, the value of strain climbs more rapidly; however there is no definite break separating the elastic and plastic regions of the curve.

When designing for permanent loads, values must therefore be chosen which lie below the 2 % strain limit.
EPS foam with a density of 20 kg/m³ can sustain loads of about 0.050 N/mm² (50 kPa).

The draft European standard "Thermal Insulation for the Building Trade" describes a method for determining the compressive creep strength of insulating materials. It can be applied to estimate permissible loads in practice and/or to check the long-term performance of certain products subjected to compressive load. (The calculation is based on the Findley equation).

This figure shows 3 extrapolated creep curves of EPS with a density of 20 kg/³: the compressive creep under a load of 0,05 MPa (50 kPa) is below 2 % over a time period of 25 years.

5. Tests on a Full-Scale Model Road

Our experience with EPS foam applied as a light-weight foundation material in a sub-base is very promising, but a standard design procedure does not exist for this structure type.
With the objective of acquiring knowledge and experience with these construction methods in Germany as well, comparative studies have been carried out on a full-scale model road.

At the German Institute for Road Research (Bundesanstalt für Straßenwesen, BAST) in Bergisch Gladbach, six test sections were built for the investigation of the structural behaviour of asphalt pavements with an EPS sub-base.

The size of the test area is 38 x 7.5 m; it is divided into sections with dimensions of 13 x 3.25 m or 12 x 3.25 m. The test pavements differ with respect to the roadbase type and the asphalt thickness. They are marked with the numbers 6, 7 and 8 and the indexes 1 and 2. The pavement structure number 6 has a gravel and a concrete layer in the roadbase ("Norwegian" pavement structure). The number 7 has a pure gravel roadbase ("Dutch" pavement structure). The number 8 has a cemented sand layer ("German" pavement structure). All three pavement structure types have two different asphalt layer thicknesses.

The first variant with the index 1 (6.1, 7.1 and 8.1) has an asphalt layer of 140 mm (40 mm dense asphaltic concrete and 100 mm gravel asphaltic concrete) and a roadbase of 420 mm. The thickness of the asphalt layer for the second variant is 220 mm (40 mm d.a.c. and 180 mm g.a.c.) and the roadbase is 340 mm.

The studies comprised intensive material tests and numerous measurements during placement and on the finished structures. The main elements of the studies were real traffic loadings produced by vehicle passages and fullscale pavement tests where traffic loads were simulated by pulse generators.

The research findings confirmed the suitability of EPS as a construction material, and yielded information about the placement technique required for the various construction materials and the serviceability of these structures during the process of construction.

The studies revealed that the construction method employing an unbound sub-base can be considered as suitable for highways of the construction classes V and VI, according to the German Guide for Road Pavement Design (RStO), traffic load $\sim$ 500 trucks > 5 t/24 h).
If a concrete slab is used as the sub-base, the construction method is also suitable for class III highways (traffic load $\sim$ 1500 trucks > 5 t/24 h).

A team from the Road and Railroad Research Laboratory, Faculty of Civil Engineering, Delft University of Technology, conducted measurements using the FWD (Falling Weight Deflectometer) on April, 1990. These measurements have provided data for calculations of the moduli of elasticity of the pavement layer materials and of the subsoil.

Both test reports were published a few months ago in a booklet of the BASt report "Straßenbau", Heft 4: "EPS-Hartschaum als Baustoff für Straßen".

6. Standardization

These findings, as well as years of practical experience, were gathered together in a proposed draft by the working group from the German Road and Transport Research Association of which I am a member.
A Standard, entitled "Advice for the Use of Light-Weight Building Materials in Road Building, Part 1: Rigid EPS foam", will be published during the next few months.

So far, product standardization, testing methods (quality control) and design guidelines for the use of EPS blocks have been handled by each user country individually. Testing methods and product requirements should therefore be harmonised throughout the world.

Under the auspices of the Comité Européen de Normalisation (CEN), the Technical Comité TC 227/WGL was asked to prepare a paper regarding the possible standardization of polystyrene blocks intended for light-weight road fills (Resolution 18, Stockholm, March 21-22, 1991).

This memorandum discusses the aspects of polystyrene blocks for super light road embankments, with regard to testing methods and standardization of the physical properties of the EPS foam. As far as possible, this should be done in accordance with the CEN regulations for similar materials, but should also take into consideration the properties that are of particular interest for road applications.

A first working paper is not jet published, because-as far as I know-the working group is still collecting data and waiting for a European harmonised road pavement standard.

7. Present Applications

The EPS Geofoam system has now been introduced worldwide with success.

Table II shows the past use of EPS in road fills in several countries and the current use in 1991. The figures for 1991 are roughly comparable with the average use of EPS as Geofoam per year in these countries.

In Germany three larger projects near Emden and Hamburg are planned to be under construction at the end of this year.

EPS is mainly used in the following areas of road construction:

- Substructure on poor load-bearing subsoils
  Reduced loads on subsoil is the most common application so far.

- Backfill at bridge abutments
  To reduce the pressure (caused by horizontal forces) and differential settlement at bridge abutments.

- Valleyside roads
  To reconstruct the slide areas of valleyside roads that have failed.

Some remarks to special applications:

In the so called "polder areas" of the Netherlands the soil conditions are very poor. This area is below sea level and therefore, the ground water level is just below the surface. For that reason, the buoyancy of EPS has to be taken into account. It is therefore essential to know the highest possible water level, in order to keep the EPS fill buried in place.

For buoyancy calculations an EPS weight of 20 kg/m^3 (foam density) is used, whereas 100 kg/m^3 is applied for settlement and stability calculations. The buoyancy force is equivalent to the volume of water displaced by EPS.
In other words, the weight of the road construction (kg/m^2) over the water level must be heavier than the volume of EPS (dm^3/m^2), which is flooded by water.

The most impressive application of EPS is as a foundation material for a temporary bridge across Euroroad 6 at the Lokkeberg intersection in Norway, near the Swedish border. Details of this project are published in the reports of the Norwegian Road Research Laboratory.
The project provided an opportunity to investigate the possibilities for placing the bridge foundation directly on the EPS fill. The alternative would have been to support the bridge on the ends with load-bearing piles driven into the bedrock.

Design calculations showed that the bridge foundation could be supported by the EPS fill provided the EPS blocks could sustain a load of 60 kN/m^2 exclusive live loads and material factors. Fill geometry and the bridge abutments were designed, so that both vertical and horizontal loads including braking forces were accomodated. In the design, a value of $\mu = 0.7$ was used for the coefficient of friction between the EPS-blocks. The same value was utilized for the friction between blocks and the layer of non-cohesive soil beneath the blocks.

The construction began in September 89 and was finished in December 89. Both bridge abutments are supported on 4.5 m high EPS embankments.

In the upper EPS layer just beneath the bridge abutment, a compressive strength of at least 200 kN/m² was specified, corresponding to a unit density of about 40 kg/m³ for the EPS blocks. Further down in the remaining upper half of the fill, blocks with a compressive strength of 150 kN/m² were used. For the remaining lower half of the fill, and also for the embankments leading up to the bridge, the normal EPS quality of 100 kN/m² was used. A total of 4600 m³ of EPS was used at the Lokkeberg intersection.

In the middle of the EPS fill a horizontal 10 cm concrete slab was cast. Another slab was placed on the embankments leading up to the bridge abutments.

The dimensions of the abutment are 7.4 x 7.5 meter.
The foundation is 1.0 m thick, directly under the bridge support and 0.5 m on the remaining part, as shown in Figures 9 and 10.

Shotcrete was sprayed on the front slopes of the EPS, while ordinary soil protection was provided on the side slopes.

The total pavement thickness constructed on top of the bridge abutments is 80 cm.

The bridge has now been in use for three years and is operating well. The deformations measured just after the structure were completed, are in the range of 5 cm (ca. 1 % strain).
No significant changes have occurred, since the structure was completed and according to the Norwegian test results, there are no signs of further creep effects.

BASF Activities

As the inventor of EPS and largest EPS raw material supplier, BASF has been involved in this EPS road building application from the beginning.

To encourage such applications, we are in contact with external experts and research bodies, we are also collecting new information and developing new knowledge, and we take part in international symposia for the purpose of market promotion and standardization.

The applications of EPS foam in light fill in road embankments is now considered as the "state of the art" in many countries.

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Encl.: Illustrations

<u>*References:*</u>

F. Hohwiller, Chr. Apostodopoulos:	Styropor Hartschaumplatten als Frostschutzschicht im Fahrbahnbau "Straßenbau-Technik", Hef 3/74
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Milan Duskov:	"Falling Weight Deflection Measurement on Asphalt Test Pavements with EPS at the Bast"
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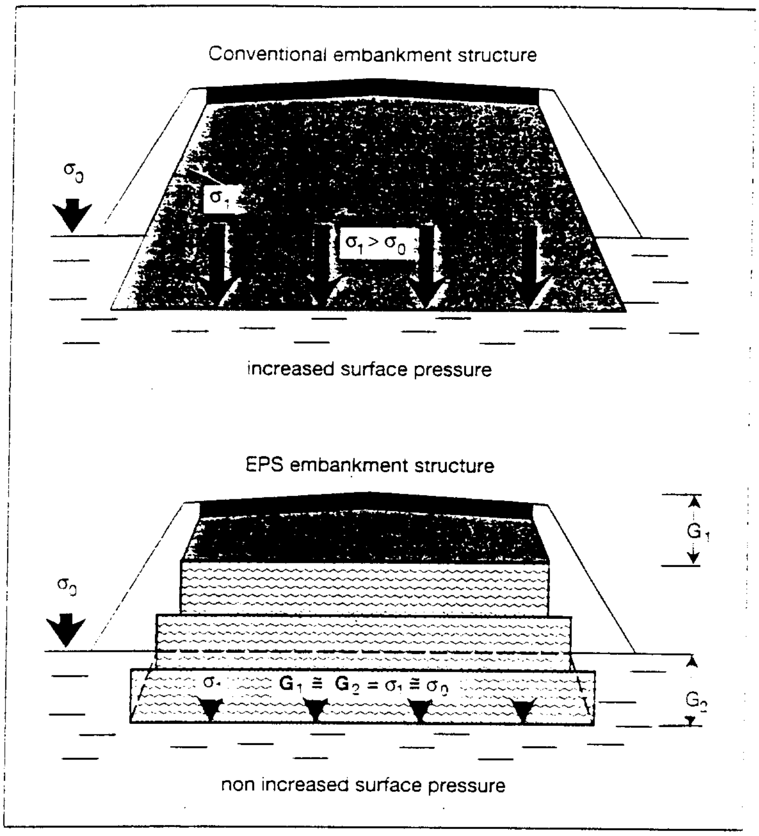


Fig.1 Comparison of conventional and EPS embankment structures.

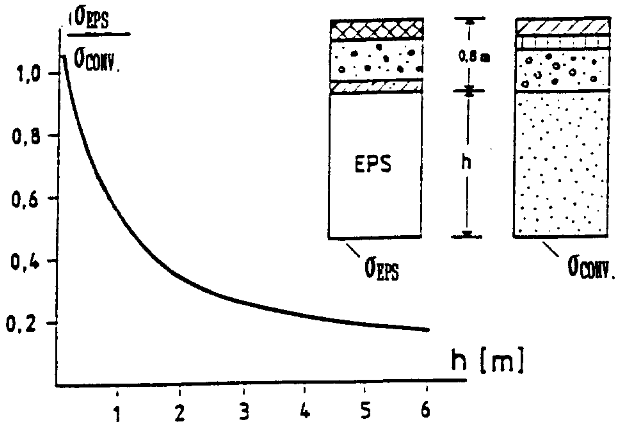


Fig.2 Soil pressure of EPS/conventional embankments ($\sigma_{EPS}/\sigma_{CONV.}$) in relation to height(h).

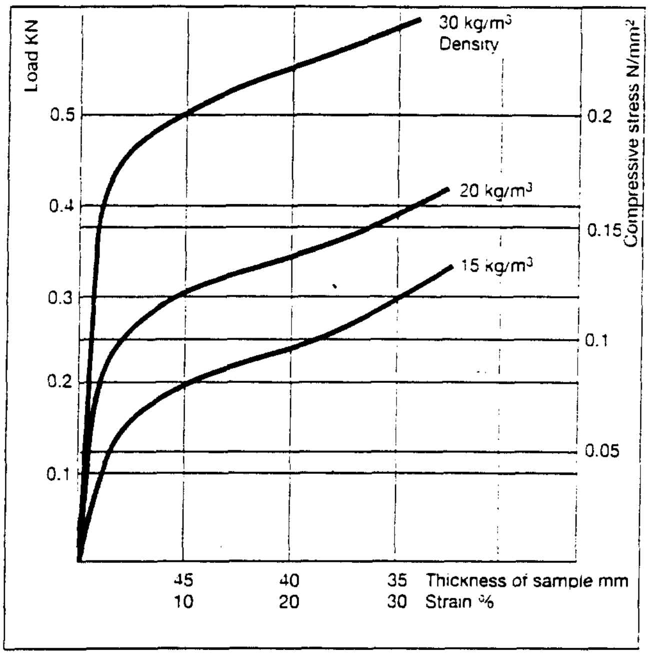


Fig.3 Compressive stress-Compressive strain curves.

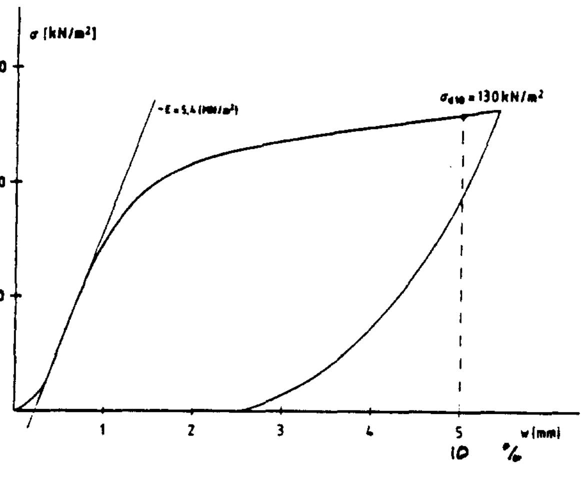


Fig.4 EPS, density 20 kg/m^3: Compressive stress/strain.

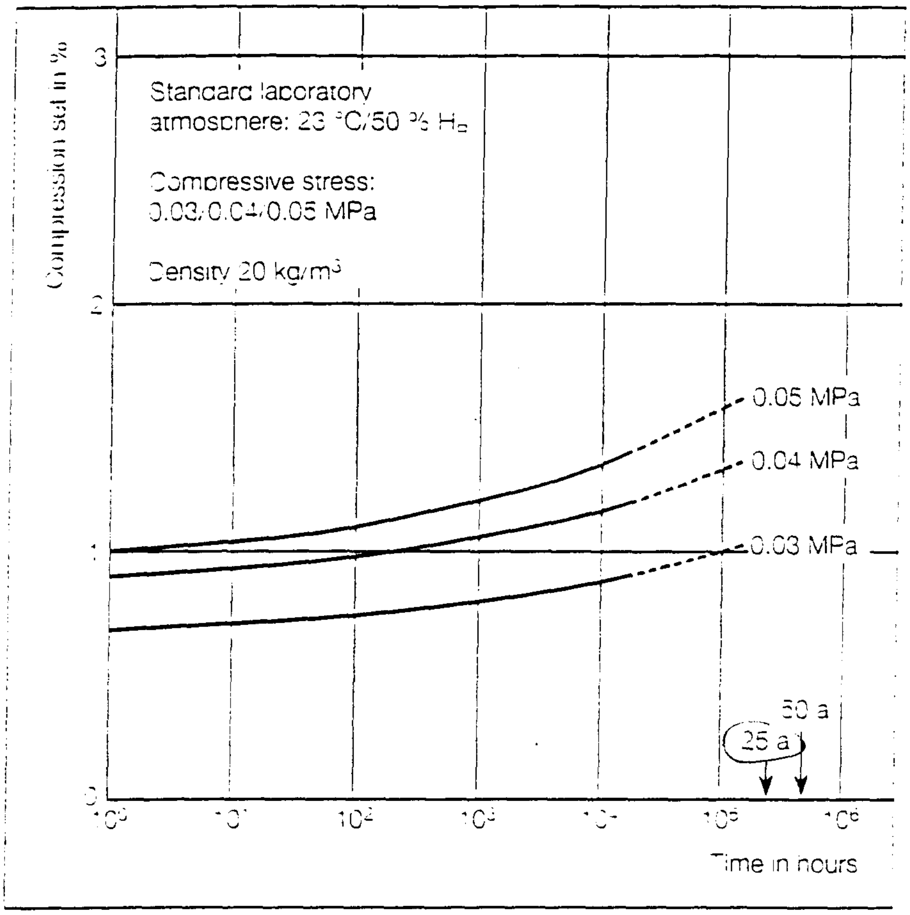


Fig.5 Creep curves for expanded polystyrene.

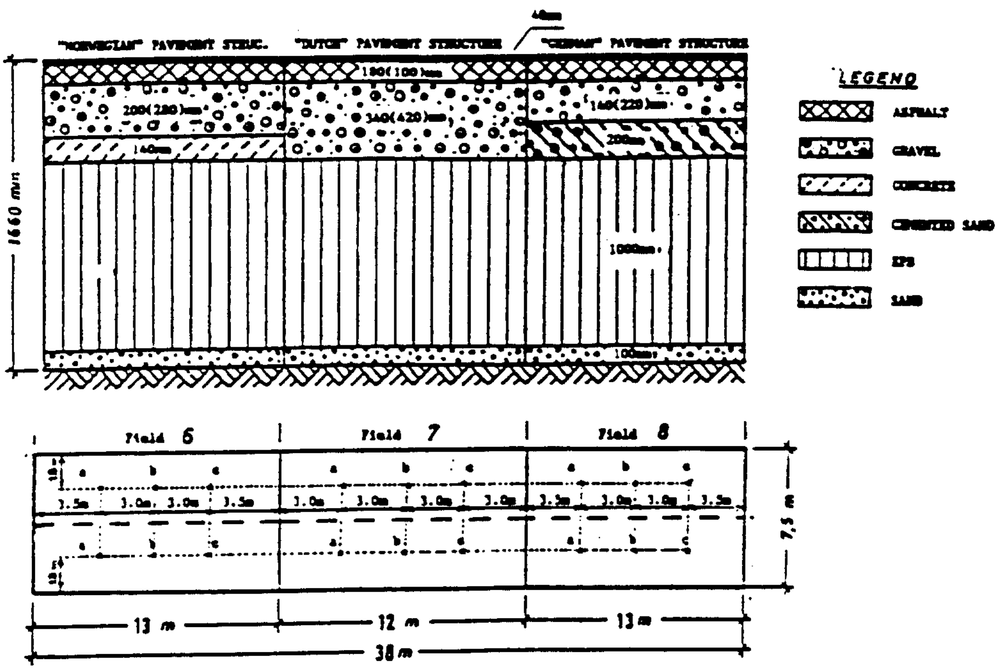


Fig.6 Asphalt test pavement structures with an EPS subbase at the Bundesanstalt für Strassenwesen(BAST).

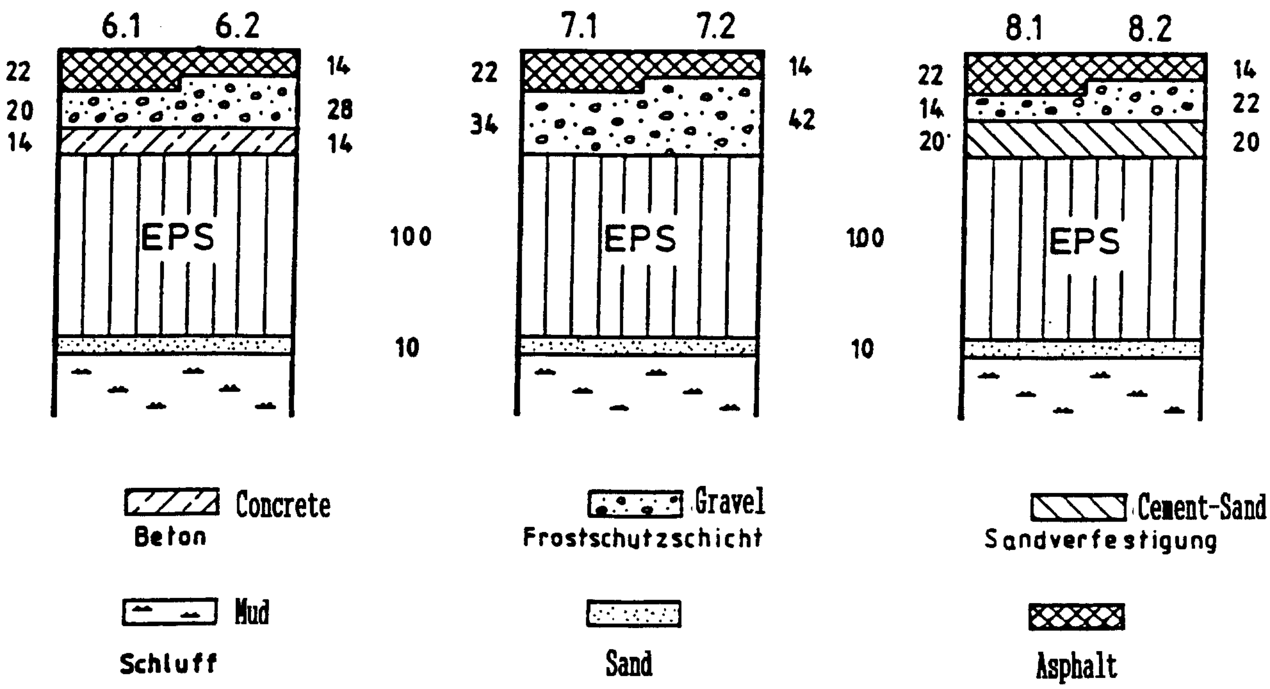
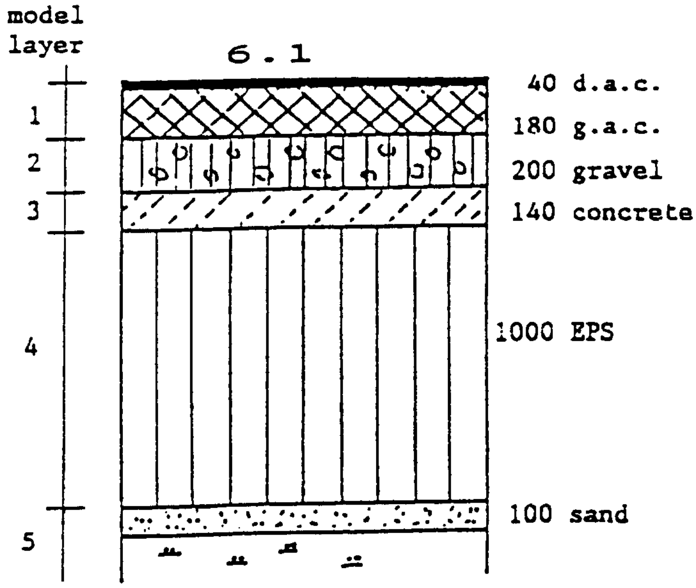


Fig.7 Aufbau der Versuchsfelder.

Fig.8 Pavement structure.



Model

	E [MPa]	v [-]	H [mm]
1	9000	0.35	220
2	240	0.35	200
3	6700	0.35	140
4	34	0.10	1000
5	41	0.35	

pavement	FWD load [kN]	E-modulus $[MN/m^2]$				
pavement	FWD load [kN]	asphalt h_a=220mm	gravel h_g=200mm	concrete h_c=140mm	EPS h_{EPS}=1000mm	subsoil
6.1	35	9000	190	6500	28	50
	50	9000	240	6700	34	41
	70	9000	230	6500	34	41
pavement	FWD load [kN]	asphalt h_a=220mm	gravel h_g=170mm	gravel h_g=170mm	EPS h_{EPS}=1000mm	subsoil
7.1	35	9600	28	18	27	28
	50	8800	28	15	26	36
	70	7900	28	17	26	40
pavement	FWD load [kN]	asphalt h_a=220mm	gravel h_g=70mm	gravel h_g=70mm	cem.sand h_{cs}=200mm	EPS & subsoil
8.1	35	9000	700	600	1300	47
	50	9500	550	500	1100	48
	70	9500	450	300	1100	48

Tab. I Back-calculated E-modulus values of the various pavement layers based on FWD measurements using a load of 35 kN, 50 kN and 70 kN respectively.

Table II : Past and Present Use of EPS in Road Fills

A very rough evaluation of past and present EPS use for light weight road fills is shown in the accompanying table.

Country	Previous use	total (approx.)		Current use 1991 (approx.)
	Number of projects	Volume	Period	Volume m^3
Norway	150	250 000	1972 - 90	30 - 40 000
Sweden	> 25	150 000	- 90	30 - 50 000
Finland	1			?
United Kingdom	> 3		- 90	35 - 50 000
Ireland	2		(1990)	?
France	20 ?	> 15 000	1984 - 90 ?	5 - 10 000
Netherlands	20 ?	> 55 000		10 - 15 000
Canada/Br. Col.	?	45 000	(1985)	?
Japan	150	130 000	1985 - 89	100 000

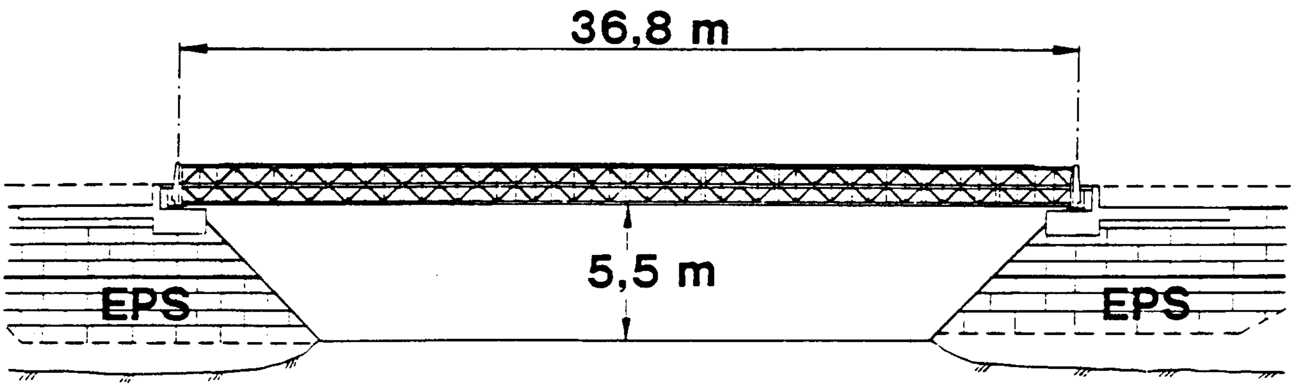
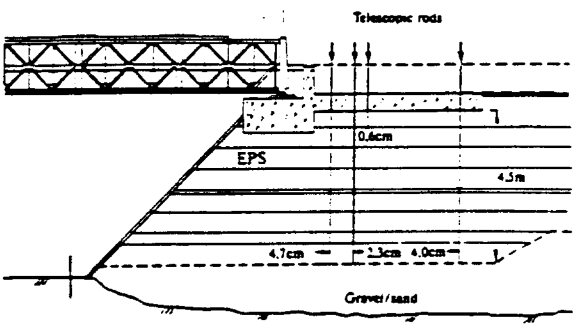
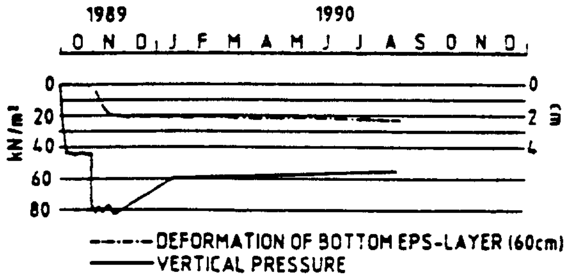


Fig.9 Longitudinal section of bridge at Løkkeberg.



(a)



(b)

Fig.10 (a) Deformation of the EPS layers and (b) Creep effect of EPS.