STRUCTURAL DESIGN OF ROAD EMBANKMENTS AND FOUNDATIONS

NEW DESIGN CODE FOR LOAD BEARING POLYSTYRENE EPS AND XPS

S. ERIK B. THELBERG[1]

Structural design of Road Embankment.
New design code for load bearing polystyrene EPS and XPS

Road Embankment
Design method
Creep
Compression strength
Deformations
Duration
Top Fill
Compensation method
Partial factor
Characteristics values
Capta factor

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STRUCTURAL DESIGN OF ROAD EMBANKMENT AND FOUNDATIONS

NEW DESIGN CODE FOR LOAD BEARING POLYSTYRENE EPS/XPS PRODUCTS

BACKGROUND

No modern calculation technique has been used as yet for load bearing polystyrene applications below foundations and for road embankments. The new computer design method is now in line with the Eurocodes both for structural and geotechnical behaviour. The designers nowadays use a guide line from Svenska Vägverket, Sweden, with requirements, rules and tables how to choose the EPS quality, and the chosen EPS quality is of density 20-30 kg/m^3 and a concrete slab is shown as protection against petroleum.

My idea was: Is it possible to design a road embankment where the EPS-types fulfill the requirements at a lower cost? A simple calculation gives lower EPS density in the slopes and in the deeper levels than today. But the heavy exemption of traffic loads have a great impact on the upper layers of the EPS. Also the thickness of the top fill and the grade has impact e.g. crashed stone instead of sand. It is also investigated to delete the concrete slab, and some projects are evaluated. Type section drawings for the top fill without the concrete slab have been developed. Petroleum protection is done with a HDPE (Polyeten) mat.

There is a need to use a modern design method in line with the Eurocodes both for structural and geotechnical applications. It has been used for several years for steel, wood, concrete and subsoil, but not for load bearing applications of geofoam. It is very important that these codes or rules are implemented also for load bearing EPS and XPS-foams, because of more than 30 years of good experience of the applications in Sweden and Norway.

To investigate the possibilities as mentioned, the Swedish Plastic Federation started and financed the development project together with the Swedish Road Authorities. As we know, there have been no reports of failure with EPS road embankments in Sweden. One EPS project in 2001 is reported. The highway E6 had settlements of an EPS embankment. It was because of too bad clay subsoil and too low compensation depth. The old EPS embankment was replaced with a new higher EPS embankment.

IMPORTANT APPLICATIONS, (Appendix 4)

1. The compensation method ,"floating foundation"

This is a foundation method for buildings. On thick layers of EPS, 300-2000 mm there is cast a very stiff T-shaped reinforced slab. It is used where the subsoil is deep and weak, e.g. clay, and where permanent loads gives settlements over years.

This foundation method is called "Markribbdäck". Expensive piling can than be avoided and the foundations can be built cheaper. The method is used for more than 15 years. It was reported at a geotechnical symposium in Stockholm this year. In this paper two projects are presented. The floating foundation can be combined with piling under point loads from columns. It is then called creep piling system.

2. Settlements in roads and ground slabs on weak deep soil

Settlements are often repaired by replacing the old layers or level adjustment materials (sand and asphalt) with light weight fill of EPS. Settlements in ground slabs are also repaired in the same way. The slab is removed and some top subsoil is replaced by EPS. A new concrete slab is cast on the top of the EPS layer

AIM

Design method FEM analyze for road embankments of EPS to determine the right EPS quality for different loads. Effect of deleted concrete slab.

EPS TYPES

In the new CEN product standards for insulation material, e.g. EPS, there are declared several types of EPS for load bearing applications. The type EPS-60 refer to the compression strength 60 kPa. In the product standard it is listed requirements and test methods for all actual properties, for instance compression strength creep, water absorption. The draft has the No. PrEN 13163 E, Factory made products of expanded polystyrene (EPS) – Specification. (Appendix 1 a-c)

RESULT

Technical correct dimensioned embankment gives better quality and economy, increased capability to compete with other ground stabilizing methods, e.g. piling and light weight aggregates.
About 22 load cases have been calculated. Here are only three load cases presented: Loadcase 1, Loadcase 2A and Loadcase 1+3A-D. (Appendix 2, Appendix 3 a-c)

1. <u>Loadcase 1 Top fill and Adjusting load for settlements. No traffic load.</u>

This results in stresses in the top layer of EPS so that the compression strength must be between 60-120 kPa, depending on the thickness of the top fill 500-1250 mm.

2. <u>Loadcase 2A. Exemption load, 1 axle, 15 tons</u>

This results in stresses in the top layer of EPS so that the compression strength must be between 120-300 kPa, depending on the thickness of the top fill 500-1250 mm. Below about 1 m the EPS-60 can be used if the top fill is 500 mm. If the top fill is increased to 750-1250 mm EPS-80 must be used.

3. <u>Loadcase 1+3A-D. Summary of permanent load and exemption loads</u>

This results in increased EPS qualities about 20-30 kPa, compared with Loadcase 2A, and down to deeper levels. EPS-150 to EPS-300 must be used for the EPS top layer depending on the thickness of the top fill. Deeper than 1,7 m EPS-80 to EPS-100 can be used when top fill is between 500-1000mm.

The effect of exemption traffic loads have now been sent over to the Swedish Road Authorities for comments.

NEW DESIGN-CODE FOR POLYSTYRENE THERMAL INSULATING PRODUCTS (EPS,XPS)

MOTIVATION

1. Lack of common design-code for EPS and XPS (and other load-bearing, thermal insulating products)

2. The most frequently used design-code for EPS in Sweden today only deals with two load cases – short term loads and long term loads. This means that we have a lack of fitness between duration of different loads and the load-bearing capacity of polystyrene products.

3. New code should be based on fundamental principles in Eurocode 1 and be similar to chapter 5 (wood-structures) of the Swedish Building Code BKR99.

PARTIAL SAFETY FACTOR METHOD
ULTIMATE LIMIT STATE

General design condition: $R_d \geq S_d$ (unconditional)

Where S_d is design effect of action such as compression, etc.

$F_d = \gamma_f \cdot F_k \rightarrow S_d$

γ_f= partial factor for loads (or action).
(In Sweden γ_f = 1,0 or 1,15 for permanent loads and γ_f = 1,0 or 1,3 for variable loads depending on current load combination.)

F_k= characteristic value for force (or load) defined as mean value for permanent loads and as 98% fractile for variable loads (once per 50 year).

And R_d is load bearing capacity

Equation No.1

$$\left.\begin{array}{l} \left.\begin{array}{l} f_d = \dfrac{\kappa_r \cdot f_k}{\gamma_m \cdot \gamma_n} \\ E_d = \dfrac{\kappa_r \cdot E_k}{\gamma_m \cdot \gamma_n} \end{array}\right\} \Rightarrow R_a \\ \left.\begin{array}{l} f_d = \dfrac{\kappa_r \cdot f_k}{\gamma_m \cdot \gamma_n} \\ E_d = \kappa_r \cdot E_k \cdot \gamma_m \cdot \gamma_n \end{array}\right\} \Rightarrow R_b \end{array}\right\} \Rightarrow R_d \leq R_{a,b}$$

Where κ_r= factor which considers the connection between load bearing capacity of material and duration of different loads at ultimate limit (connection between creep and duration of load)

f_k= characteristic value for strength according to SS 16 95 24 (prEN 826) defined as 5 % fractile

E_k = characteristic value for stiffness defined as mean value

γ_m = partial safety factor for the material "Discussion-values" for EPS and XPS is $\gamma_m = 1,3$ for manufacturers with production inspection according to agreement certificate and $\gamma_m = 1,5$ for those without any production inspection.

γ_n = special partial factor in Sweden for safety class (for common foundation structures $\gamma_n = 1,0$)

R_a = load bearing capacity with low value on E_d

R_b = load bearing capacity with high value on E_d

SERVICEABILITY LIMIT STATE

General design condition: $S_d \le R_d$ (consultative)

where S_d is design effect of action such as deformation, etc.

Equation No.2

$$\left.\begin{aligned} F_d &= \gamma_f \cdot \psi \cdot F_k \\ E_d &= \frac{\kappa_s \cdot E_k}{\gamma_m \cdot \gamma_n} \end{aligned}\right\} \Rightarrow S_d$$

$\gamma_m = \gamma_f = 1,0$ (real behaviour)

$\psi \cdot F_k$ = common value for force (or load)

κ_s = factor which considers the connection between behaviour of material and duration of different loads at serviceability limit (connection between creep and duration of load)

and R_d is recommended values (e.g. 2% for XPS and 3 % for EPS) given by manufacturer

Commentary:

The difference between ultimate limit state and serviceability limit state is that the former is unconditional and the later is consultative. This means that if the designer (builder, structural engineer) finds it appropriate for his special structure he is free to choose another value for R_d on his own risk. But of course this value must always be in acceptable accordance with the value given by manufacturer.

DURATION OF LOADS

The factors κ_r and κ_s shall be decided according to following groups of loads

Type of load	Accumulated duration	Examples of loads
Permanent load		
Loadtype P	> 10 years (30-50 years)	selfweight of permanent Parts of building
Variable load		
Loadtype A	6 months to 10 years	fixed part of imposed loads Snow load, common value

Loadtype B	1 week to 6 months	free part of imposed loads Wind load, common value Snow load, charfacteristic value
Loadtype C	< 1 week	wind load, characteristic value

Commentary

In each load-case the load with the shortest duration decides the value of κ (κ_P, κ_A, κ_B or κ_C). This means that a loadcase which gives the greatest effect of action not necessarily will be the decisive one. It is necessary to examine a number of load-cases to be sure finding the decisive load-case.

COMPUTER PROGRAM ELAS

ELAS is a computer program to calculate a ”Cooperation Foundation” with PREFEM together with a modified version ”SÄTTNING” (Settlement). With program PREFEM it is calculated moment, shear forces, etc. for slabs with, FEM- analyses with program SÄTTNING it is calculated deformations in a 3-dimensional soil layer model, see separate presentation. PREFEM has been developed by a computer company in Gothenburg. ELAS makes the iteration and checks that the deformations are the same with SÄTTNING as with PREFEM.

COMPUTER PROGRAM ELAS

<table>
<tr><td colspan="2" align="center">ELAS

Perform an iterations process until the slab deformation
is in line as with the settlement of the soil</td></tr>
<tr><td align="center">↗↙</td><td align="center">↖↘</td></tr>
<tr><td>PREFEM

FEM-program for calculation of square angled slabs

Stiffness properties is declared with:
o E-module
o Slab thickness
o Contraction data</td><td>SETTLEMENT

Calculation of total deformations for loads of an arbitrary 3-dimensional soil layer model

When calculating with the CRS-method shall be declared the soil properties:
o Soil density
o OC
o Compression modules:
Mo, ML and M

Load spread is calculated for:
o Rectangular load face according to elastic theory</td></tr>
</table>

SUMMARY:

It is possible to design Road Embankments and loadbearing polystyrene foundations on weak subsoil as cooperation structures. The design method is two FEM-cooperation computer programs with all the load parameters and material datas as indata. Successful projects have been buit where the new design method has been used.

The design method is in line with the Eurocodes for constructions and also for geological soil design.

ACKNOWLEDGEMENTS:

I will thank the Swedish Plastic Federation and Henrik Carlsson, J&W, for their contribution to the development of the modern calculation methods and Per-Gunnar Larsson, Bohusgeo, for his advanced foundation systems with thick EPS, compensation method, presented at a geophysic symposium this year.

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Carlsson, Henrik, J&W (1995), New design code for Polystyrene Thermal Insulating Products, Swedish Plastic Federation

CEN, European Committee for Standardization, (2001), prEN 131163E, Factory made Products of expanded polystyrene (EPS) – Specification

CEN, European Committee for Standardisation, (2001), Geofoam standard

Larsson, Per-Gunnar (2001), Computer program ELAS and SÄTTNING (Settlement), Bohusgeo, Uddevalla and AEC, Gothenburg.

Swedish Building regulations, BKR 99

Swedish Road Authority's Guideline

Table 1. Factory controlled material

	ULTIMATE STAGE	ULTIMATE STAGE	ULTIMATE STAGE	ULTIMATE STAGE	SERVICE STAGE	SERVICE STAGE	SERVICE STAGE	SERVICE STAGE
Material type	Characteristic compr. strength 10% declared by the manufacturer (kPa) fk	Design compr. Strength durability P (permanent load) (kPa) f d	Design compr. Strength durability B (permanent load + traffic load) (kPa) f d	Design compr.strength durability C (permanent load + exemption load) (kPa) f d	Dynamic E-modulus (MPa)	E-modulus for elastic def. (secantmodul at 2% def.) E-short time (MPa)	E-modulus for total def. after 20 years E-tot. 20 (MPa)	E-modulus for total def. after 40 years E-tot. 40 (MPa)
EPS 60	50	19	23	27	4	1,5	0,7	0,7
EPS 80	70	27	32	38	5	2,1	1,0	1,0
EPS 100	90	35	42	48	6	2,7	1,3	1,2
EPS 120	110	42	51	59	9	3,3	1,6	1,5
EPS 150	140	54	65	75	14	4,2	2,0	1,9
EPS 200	190	73	88	102	19	5,7	2,7	2,6
EPS 300	290	112	134	156	29	8,7	4,1	4,0
EPS 400	390	150	180	210	39	11,7	5,6	5,3

$f_d = \kappa * f_k / \eta * \gamma_m * \gamma_n$ design compressive strength

KEY VALUES:

f k		characteristic compressive strength (the lower 5%-fractile of the compressive strength of the material)
κ P	0,5	durability (permanent load; total durability more than 10 years)
κ B	0,6	durability B (permanent load + traffic load; total durability between 1 week and 6 months)
κ C	0,7	durability C (permanent load + exemption traffic load; total durability less than 1 week)
η	1,0	factor that include systematic differences between real material properties and properties from testing
γ m	1,3	partial coefficient that regards unsafety at evaluating the load capacity for the EPS-material
γ n	1,0	partial coefficient that regards the safety class
Φ 20	1,1	creep coefficient for EPS at 20 years under load
Φ 40	1,2	creep coefficient for EPS at 40 years under load

EPS in Road Embankment

Table 2. Not factory controlled material

	ULTIMATE STAGE	ULTIMATE STAGE	ULTIMATE STAGE	ULTIMATE STAGE	SERVICE STAGE	SERVICE STAGE	SERVICE STAGE	SERVICE STAGE
Material type	**Characteristic compr. strength 10% declared by the manufacturer s=12 (kPa) fk**	**Design compr. Strength durability P (permanent load) (kPa) f d**	**Design compr. Strength durability B (permanent load + traffic load) (kPa) f d**	**Design compr.strength durability C (permanent load + exemption load) (kPa) f d**	**Dynamic E-modulus (MPa)**	**E-modulus for elastic def. (secantmodul at 2% def.) E-short time (MPa)**	**E-modulus for total def. after 20 years E-tot. 20 (MPa)**	**E-modulus for total def. after 40 years E-tot. 40 (MPa)**
EPS 60	43	14	17	20	4	1,3	0,6	0,6
EPS 80	62	21	25	29	5	1,9	0,9	0,8
EPS 100	82	27	33	38	6	2,5	1,2	1,1
EPS 120	102	34	41	48	9	3,1	1,5	1,4
EPS 150	132	44	53	62	13	4,0	1,9	1,8
EPS 200	181	60	72	64	18	5,4	2,6	2,5
EPS 300	281	94	112	131	28	8,4	4,0	3,8
EPS 400	381	127	152	178	38	11,4	5,4	5,2

$f_d = \kappa * f_k / \eta * \gamma_m * \gamma_n$ — design compressive strength

KEY VALUES:

f_k		characteristic compressive strength (the lower 5%-fractile of the compressive strength of the material)
κ_P	0,5	durability (permanent load; total durability more than 10 years)
κ_B	0,6	durability B (permanent load + traffic load; total durability between 1 week and 6 months)
κ_C	0,7	durability C (permanent load + exemption traffic load; total durability less than 1 week)
η	1,0	factor that include systematic differences between real material properties and properties from testing
γ_m	1,5	partial coefficient that regards unsafety at evaluating the load capacity for the EPS-material
γ_n	1,0	partial coefficient that regards the safety class
Φ_{20}	1,1	creep coefficient for EPS at 20 years under load
Φ_{40}	1,2	creep coefficient for EPS at 40 years under load

EPS in Road Embankment

Table 3. Other design data for EPS-material

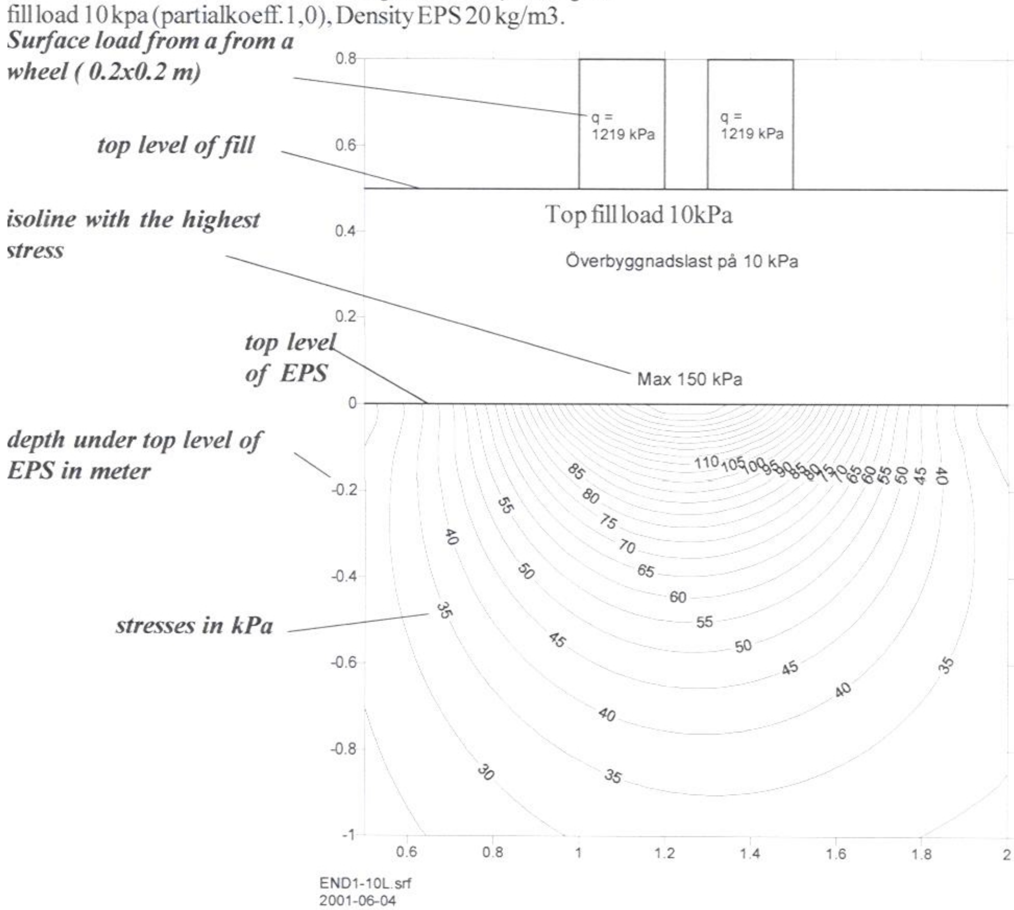
Type of Material	Design EPS density (kg/m3)	Design friction coefficient	Design shear strenth (kPa)	Design horisontal permanent pressure from the EPS-filling
EPS 60	50 resp. 0	0,7	36	0,1 x $\sigma_{vertical}$
EPS 80	50 resp. 0	0,7	47	0,1 x $\sigma_{vertical}$
EPS 100	50 resp. 0	0,7	62	0,1 x $\sigma_{vertical}$
EPS 120	50 resp. 0	0,7	72	0,1 x $\sigma_{vertical}$
EPS 150	50 resp. 0	0,7	88	0,1 x $\sigma_{vertical}$
EPS 200	50 resp. 0	0,7	113	0,1 x $\sigma_{vertical}$
EPS 300	50 resp. 0	0,7	211	0,1 x $\sigma_{vertical}$
EPS 400	50 resp. 0	0,7	286	0,1 x $\sigma_{vertical}$

EPS in road embankment - calculation of stresses

Common conditions and explanations

Loadcase 2a, Exemption 1 axle load 15 ton (partialkoeff. 1,3) Top fill load 10 kpa (partialkoeff. 1,0), Density EPS 20 kg/m3.

Lastfall 2a
Dispenslast 1-AXEL på 15 ton (partialkoeff. 1.3)
Överbyggnadslast på 10 kPa (partialkoeff. 1.0)
Egenvikt EPS på 50 kg/m3



The calculation of stresses have been done in sections and are presented in some figures as the example above. For the calculations following conditions:.

- the loadspread by the traffic axle loads are calculated with Boussinesq theory
- to consider added stresses by EPS weight extra load 0,25 kPa is added for every 1/2 meter in the depth.
- all calculations are done with eternity width of the bank.
- density for the top fill is 20 kN/m^3
- all calculations refer to embankment without the concrete slab.

Top fill (Gk) and Adjusting load for Settlement (δGk)
Partial coefficient (γ) 1.15 for both Gk and δGk

δGk 0 kPa 0 cm
Top fill mm

500	750	1000	1250
60	60	80	100

δGk 2 kPa 10 cm
Top fill mm

500	750	1000	1250
60	80	80	100

δGk 4 kPa 20 cm
Top fill mm

500	750	1000	1250
60	80	100	100

δGk 5 kPa 25 cm
Top fill mm

500	750	1000	1250
60	80	100	100

δGk 8 kPa 40 cm
Top fill mm

500	750	1000	1250
80	80	100	120

Factory control material

EPS	kPa
60	19
80	27
100	35
120	42
150	54
200	73
300	112
400	150

γ= 1,15

	δGk	δGk	δGk	δGk	δGk	
Last	0	2	4	5	8	Top fill
10	12	14	16	17	21	500
15	17	20	22	23	26	750
20	23	25	28	29	32	1000
25	29	31	33	35	38	1250

Loadcase 2A

Exemption load 1-axle à 15 tons

Appendix 3b

Top Layer	500	750	1000	1250
0,00	300	200	150	120
-0,05	300	200	150	120
-0,10	300	150	120	120
-0,15	200	150	120	120
-0,20	200	150	120	100
-0,25	200	150	120	100
-0,30	200	120	100	100
-0,35	150	120	100	100
-0,40	150	120	100	100
-0,45	120	100	100	100
-0,50	120	100	100	100
-0,55	120	100	100	100
-0,60	100	100	100	100
-0,65	100	100	100	100
-0,70	100	100	100	100
-0,75	100	80	80	100
-0,80	100	80	80	100
-0,85	80	80	80	100
-0,90	80	80	80	100
-0,95	80	80	80	80
-1,00	80	80	80	80
-1,30	60	80	80	80
-1,60	60	80	80	80
-1,90	60	60	80	80
-2,20	60	60	80	80
-2,50	60	60	80	80
-2,80	60	60	60	80
-3,10	60	60	60	80
-3,40	60	60	60	80
-3,70	60	60	60	80
-4,00	60	60	60	80
-4,30	60	60	60	80
-4,60	60	60	60	80
-4,90	60	60	60	80
-5,20	60	60	60	80
-5,50	60	60	60	80
-5,80	60	60	60	80
-6,10	60	60	60	80
-6,40	60	60	60	80
-6,70	60	60	60	80
-7,00	60	60	60	80
-7,30	60	60	60	80
-7,60	60	60	60	80
-7,90	60	60	60	80
-8,20	60	60	60	80
-8,50	60	60	60	80
-8,80	60	60	60	80
-9,10	60	60	60	80
-9,40	60	60	60	80
-9,70	60	60	60	80
-10,00	60	60	60	80

Factory controlled material

EPS	kPa	Design
60	27	Comression
80	38	Strength
100	48	Durability C
120	59	(permanent
150	75	load and
200	102	exemption
300	156	load)
400	210	

Loadcse 1 + 3A-D

Appendix 3c

Summary of permanent load and all exemption loads + adjusting load of Settlement 5 kPa (0.25 m)

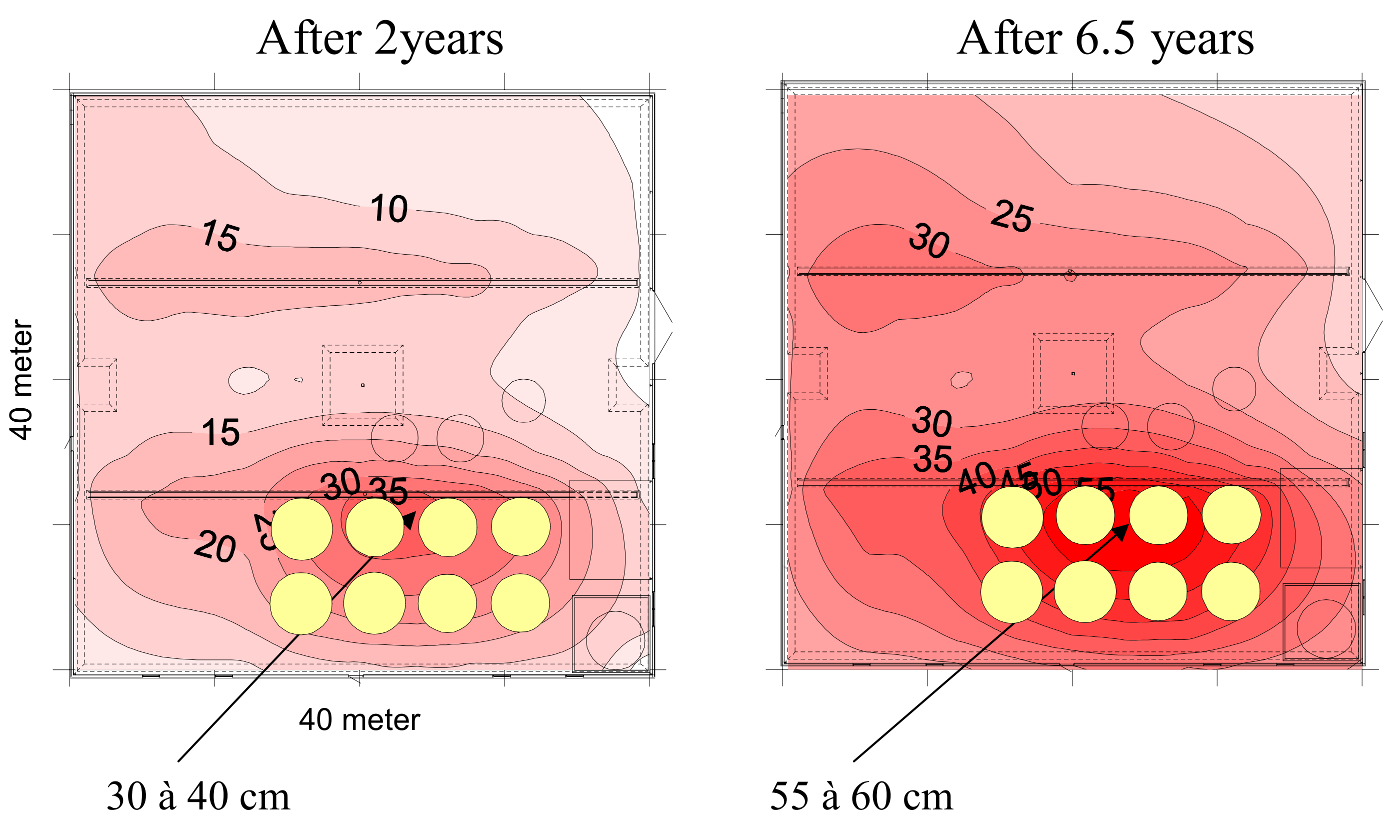
	500+250	750+250	1000+250
0,00	300	200	150
-0,05	300	200	150
-0,10	300	150	150
-0,15	200	150	120
-0,20	200	150	120
-0,25	200	150	120
-0,30	200	120	120
-0,35	150	120	120
-0,40	150	120	120
-0,45	120	120	120
-0,50	120	120	120
-0,55	120	100	120
-0,60	120	100	120
-0,65	100	100	120
-0,70	100	100	120
-0,75	100	100	120
-0,80	100	100	120
-0,85	100	100	120
-0,90	100	100	120
-0,95	100	100	120
-1,00	100	100	120
-1,30	100	100	100
-1,60	100	100	100
-1,90	80	100	100
-2,20	80	100	100
-2,50	80	100	100
-2,80	80	80	100
-3,10	80	80	100
-3,40	80	80	100
-3,70	80	80	100
-4,00	80	80	100
-4,30	80	80	100
-4,60	80	80	100
-4,90	80	80	100
-5,20	80	80	100
-5,50	80	80	100
-5,80	80	80	100
-6,10	80	80	100
-6,40	80	80	100
-6,70	80	80	100
-7,00	80	80	100
-7,30	80	80	100
-7,60	60	80	100
-7,90	60	80	100
-8,20	60	80	100
-8,50	60	80	100
-8,80	60	80	100
-9,10	60	80	100
-9,40	60	80	100
-9,70	60	80	100
-10,00	60	80	100

Factory controlled material

EPS	kPa
60	27
80	38
100	48
120	59
150	75
200	102
300	156
400	210

Measured settlements in cm

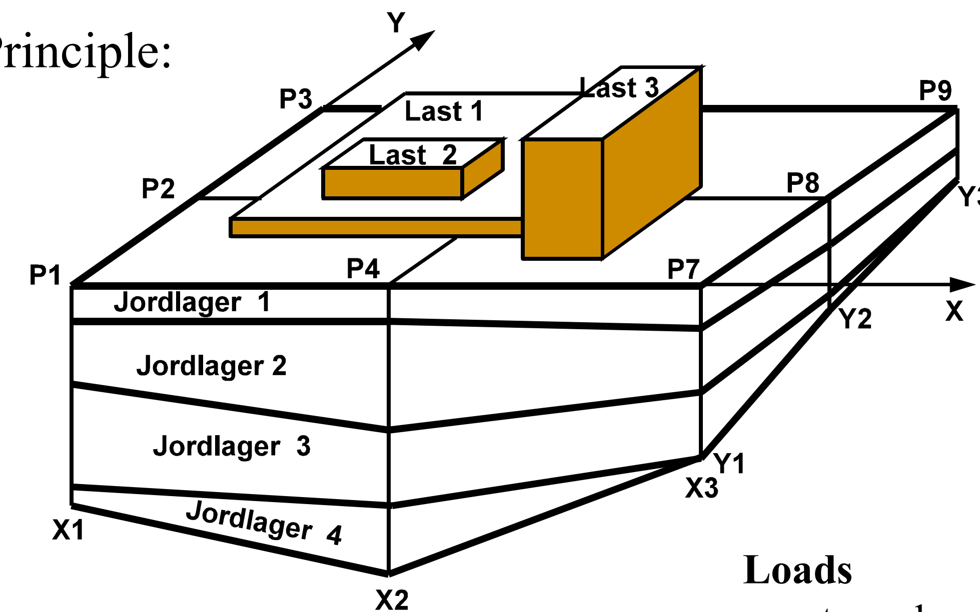
Appendix 4



Appendix 4

Settlement calculation in a 3-dimensional model

Principle:



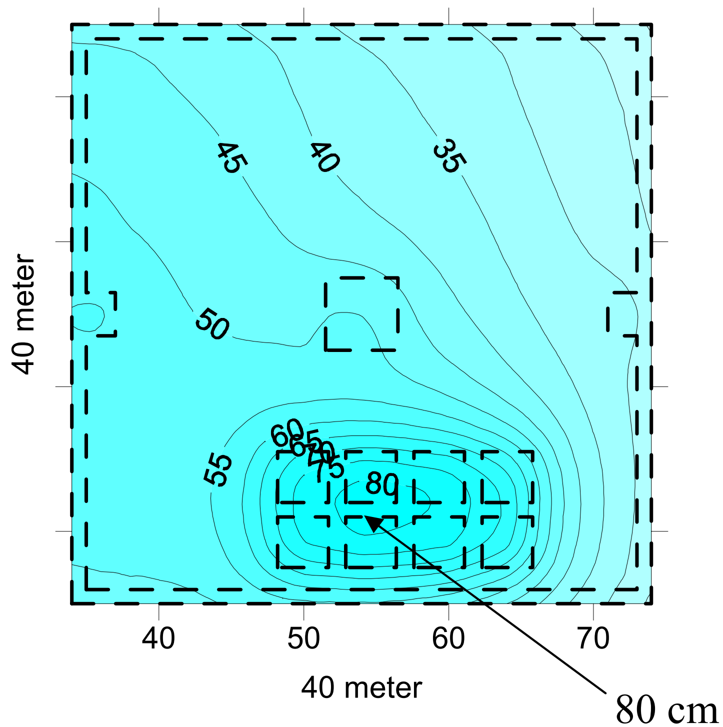
Loads

- rectangular surface loads
- free attac level
- own load history

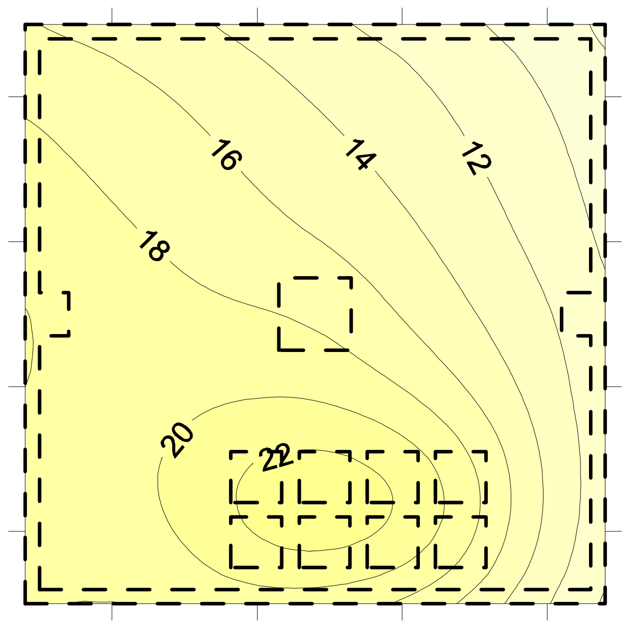
Appendix 4

Calculated settlements in cm **if no** foundation repair had been done

After 16.5 years
that is further 10 years

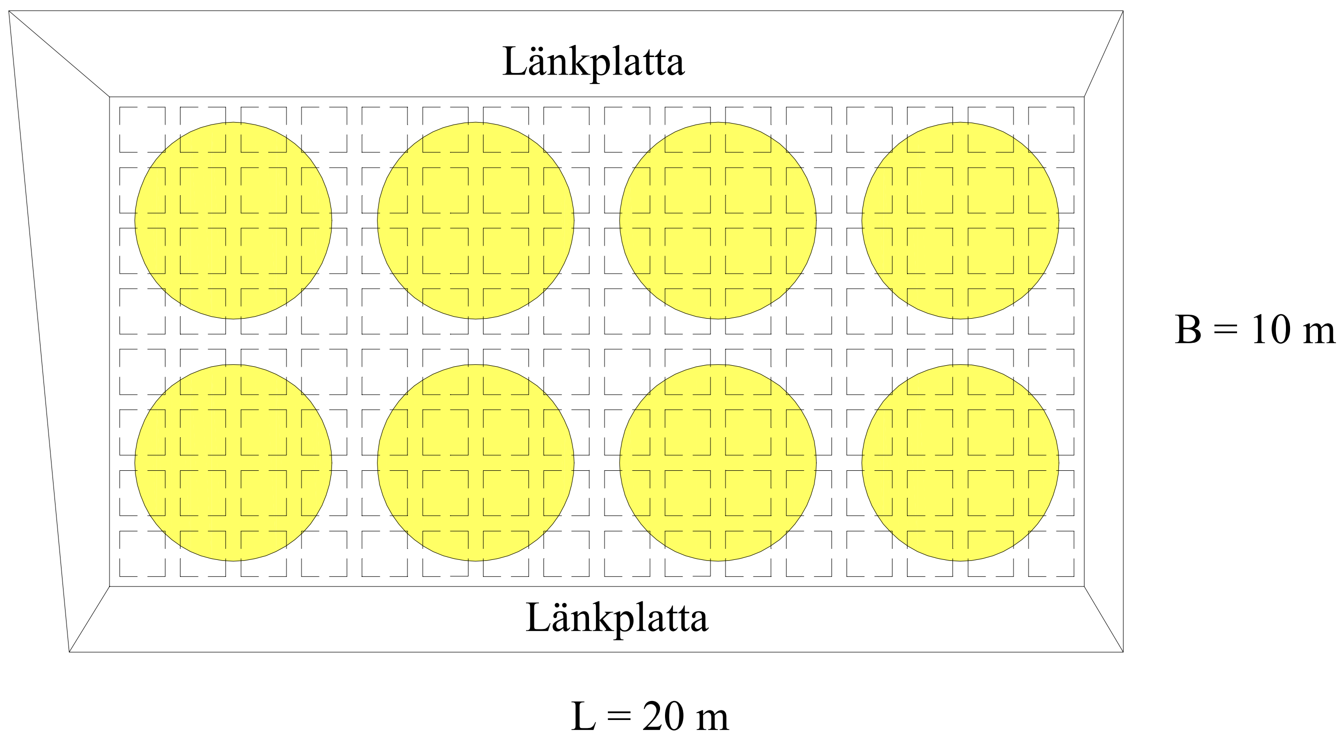


Additional settlement between
6.5 years och 16.5 years

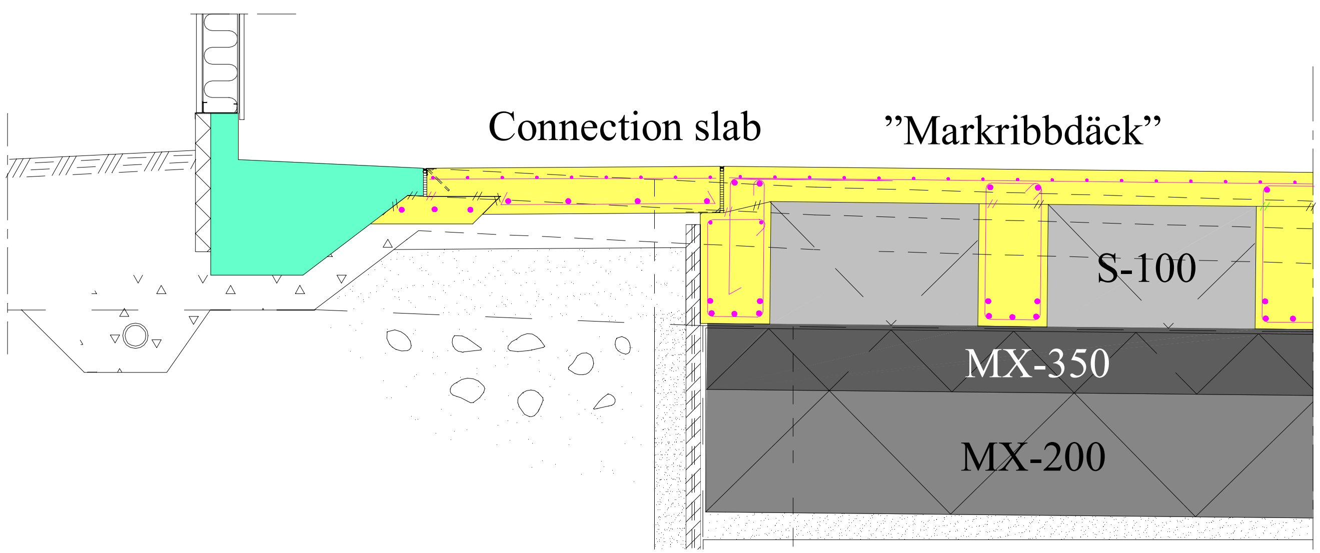


Appendix 4

”Markribbdäcket” with link slabs



Principle section - ”markribbdäck” Appendix 4

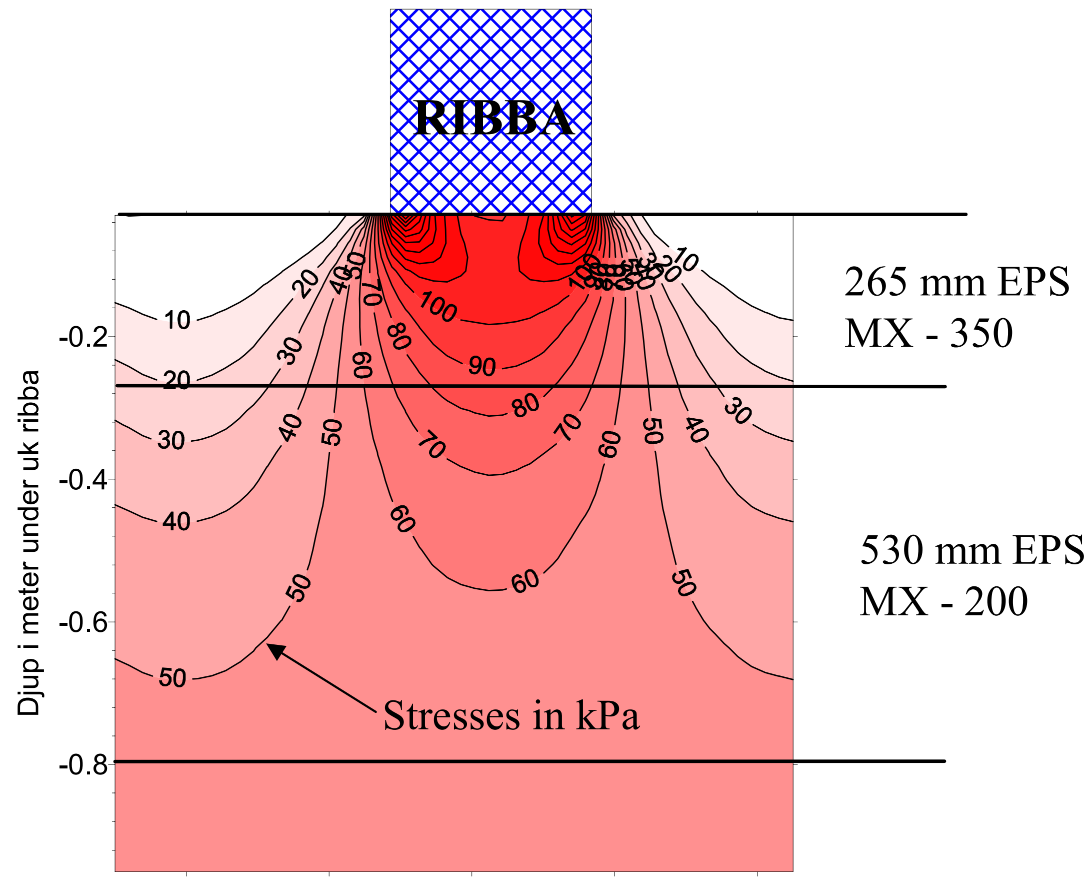


Appendix 4

Concrete pumping on the EPS blocks

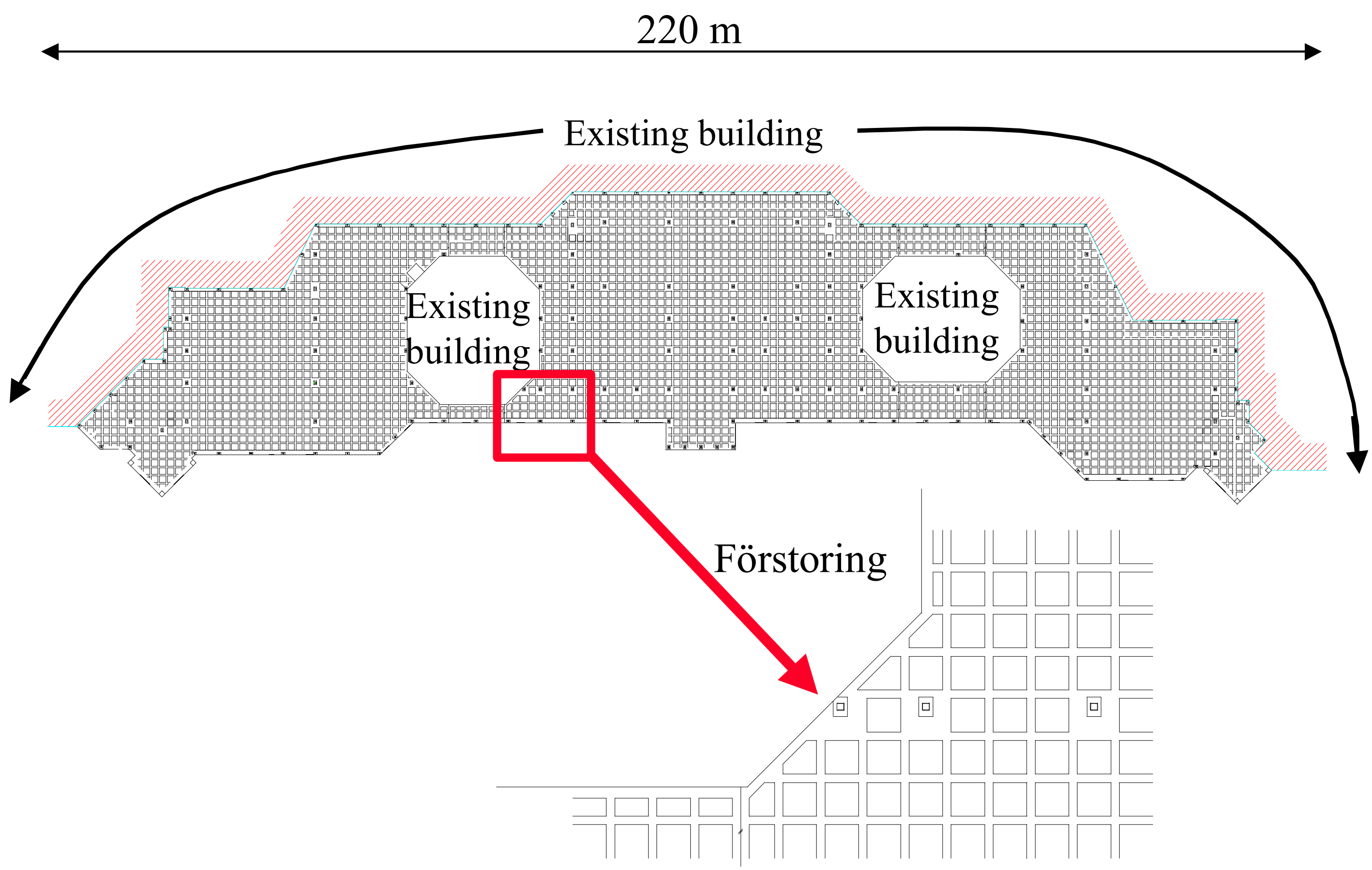
Appendix 4

Stress distribution under a cross beam (RIBBA)



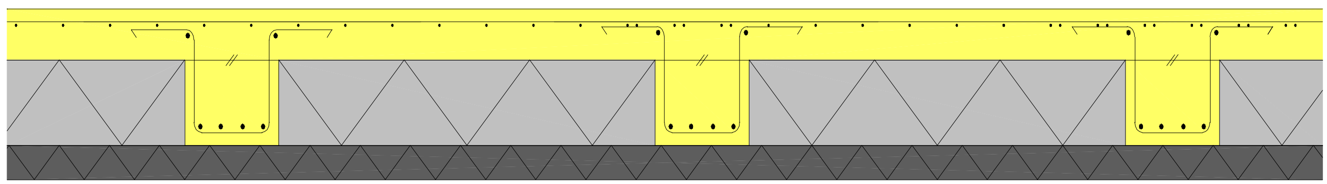
Appendix 4

7000 m2 ”markribbdäck”



Appendix 4

7000 m2 ”markribbdäck”
Principle section



- 120 mm slab
- rib beams in net 1.5 x 1.5 m
- 320 mm high ribs incl 120 mm slab

Control of level after 3 years completed building - no settlements could be measured