UB764

Survey into the influence of BITUFOR on the weight-bearing capacity of carriageways

Calculating the weight-bearing capacity of a runway surface with an upper surface reinforcement with the use of a strengthening model

- Erfurt airport : take-off and landing runways -

Report

by

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1. Terms of reference

The upper part of the take-off and landing runways of the Erfurt Airport are to be renovated and reinforced. The present structure is illustrated in Figure 1.

180 mm thick layer of asphalt
250 mm thick slab of concrete
unbound subsoil

Figure 1 : Present structure of the take-off and landing runway /1/

The renovation will involve

- removing the layers of asphalt
- relieving stress in the slabs of concrete
- reinforcing the top section with a layer of asphalt 450 mm thick.

The alternative proposals put forward by Bekaert of Zwevegem are shown in Figure 2.

Proposal I	Proposal II
350 mm new layer of asphalt	250 mm new layer of asphalt
7 mm BITUFOR	7 mm BITUFOR
	100 mm old layers of asphalt
250 mm thick stress-relieved concrete slabs	250 mm thick non stress-relieved concrete slabs

Figure 2 : Alternative proposals by Bekaert for the renovation using BITUFOR

The structural variants presented in Figures 1 and 2 need to be examined on the basis of calculations to assess their:

- weight-bearing capacity
- stress resistance

2. Stage of technology and science

The 7 mm thick layer labelled as BITUFOR in proposals I and II is a combined system, which consists of

- a steel wire netting with highly elastic cross-braids

and

- one or two slurry seal layers /2/.

2.1 Structure, composition and characteristics

The steel wire netting known as "Mesh-Track" is a stable mesh netting of thickly zinc-coated steel wire. The wire netting is strengthened with highly elastic three-wire cross-braids set 23.5 cms apart. The hexagonal meshes are twisted three times round each other. The mesh width measures 80 x 118 mm. Stability is imparted mainly by the cross-braids. The form of the mesh gives the wire netting flexibility, both lengthwise and breadthwise. Figure 3 shows the technical data.

Specification

Diameter:
Wire: 2.45 mm
Twisted braid: 3 x 3 mm
Zinc weight:
Wire: min. 240 g/m²
Twisted braid: min. 150 g/m²
Failure strength:
Wire: min. 1800 N
Twisted braid: min. 38000 N
Tensile strength of the mesh:
In length: 40 kN/m
In breadth: 160 kN/m
EA per mm width:
In length: 23600 N/mm
In breadth: 30100 N/mm
Elasticity module: 200 kN/mm²
Mesh size: 118 x 80 mm
Distance between braids: 235 mm

Bitufor-Mesh Track MT 1
(heavy type)

Diameter:
Wire: 2.20 mm
Twisted braid: 2 x 3 mm
Zinc weight:
Wire: min. 240 g/m²
Twisted braid: min. 150 g/m²
Failure strength:
Wire: min. 1450 N
Twisted braid: min. 25300 N
Tensile strength of the mesh:
In length: 32 kN/m
In breadth: 106 kN/m
EA per mm width:
In length: 19000 N/mm
In breadth: 22000 N/mm
Elasticity module: 200 kN/mm²
Mesh size: 118 x 80 mm
Distance between braids: 235 mm

Bitufor-Mesh Track MT 2
(light type)

Figure 3 : Technical data concerning the BITUFOR-Mesh Track steel mesh /3, 4/

The second component of the BITUFOR-System is the **slurry-seal-layer**. The purpose of this membrane is to achieve an optimal bond between the top surface of the carriageway, the steel wire netting and the new asphalt layer. The bitumen component of this layer consists of a modified Bitumen emulsion / 2 /. The layer normally consists, according to / 3 /, of:

Course grain	0 - 6 mm	50%
Fine grain	0 - 2 mm	30%
Filler		8%
Bitumen emulsion		12%
(Bitumen content 66%)		

The BITUFOR-System is illustrated in Figure 4.

New asphalt coating

BITUFOR,

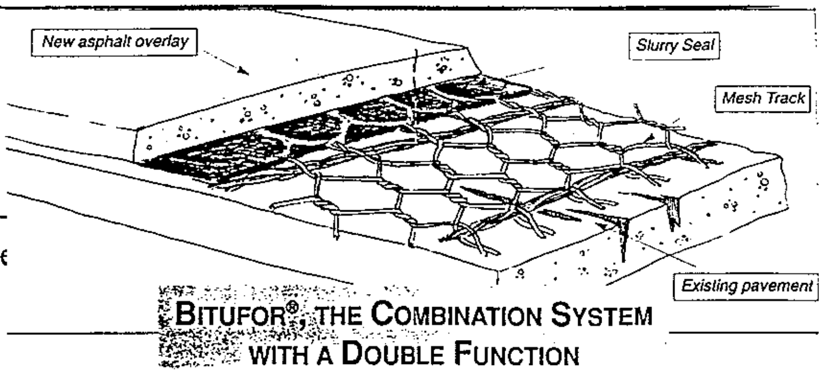


Figure 4: BITUFOR - Syst

Figure 5 shows the BITUFOR-System installed with the asphalt layer covering.

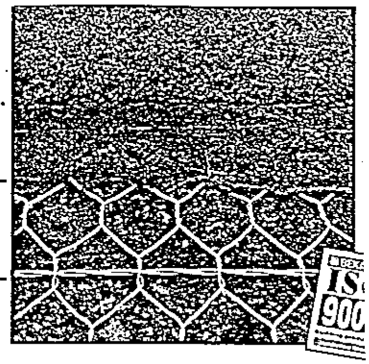


Figure 5: A built-in BITUFOR-System with an asphalt layer on top /5/

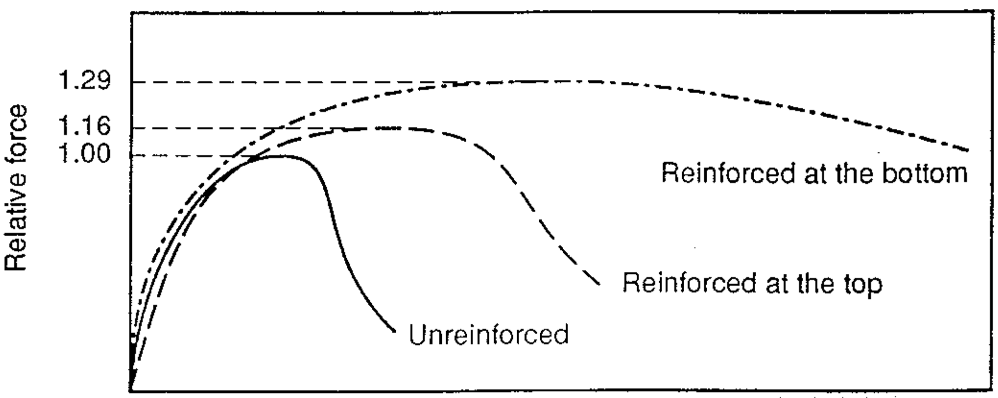
According to the commissioner of this report, the BITUFOR-System to be installed at Erfurt Airport, will be structured as follows:

- 1.5 mm Slurry-Seal-layer
- 4.0 mm Mesh Track
- 1.5 mm Slurry-Seal-layer.

With the steel Mesh Track, the BITUFOR-System creates a reinforced layer of asphalt. The steel inlay has the effect of lowering the position of the "neutral fibre" causing a shift in stress in the asphalt layer. If a crack appears, the reinforcement absorbs the stretch and the asphalt the pressure / 3 /.

In order to determine the strength of reinforced asphalt, Netherlands Consultants BV have carried out three-point deformation tests /3/, the results of which are set out in Figure 6.

Relative force Reinforced at the bottom



The reinforcement influences the failure strength of the slab. The failure stress ratio between the unreinforced slab, the slab with reinforcement at the top and the slab with reinforcement at the bottom is

1 : 1.16 : 1.29

Figure 6 : Results of three-point deformation tests /3/

On the basis of failure calculations, the results of these tests show that the entire life-spans, i.e. the fatigue phase and the cracking phase, of an unreinforced slab, of a slab of which the top part has been reinforced and of a slab of which the bottom part has been reinforced, have the following relationship to each other / 3 /:

Functions of anticracking interlayers in relation to the type of interface product

Characteristics	Nonwovens		Geogrids			Steel reinforcing nettings
Constituent material	Polypropylene	Polyester	Polypropylene	Polyester	Glass fibres	Steel
Heat resistance	- (1)	+	- (1)	+	+	+
Elongation at break	++ (2)	++ (2)	-/+	-/+	-	+/++ (2)(3)
Tensile strength	-	-	+	+	+/++ (4)	++ (4)
Strengthening	-	-	-/+ (5)	-/+ (5)	+/++ (6)	++ (6)

(1) - : to be advised against under mixes which need to be laid at over 160°C.
(2) ++ : able to resist severe deformations at cracks, acting as flexible layers.
(3) By the design of the netting, not by the intrinsic properties of the steel.
(4) Depends on the product : mesh ; dimensions of ribs, taking account of coatings (if any)
(5) -/+ : no strengthening at winter temperatures ; strengthening at summer temperatures ; depends on traffic speed at intermediate temperatures.
(6) + and ++ : reduce deformations in overlays above cracks, having a strengthening function.

Table 1 : Comparison of the advantages and disadvantages of the different materials used for interlays /6/

2.2 Applications

The BITUFOR System has been used for the renovation of asphalt coated and concrete streets / 2 / in the following ways:

- Overlaying of concrete streets with layers of asphalt;
- as a measure to prevent track grooves from forming on asphalt-coated surfaces;
- asphalt streets on marsh lands (sub-soil unable to support heavy loads);
- asphalt streets on steep inclines;
- as a measure to prevent the formation of cracks in asphalt-coated streets as a result of frost and street-widening roadworks;
- for strengthening the surfaces of inadequately supported road structures.

A comparative analysis of the efficacy of different interlayer-systems for the above-mentioned applications was made in the Netherlands in 1992 /8/. The results are summarised in Table 2.

- Japan

2.3 Installation

The BITUFOR-System is installed in 7 stages / 5 /:

- Cleaning of the road surface.
- Laying down a regulating layer to remove any uneven patches
- Unrolling the steel netting "over head" on the regulating layer.
- Nailing down the steel netting at the start of the section (first braid)
- Rolling the steel netting flat with a rubber wheel roller.
- Nailing down the steel netting at the end of the section (last braid)
- Continuous fixing of the steel netting along the length of the section with a slurry layer.

Once the BITUFOR-System has been installed, the first layer of asphalt is laid, with minimum thickness of 5 cms.

On the basis of the appraisal mentioned in paragraph 2.2 of the different projects in which the BITUFOR-System was used, the BRRC /9/ has issued the following recommendations for the renovation of concrete carriageways /2/:

- demolition of unstable, "pumping" concrete slabs followed by compression,

- the laying, if necessary, of regulating layer to eliminate cavities between the steel netting and the substructure,

- use of a rubber roller during the laying of the steel netting, and

- the laying of a layer of asphalt that should be at least 5 cm thick

2.4 Long term behaviour

As can be seen from paragraph 2.2, investigations over the long term behaviour of projects in which the BITUFOR-System has been used, have been made by the Belgian Road Research Centre (BRRC).

3. Surveys measuring weight-bearing capacity and wear and tear on surface-strengthened runways

The life of a carriageway correctly designed for the traffic it is intended to carry and constructed according to the technical rules of construction, can be subdivided, according to its elastic and plastic deformation behaviour, into different "operating phases" described in detail in /10/. The essential aspects of these operating phases are:

I. Building phase:

I.1 Installing and compacting the material (null-status for the material);

I.2 Installing and compacting the next strengthening layer(s);

I.3 Rest period until the road is open to the traffic (null-status for the whole structure).

Once operation phase I.3 has been completed, the carriageway bears the traffic. The process of deformation in the structure of the carriageway that then takes place is divided into:

II. Consolidation phase:

This is the phase in which most of the post-compression occurs, with the grain shifting and becoming finer and the stresses consolidating in the layers.

III. Inertia phase:

This phase is marked by a predominantly elastic process of deformation and largely constant rigidity during the middle of the year; the inertia phase accounts for the longest part of the life of a carriageway.

IV. Fatigue phase:

This last phase heralds the end of the life of a carriageway, of one of its layers or of the sub-structure. Signs of fatigue include the progressive formation of track grooves and/or cracks.

The process of deformation of the upper surface of a carriageway throughout the various operating phases in terms of time is shown in Figure 9.

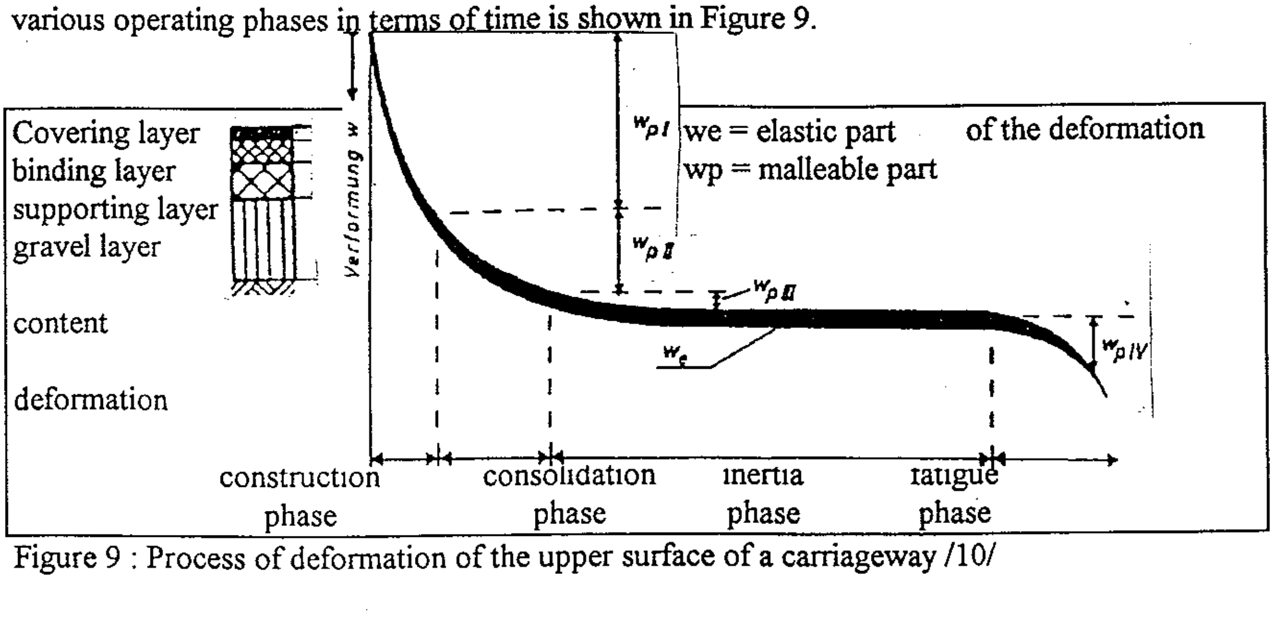


Figure 9 : Process of deformation of the upper surface of a carriageway /10/

The deformation of the carriageway or of its layers that results from the load it has to support thus involves elastic, plastic and viscous aspects. The stresses and deformations from the traffic it has to bear are mechanical factors that affect above all the weight bearing capacity, the way the structure copes with the weight-carrying demands placed on it, and consequently its life as a carriageway. The stress-deformation behaviour of the carriageway and its layers is determined by the mechanical ratios of the layers such as elasticity module E and cross-stretch ratio ν, as well as their thickness h.

3.1 Theoretical bases

As detailed in /10/, there are a number of ways in which to calculate the stresses and deformations of a carriageway resulting from static and dynamic loads. In addition to the load, these formulae require as input values

- the elasticity module E and the cross-stretch ratios ν of the layers of the carriageway,
- the thickness h of the layers
- the layer bond in the layer borders between the layers.

The full stress-deformation behaviour of a multi-layered carriageway structure with an axial-symmetrical distribution of the wheel-load can be calculated according to the multi-layer theory if these values are known. The multi-layer structuring model is shown in Figure 10.

Forces P and Q
constant contact stress

surface
radius of contact area

Layer 1
layer thickness
layer border 1

Layer 2
layer thickness
layer border N-2

Layer N-1
layer thickness
layer border N-1

Layer N
corresponds to the endlessly extended elastic isotropic half space
(sub-soil/infrastructure)

top area
polar coordinates

Cartesian
coordinates x, y, z

See dia 10

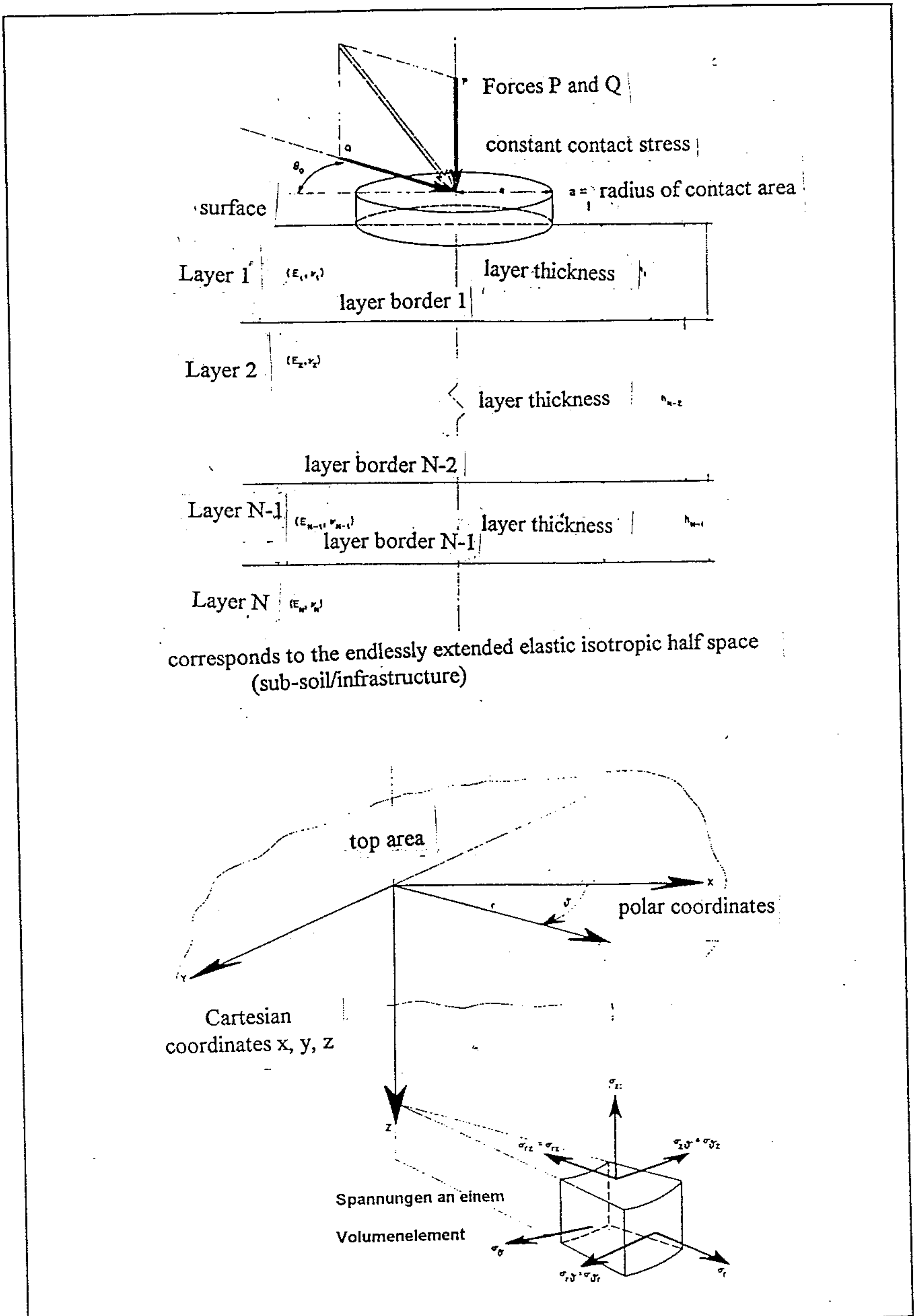


Bild 10: **Mehrschichten-Befestigungsmodell /10/**

stress exerted
on one volume unit

Figure 10 : Multi-layer structuring model /10/

The technically highly-developed BISAR-program developed by Deutsche Shell AG described in /10/ can be used to calculate elastic multi-layer systems. This program assumes a multi-layer system based on an elastic, homogeneous half-space and meeting the following requirements:

- the layers and the sub-soil are endlessly extended in a horizontal direction;
- the substance of the individual layers and of the subsoil is homogeneous, isotropic and linearly elastic; the relevant values are the elasticity modules, the layer thicknesses as well as the cross-stretch ratios;
- the loads are applied circularly and slackly, i.e. with constant surface pressure;
- the bonding between the individual layers can be input as a variable ranging from full bond (LB=100%) to total freedom from friction (LB=0%).

The survey conducted to measure the three surface structure variants mentioned in Section 1 for the take-off and landing runways :

- Variant A: execution according to the construction proposed by /1/
- Variant B: Alternative proposal I as per Figure 2
- Variant C: Alternative proposal II as per Figure 2

was carried out with a view to calculating

- **the weight-bearing capacity**
- **the stress**

by applying the layer-values listed in Table 3.

System	Layer	E-Module N/mm² 1)	Width stretch ratio 2)	layer thickness mm	layer bond (%)
Variant A	new asphalt layer	4000	0,5	450	100
	relaxed concrete	2500	0,3	250	0
	gravel layer	500	0,4	300	50
	underground	150	0,4	---	---
Variant B	new asphalt layer	4000	0,5	350	100
	Mesh Track	28000	0,3	4	100
	relaxed concrete	2500	0,3	250	0
	gravel layer	500	0,4	300	50
	underground	150	0,4	---	---
Variant C	new asphalt layer	4000	0,5	250	100
	Mesh Track	28000	0,3	4	100
	old asphalt layer	4000	0,5	100	100
	non-relaxed concrete	7500	0,3	250	0
	gravel layer	500	0,4	300	50
	underground	150	0,4	---	---

1) in accordance with the contractor's instructions 2) from documentation /10/

Table 3 : The layer-values of the systems

The system load was based on a single wheel load:

- vertical power P = 150,000 N
- radius of contact surface a = 150 mm.

The BISAR-Program was used to calculate stress, deformations, stretching and sliding in respect of the positions shown in Table 4.

Variant A	Layer	x in mm	y in mm	z in mm
	new asphalt layer	0	0	0
	new asphalt layer	0	0	450
	relaxed concrete	0	0	450
	relaxed concrete	0	0	700
Variant B	Layer	x in mm	y in mm	z in mm
	new asphalt layer	0	0	0
	new asphalt layer	0	0	350
	relaxed concrete	0	0	354
	relaxed concrete	0	0	604
Variant C	Layer	x in mm	y in mm	z in mm
	new asphalt layer	0	0	0
	new asphalt layer	0	0	250
	old asphalt layer	0	0	254
	old asphalt layer	0	0	354
	non-relaxed concrete	0	0	354
	non-relaxed concrete	0	0	604

Table 4: Positions, for which stresses, deformations, stretching and sliding were calculated.

3.2 Calculation of the weight-bearing capacity

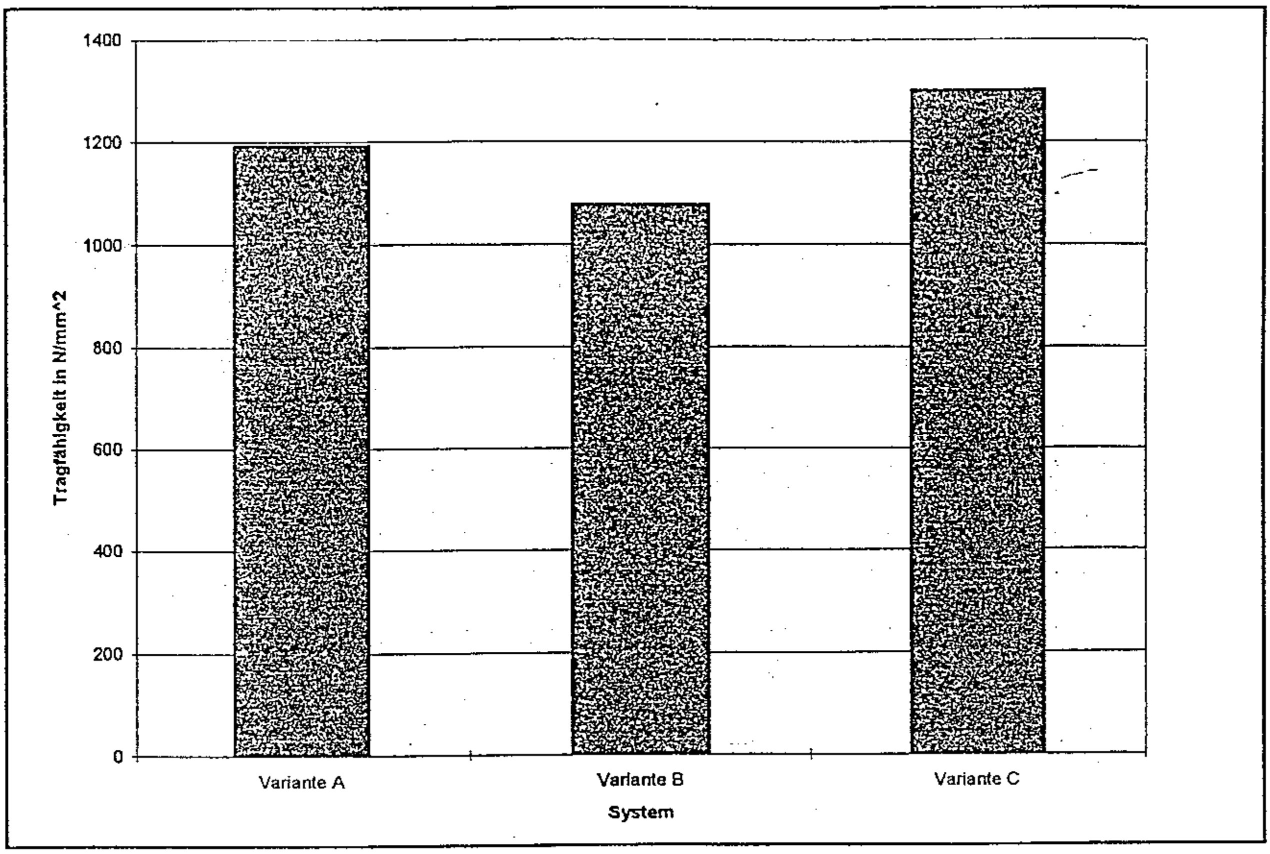
The weight-bearing capacity E_0 is determined from the vertical deformation w at the load surface mid-point calculated with coordinates x = y = z = 0 using the following formula /10/:

$$E0 = 472.5 / w \qquad \text{in N / mm}^2.$$

The calculated weight-bearing capacities are listed in Table 5 and set out graphically in Figure 11.

System	Weight-bearing capacity in N/mm²

Fig. 11


1400
1200
1000
800
600
400
200
0
Tragfähigkeit in N/mm^2
Variante A
Variante B
Variante C
System

Variant A	1193
Variant B	1079
Variant C	1302

Table 5: Weight-bearing capacities of variants A to C.

Weight-bearing capacity in N/mm²		
Variant A	Variant B System	Variant C See Fig. 11 attached

Figure 11: Weight-bearing capacities of variants A to C.

From this Figure it can be seen that the construction of variant C in accordance with proposal II set out in Figure 2 displays a greater weight-bearing capacity than the construction of variants A and B.

3.3 Calculation of the load

The amount of load to which the surfaces would be subjected was calculated according to /10/ using the modification of shape-energy hypothesis form-changing-energy hypothesis, the formula for which is set out in Table 6.

Modification of shape-energy hypothesis

Table 6 : Equation for calculating the comparative stress ♦, using the modification of shape-energy hypothesis.

The calculated comparative stresses are listed in Table 7.

System	Layer	Comparative stress in N/mm²
Variant A	Topside of the new asphalt layer	0.310
	Underside of the new asphalt layer	0.451
	Topside of the relaxed concrete	0.309
	Underside of the relaxed concrete	0.313
Variant B	Topside of the new asphalt layer	0.410
	Underside of the new asphalt layer	0.517
	Topside of the relaxed concrete	0.416
	Underside of the relaxed concrete	0.416
Variant C	Topside of the new asphalt layer	0.180
	Underside of the new asphalt layer	0.481
	Topside of the old asphalt layer	0.511
	Underside of the old asphalt layer	0.190

Topside of the non-relaxed concrete	0,520
Underside of the non-relaxed concrete	0,682

Table 7 : Calculated comparative stresses of variants A to C.

The comparative stresses, which appear at the topside and underside of the new asphalt layer are set out in Figure 12.

Comparative stress in N/mm²	
Topside of the new asphalt layer	Underside of the new asphalt layer
	See Fig. 12 attached

Figure 12: Comparative stresses, which appear at the topside and underside of the new asphalt layer of variants A to C.

From this Figure it can be seen that

- the comparative stresses appearing at the topside of the asphalt layer of variant C are less than the comparative stresses appearing at the topsides of variants A and B, and so indicate less load;
- the comparative stresses appearing at the underside of the asphalt layer of variant C are greater than the comparative stresses appearing at the undersides of variants A and B.

To illustrate the different degrees of load to which the three systems would be subjected, the comparative stresses calculated for systems B and C were set against the comparative stress calculated for system A and presented in Figure 13 as "percentage load".

"Percentage load"	
Topside of the new asphalt layer	Underside of the new asphalt layer
	See Fig. 13 attached

Figure 13: "Percentage load"

From this Figure it can be seen that the wear and tear on the topside of the asphalt layer of variant C totals approx. 60% of the corresponding wear and tear borne by variant A.

In the light of what has been said in paragraph 2.2, the BITUFOR-System should prevent the formation of cracks in the asphalt layers. Cracks occur through tensile stress. Figure 14 shows the normal stresses that occur on the topside and underside of the asphalt layer.

Fig. 12

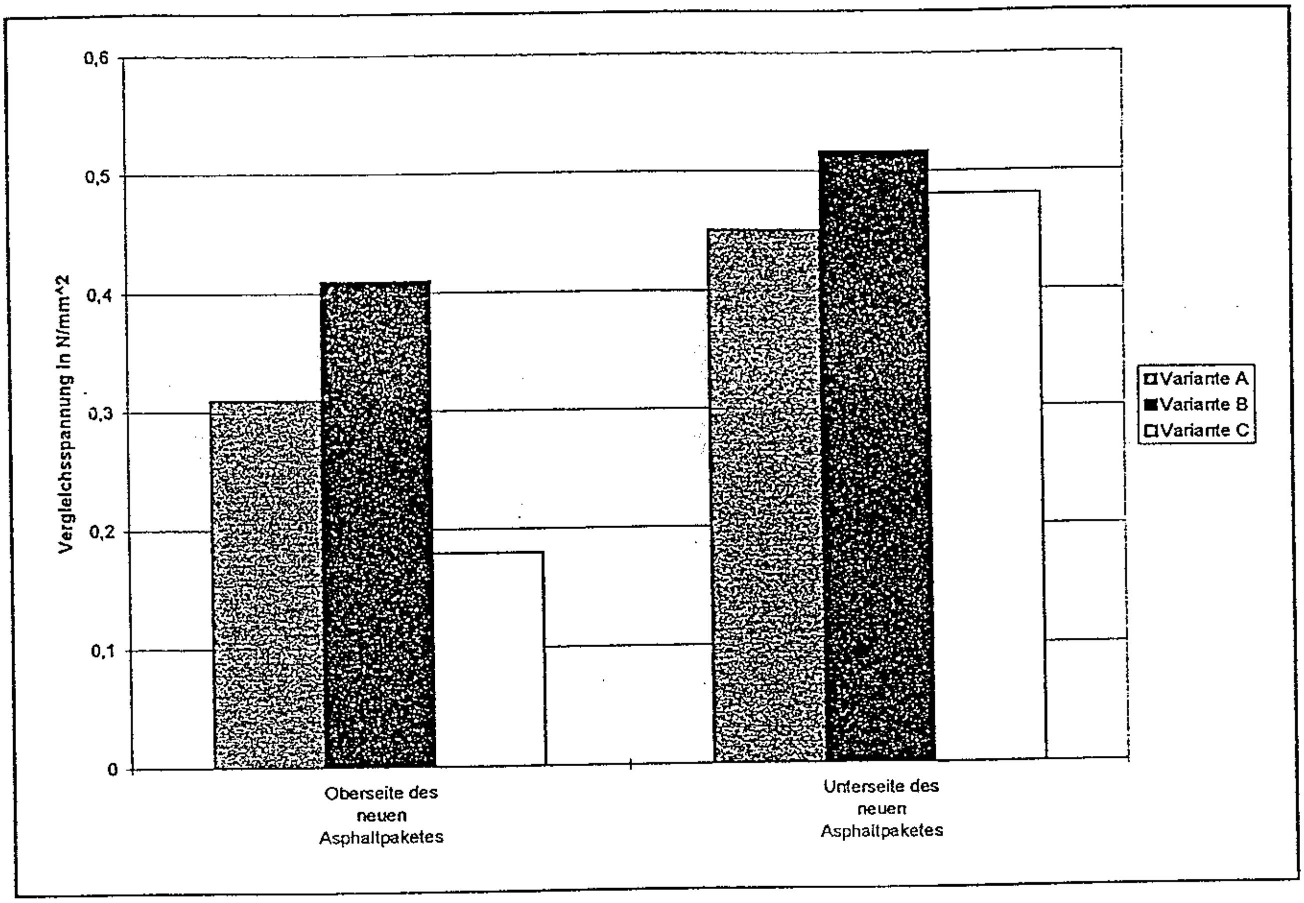
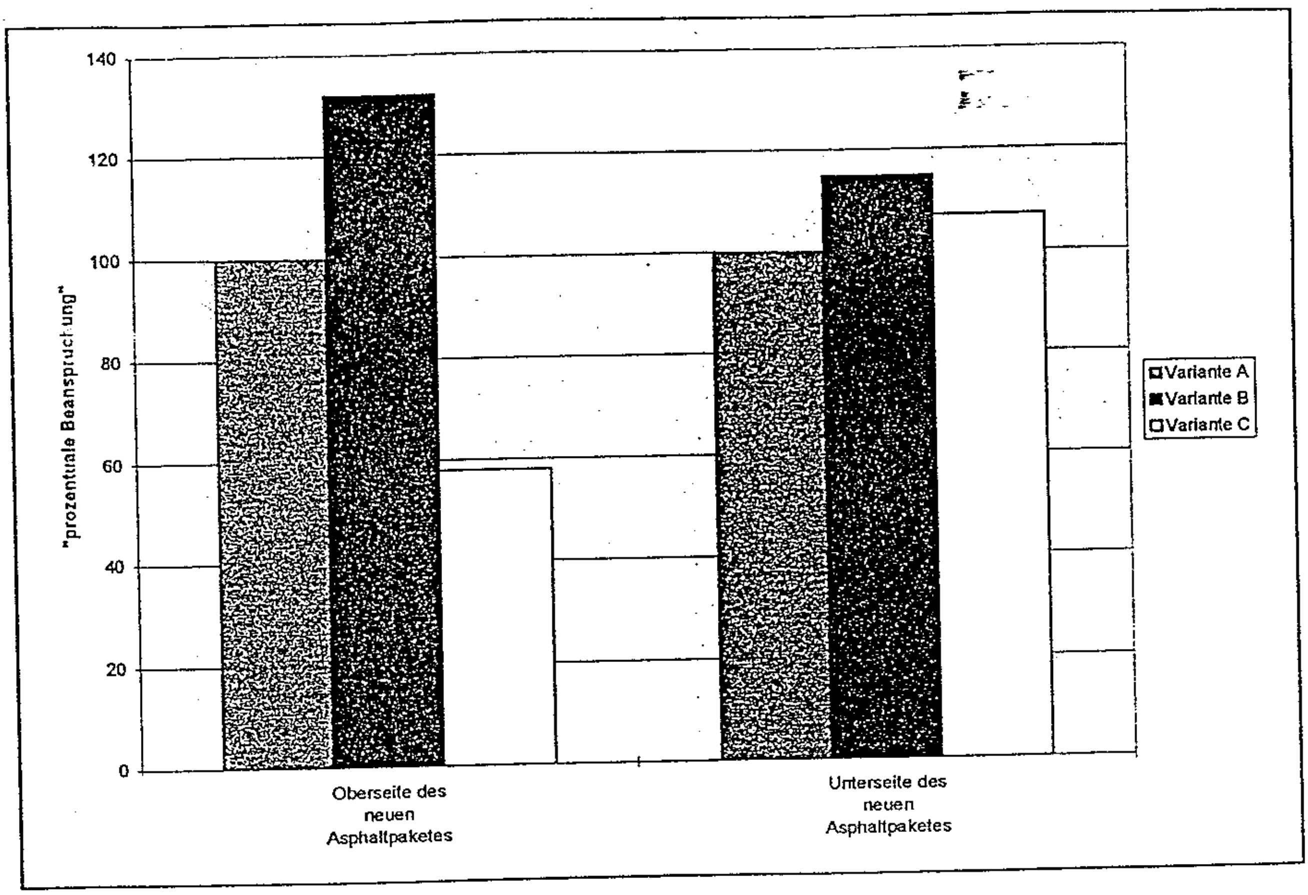

Vergleichsspannung in N/mm^2
0,6
0,5
0,4
0,3
0,2
0,1
0
Oberseite des neuen Asphaltpaketes
Unterseite des neuen Asphaltpaketes
Variante A
Variante B
Variante C

Fig. 13


140
120
100
80
60
40
20
0
"prozentuale Beanspruchung"
Oberseite des neuen Asphaltpaketes
Unterseite des neuen Asphaltpaketes
Variante A
Variante B
Variante C

System	Layer	Normal tensility in N/mm²
Variant A	Topside of the new asphalt layer	
	Underside of the new asphalt layer	
Variant B	Topside of the new asphalt layer	
	Underside of the new asphalt layer	
Variant C	Topside of the new asphalt layer	
	Underside of the new asphalt layer	
	- Compressive strain + Tensile stress	

Direct stress in N/mm²

Tensile stress

Topside of the new asphalt layer

Underside of the new asphalt layer

Pressure

See Fig. 14 attached

Figure 14: Normal stresses occurring on the topside and underside of the asphalt layer

From this Figure it can be seen that variant C, unlike variants A and B, shows no tensile stress, which indicates that variant C offers greater resistance to the formation of cracks than do the two other variants.

4. Conclusions

The investigations carried out to measure the influence of a BITUFOR interlayer on the weight-bearing capacity and load resistance of carriageways have shown that the presence of the interlayer increases resistance to the formation of cracks. These results should however be supplemented by tests in the laboratory to measure weight-bearing capacity and strength, such as break-point stretch tests.

Darmstadt, 20th May 1997

On behalf of	o/a
Dr. G. Suss	Dr. B. Grätz
Academy Director	Staff Scientist

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/4/ Data sheets Bitufor MT1 and Bitufor MT2, N.V. Bekaert S.A., Zwevegem;

/5/ Bitufor - The Combined System For Street Conservation, N.V. Bekaert S.A., Zwevegem, 1996;

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/8/ CROW (1993) Asphalt Reinforcement: " Zin of Onzin"? Publication 69;

/9/ Appraisal of Bitufor Projects, Belgian Road Research Centre, Report EP 3553, 1995;

/10/ Durth, Grätz, Suss: Examination of Practical Methods for Measuring Weight Bearing Capacities and Estimation of Serviceable Life, Particularly of Roads in the New Länder, Research Area OF FE 04.162, Technical University Darmstadt, 1995, on behalf of the Federal Minister for Transport, Bonn.

Fig. 14

System	Schicht	Normalspannung in N/mm^2
Variante A	Oberseite des neuen Asphaltpaketes	-0,243
	Unterseite des neuen Asphaltpaketes	+0,263
Variante B	Oberseite des neuen Asphaltpaketes	-0,253
	Unterseite des neuen Asphaltpaketes	+0,205
Variante C	Oberseite des neuen Asphaltpaketes	-0,230
	Unterseite des neuen Asphaltpaketes	-0,325

- Druckspannung   + Zugspannung