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Testing, monitoring, certification, consulting, research, assessment

Asphalt, concrete, bitumen, hydraulic bonding agents, rock grain size, RC-construction materials, secondary industrial products, construction site waste, soils

RAP-Stra certifications:

	A	B	C	D	G	H	I
0	▨	▨	▨	D0	▨	▨	▨
1	A1	▨	-	▨	G1	H1	I1
2	▨	-	-	▨	G2	▨	I2
3	A3	B3	-	D3	G3	H3	I3
4	A4	B4	-	D4	G4	H4	I4

Concrete testing authority (VMPA-B-2001)

Testing, monitoring and certification authority for concrete according to BayBO (ID BAY 14)

Monitoring and certification authority for rock grain size and asphalt according to BauPG (ID 1280)

Member of the Federal Association of Independent Institutes for Technical Construction Tests

Test Report No. 7037-B1-A

Determination of product properties of URETEK expansion resin samples

Cyclic compression tests

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1. Problem and commission

On 31.01.2007 Institut Dr.-Ing. Gauer received samples of expansion resin from URETEK Deutschland GmbH, Northern Office. These were slab-like elements of expansion resin which had been manufactured in URETEK's laboratory with various defined bulk densities.

The expansion resin samples were to be subjected to investigations to determine the existing material characteristics. The aim was to estimate the creep characteristics under the effects of repeated dynamic stress.

2. Description of the samples and the investigations

URETEK sent six samples. Three of these were cylindrical samples with a diameter of 48 mm and three samples had a diameter of 97 mm; in each case with three different densities. All samples were 19 to 20 mm thick. It appeared that the samples had been produced from larger blocks by milling and turning.

Table 1 shows a list of the samples.

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Table 1: Samples of URETEK expansion resin

Sample no.		**01**	**02**	**03**	**04**	**05**	**06**
Diameter	mm	48	48	48	97	97	97
Stated bulk density	kg/m^3	100	200	300	100	200	300

The following investigations were performed on the samples:

- Determination of the force-deformation line (pressure tests)
- Investigation of the force-deformation behaviour (creep curve) with the cyclic compression test in air
- Investigation of the force-deformation behaviour (creep curve) with the cyclic compression test in water

3. Results of pressure tests

The results of the tests are shown in the following tables and diagrams.

The force-deformation behaviour was determined on three different samples with different densities with one-off loading. The results are shown in Figures 1, 2 and 3.

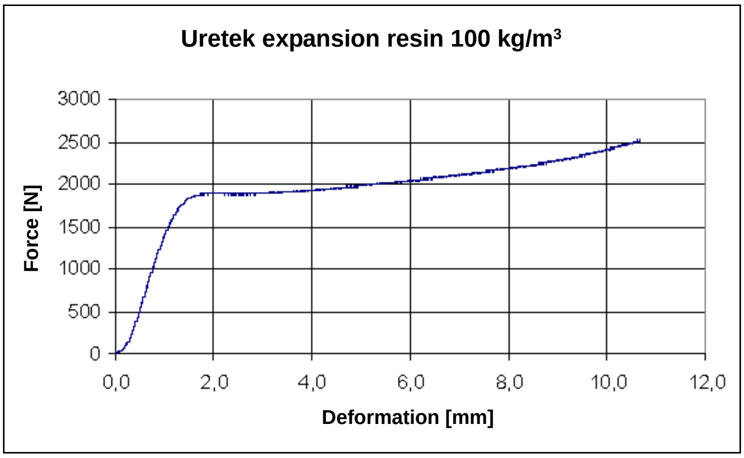


Fig. 1: Stress test on the sample where the density is given as 100 kg/m^3; a short consolidation phase was followed by an approximate linear-elastic range which changes between 1600 and 1800 N in the flow range

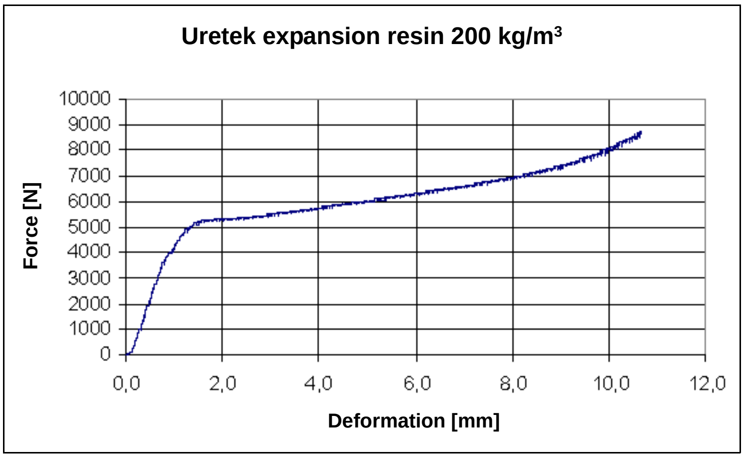


Fig. 2: *Stress test on the sample where the density is given as 200 kg/m^3; a short consolidation phase was followed by an approximate linear-elastic range which changes between 5,000 and 5,500 N in the flow range*

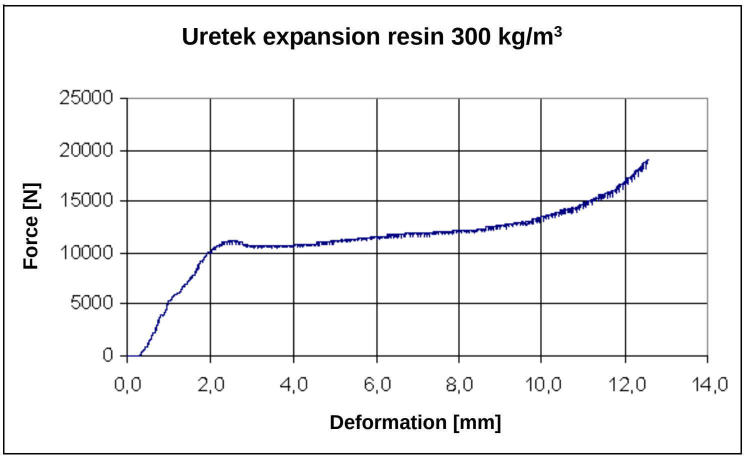


Fig. 3: *Stress test on the sample where the density is given as 300 kg/m^3; a short consolidation phase was followed by an approximate linear-elastic range which changes between 10,000 and 11,000 N in the flow range*

The force-deformation lines show that the acceptable stress is dependent on the density in the linear elastic range. A stress level within the linear-elastic range should be chosen for the cyclic compression test.

The force-deformation lines allow us to estimate the maximum acceptable stress and the expansion (deformation) that is achieved. The maximum acceptable stress is defined as the stress that deviates from the (approximate) linear course in the force-deformation line. The moduli of elasticity can be derived from the gradient of the linear stress-expansion line.

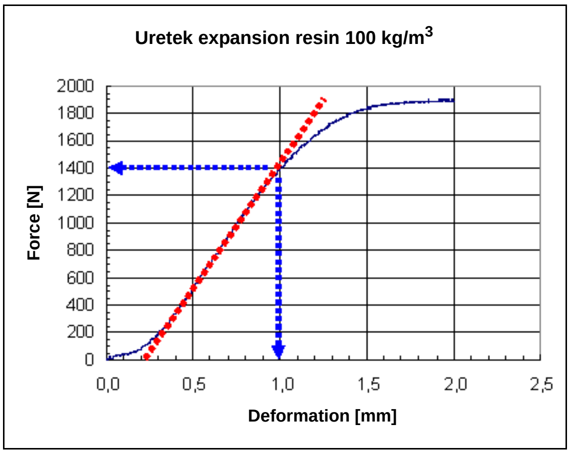


Fig. 4: *Stress test on the sample with the stated density of 100 kg/m³; end of the elastic range with a force of 1,400 N and deformation of 1 mm*

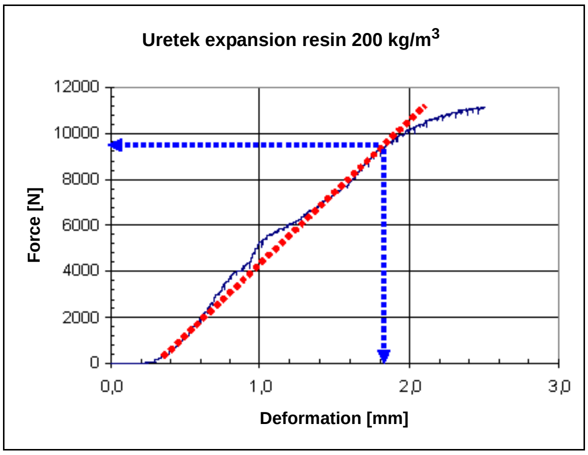


Fig. 5: *Stress test on the sample with the stated density of 200 kg/m³; end of the elastic range with a force of 3,900 N and deformation of 0.8 mm*

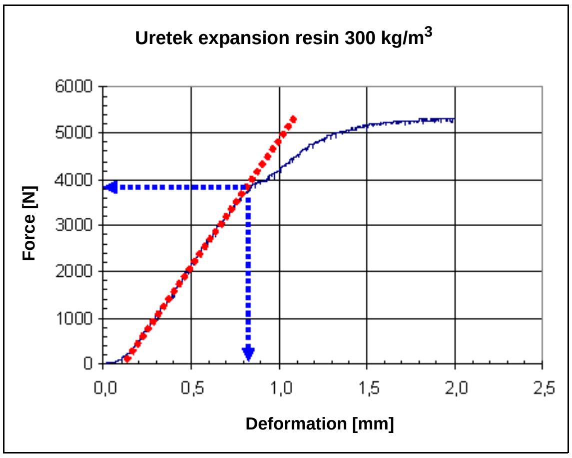


Fig. 6: *Stress test on the sample with the stated density of 300 kg/m3; end of the elastic range with a force of 9,500N and deformation of 1.8 mm*

Table 2shows the aggregated maximum acceptable stresses and expansions and the moduli of elasticity calculated from the gradients of the stress-expansion lines shown in Figures 4 to 6.

Table 2: Maximum acceptable stresses, deformations and moduli of elasticity in relation to the density of the Uretek expansion resin samples

Density	kg/m^3	100	200	300
Maximum acceptable stress	N/mm^2	0.77	2.2	5.3
at expansion	‰	50	40	90
Modulus of elasticity	N/mm^2	15.4	55.0	58.9

4. Defining the boundary conditions for the cyclic compression test

The stresses encountered in practice can be estimated from the known stresses on road surfaces. In Germany the maximum permissible axle weight is 11 metric tons. Assuming an ideal, circular tyre footprint with a diameter of 30 cm, the resulting wheel load produces a tyre contact stress of 0.78 N/mm^2. For dimensioning calculations it is usual to multiply this stress by a factor in order to take account of the increased wheel loads which are frequently encountered due to overloading and the dynamic wheel load increase resulting from unevenness (e.g. different heights between one concrete slab and the next). A common "correction value" is 1.2; this produces an arithmetical tyre contact stress of (0.78 x 1.4 =) 0.94 N/mm^2.

The existing calculation models, such as the approximation procedure according to Eisenmann to calculate bending tensile stresses in a three-layer system, do not allow consideration of a "soft", few millimetre thick expansion resin between a concrete slab and a hydraulically bonded road base. Therefore, the following engineering considerations are employed to describe the effects of elastic intermediate layers.

Like foamed insulation material in buildings, the load-bearing capacity of these layers depends on the load distribution. Isolated load concentrations exceed the stability limit and cause destruction, while load distribution over a large surface leads to a high load-bearing capacity. This can be attributed to a reduction in stress due to the increase in the supporting surface and to the prevention of lateral strain resulting from the use of the "soft" intermediate layer.

Usually expansion resins are used to fill cavities below the concrete slab and to (re)create a non-positive bond between the bottom of the concrete slab and the eroded subgrade. Because erosion is usually greatest at the highly stressed edge of the slab, this is usually where the cavities are. This means that the concrete slab is not supported at the edge and that from a static aspect there is a "jib" with the corresponding high bending stress caused by the traffic load.

The non-positive filling of the cavity with expansion resin recreates the original condition of contact between the bottom of the concrete slab and the layer below the slab (hydraulically bonded road base or unbonded ballast layer)

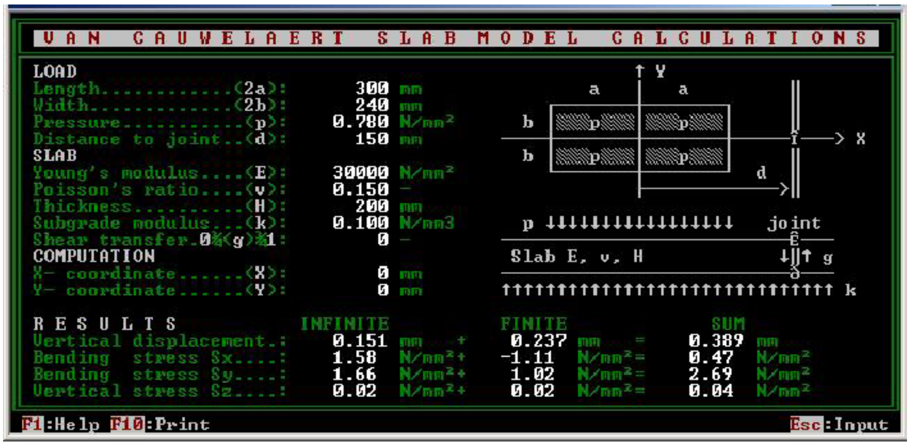
Therefore, ideally, when the expansion resin has been inserted the supporting conditions are similar to the original situation before the cavities were formed by erosion; in other words, the support conditions are much better.

To ensure that this improvement actually occurs in spite of the use of a relatively "soft" material, the load bearing capacity is measured with the FWD before and after the filling or laying of concrete slabs with expansion resin. The measurements have shown that the hollows at the edge of the slab return to normal after the expansion resin has been used.

For a wheel load of 5 tons and a concrete slab thickness of 200 mm (modulus of elasticity = 30,000 N/mm^2) the arithmetical hollow according to Eisenmann/Leykauf is around 0.4 mm.
In practice hollows of maximum 0.3 mm were measured at the edge of the slab after expansion resin had been introduced at various sections of the German motorway system, such as the A7 near Seesen. This means that the **supporting conditions with expansion resin are comparable to the original supporting conditions without expansion resin**.

Consequently, to calculate the stress and deformation a ballast modulus k can be used in the same magnitude as is assumed in concrete/hydraulically bonded road base or concrete/ballast systems. Values of k ≥ 0.1 are regarded as good load bearing conditions.

This ballast modulus was used to make calculations with the SLAB program from van Cauwelaert. The calculations were made for normal stress with a 5.5 ton wheel load and for a load increased by the safety factor 1.2. The results are shown in Figures7,8 and 3.



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VAN CAUWELAERT SLAB MODEL CALCULATIONS

LOAD
Length............(2a):       300 mm
Width.............(2b):       240 mm
Pressure...........(p):     0.780 N/mm²
Distance to joint..(d):       150 mm
SLAB
Young's modulus....(E):     30000 N/mm²
Poisson's ratio....(v):     0.150 -
Thickness..........(H):       200 mm
Subgrade modulus...(k):     0.100 N/mm3
Shear transfer.0≤(g)≤1:         0 -
COMPUTATION
X- coordinate......(X):         0 mm
Y- coordinate......(Y):         0 mm

R E S U L T S          INFINITE              FINITE             SUM
Vertical displacement.:  0.151 mm      +    0.237 mm      =    0.389 mm
Bending  stress Sx....:  1.58  N/mm²+      -1.11  N/mm²=       0.47  N/mm²
Bending  stress Sy....:  1.66  N/mm²+       1.02  N/mm²=       2.69  N/mm²
Vertical stress Sz....:  0.02  N/mm²+       0.02  N/mm²=       0.04  N/mm²

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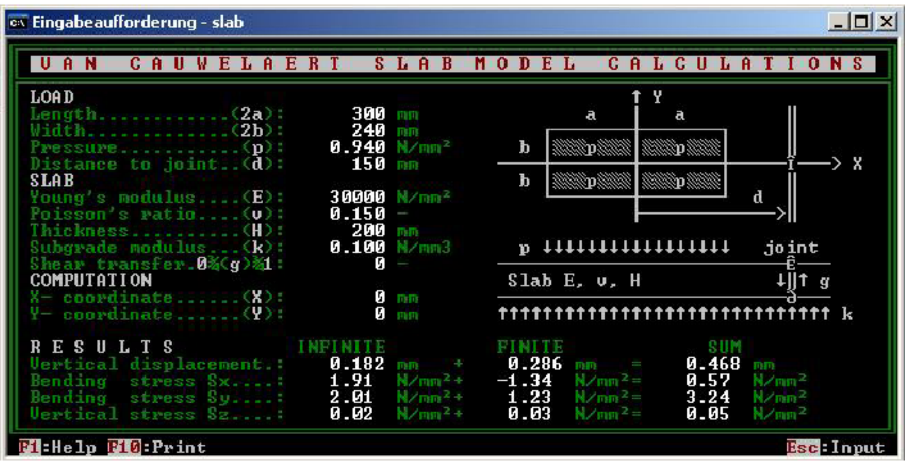
Fig. 7: Stresses and deformation when a load is applied to a 20 cm thick concrete slab on expansion resin with a ballast modulus of k = 0.1 and a wheel load of 5.5 tons



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V A N   C A U W E L A E R T   S L A B  M O D E L   C A L C U L A T I O N S

LOAD
Length.............(2a):       300 mm
Width..............(2b):       240 mm
Pressure............(p):     0.940 N/mm²
Distance to joint..(d):        150 mm
SLAB
Young's modulus....(E):      30000 N/mm²
Poisson's ratio....(υ):      0.150 -
Thickness..........(H):        200 mm
Subgrade modulus...(k):      0.100 N/mm3
Shear transfer.0%(g)%1:          0 -
COMPUTATION
X- coordinate......(X):          0 mm
Y- coordinate......(Y):          0 mm

R E S U L T S            INFINITE           FINITE             SUM
Vertical displacement.:   0.182 mm     +    0.286 mm     =     0.468 mm
Bending  stress Sx....:   1.91  N/mm²+     -1.34  N/mm²=       0.57  N/mm²
Bending  stress Sy....:   2.01  N/mm²+      1.23  N/mm²=       3.24  N/mm²
Vertical stress Sz....:   0.02  N/mm²+      0.03  N/mm²=       0.05  N/mm²
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Fig. 8: Stresses and deformation when a load is applied to a 20 cm thick concrete slab on expansion resin with a ballast modulus of k = 0.1 and a wheel load of (5.5 x 1.2 =) 6.6 tons

Basically, it can be said that the stresses on a concrete slab increase the greater the wheel load is. This is expressed by the bending tensile load (Sy) and the vertical displacement at the edge of the slab.

The calculated displacements are 0.39 mm with a 5.5 ton wheel and 0.47 mm for a wheel load which has been increased by dynamic influences. Values of this magnitude are also determined at the edge of the slab with the Falling Weight Deflectometer.

For experiments which aim to test the behaviour of expansion resin under repeated loads in quick motion in the laboratory a load which can be expected to produce a result within a reasonable period should be chosen. From these considerations we can say that hollows of around 0.4 to 0.5 mm can be expected at the edge of the slab. According to the pressure experiments in Figures 4, 5 and 6 this would lead to stresses in the expansion resin of 0.28 to approx. 1.0 N/mm^2.

Therefore, three maximum stresses were chosen for the cyclic compression tests: 0.5, 0.7 and 0.9 N/mm^2. For the expansion resin with a density of 100 kg/m^3 the two maximum stresses are already in the limiting range of the elastic behaviour (cf. Figure 4). In the variant with a density of 200 kg/m^3 the stress is around the middle of the linear-elastic range: In the variant with a density of 300 kg/m^3 the stress is around the lower third of the elastic range:

To simulate a repeated rollover of heavy, multiple axle vehicles the creep curves were determined in cyclic compression experiments on expansion resins with different densities. For the stress impulse loading according to DIN EN 12697, Part 25 "Cyclic compression test – determination of deformation in hot-mix asphalts when heat is applied" was used. As shown in Figure 11 a sinus load impulse lasting 0.2 seconds was followed by a 1.2 second pause. The maximum stresses were 0.5, 0.7 and 0.9 N/mm^2. The minimum stress was a constant 0.1 N/mm^2. All experiments were carried out at 20 °C.

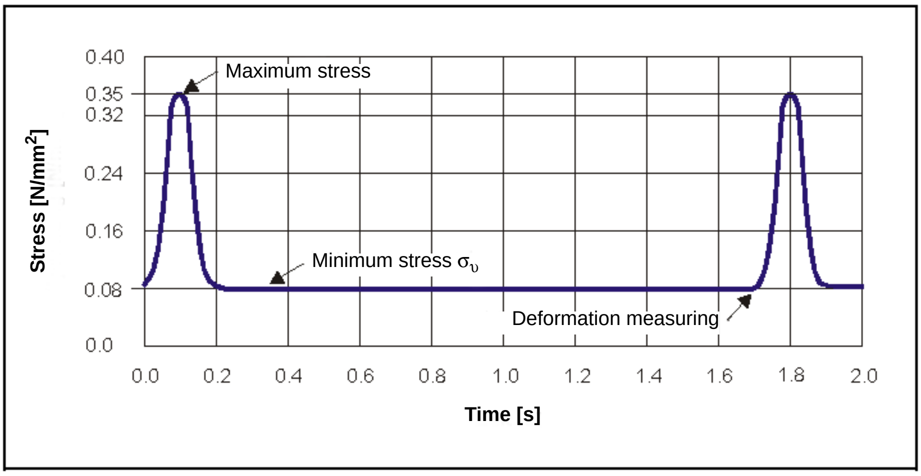

Fig. 9: Load impulse for cyclic compression test according to DIN EN 12697, Part 25, one impulse and one pause equal one cycle

The evaluation is based on the deformation in relation to the load factor, so-called pressure-creep curves. If no other termination criteria cause the experiment to be terminated, the tests are performed with 20,000 load cycles.

The following tests were performed:

Table 3: Cyclic compression tests on expansion resins

	Density	**kg/m³**	**100**	**200**
Temperature medium	Air	N/mm²	0.5	0.5
	Air	N/mm²	0.7	-
	Air	N/mm²	0.9	-
	Water	N/mm²	0.5	-
	Water	N/mm²	0.9	-

The resulting impulse creep curves are shown in Figures10,15 to 3.

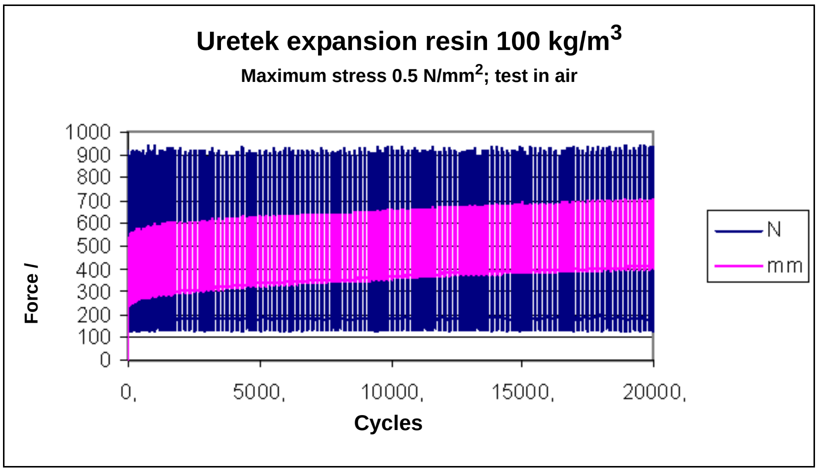

Fig. 10: Impulse creep curve of expansion resin with a density of 100 kg/m^3, Maximum stress 0.5 N/mm^2, temperature medium, air

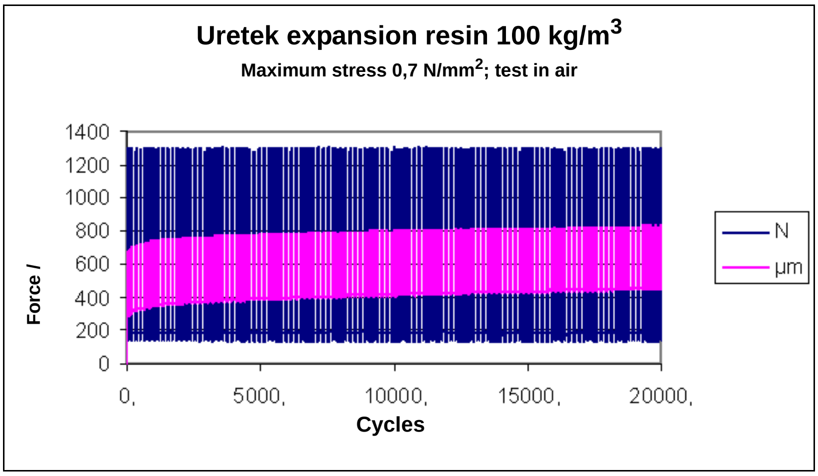

Fig. 11: Impulse creep curve of expansion resin with a density of 100 kg/m^3, Maximum stress 0.7 N/mm^2, temperature medium, air

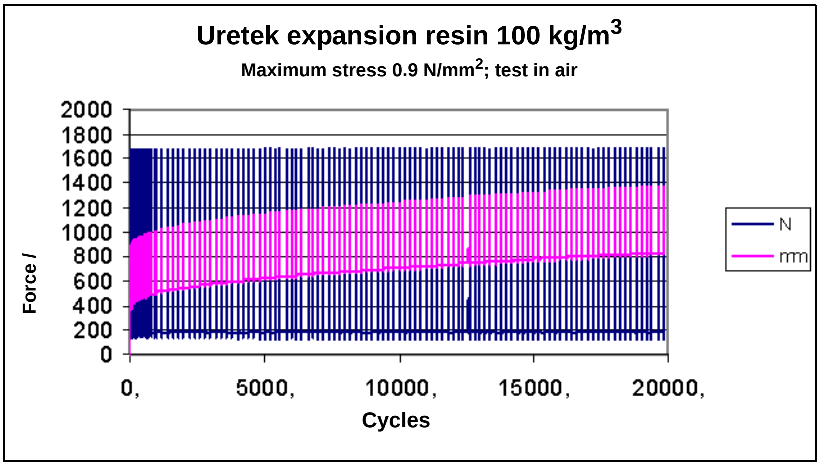

Fig. 12: Impulse creep curve of expansion resin with a density of 100 kg/m^3, Maximum stress 0.9 N/mm^2, temperature medium, air

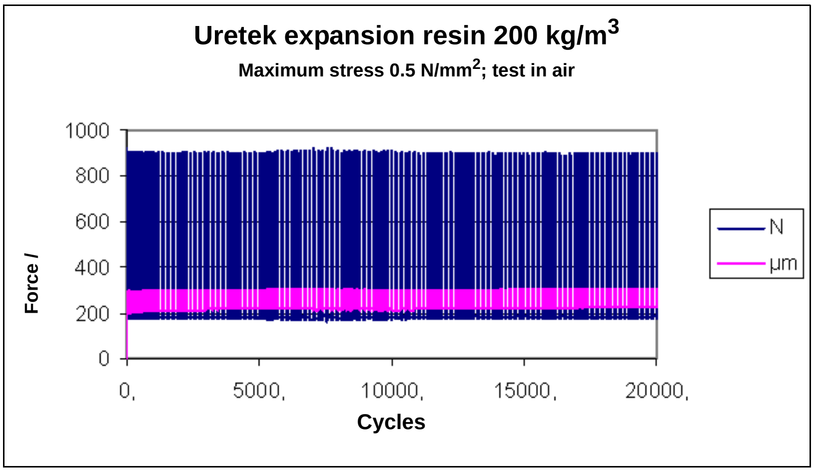

Fig. 13: Impulse creep curve of expansion resin with a density of 200 kg/m^3, Maximum stress 0.5 N/mm^2, temperature medium, air

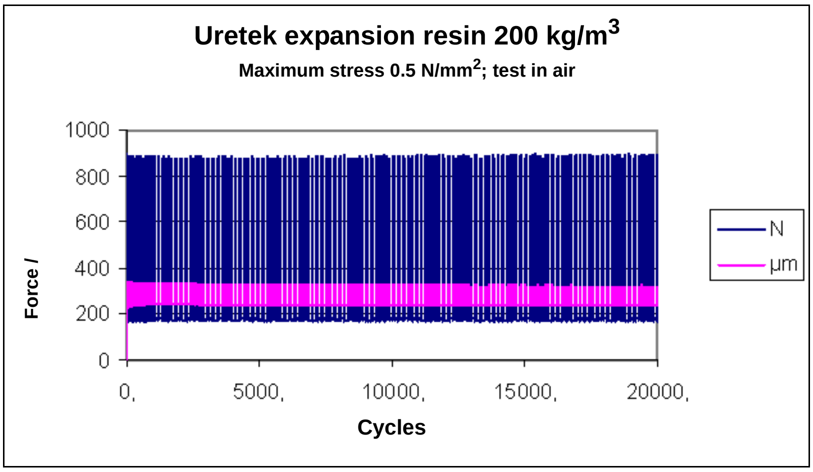

Fig. 14: Impulse creep curve of expansion resin with a density of 100 kg/m^3, Maximum stress 0.5 N/mm^2, temperature medium, water

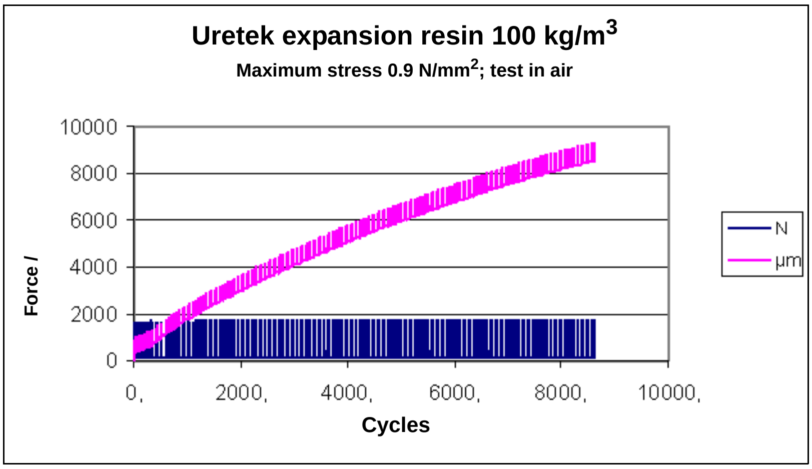

Fig. 15: Impulse creep curve of expansion resin with a density of 100 kg/m^3, Maximum stress 0.9 N/mm^2, temperature medium, water

5. Evaluation and interpretation

The resulting total deformation after 20,000 load cycles is dependent on the range of the maximum load.

For the expansion resin samples with 100 kg/m^3 at 0.5 N/mm^2 and 0.7 N/mm^2 after 20,000 load cycles the total deformation was around 0.4 mm (Figures 10 and 11), although most of the deformation (0.2 and 0.3 mm) can be attributed to the consolidation at the start of the tests. Hence, subsequent creep deformation is only around 0.2 or 0.1 mm.

Considering that

- in practice no such (initial) consolidation occurs, as the expansion resin creates a non-positive bond between the layers under pressure,
- limited lateral expansion can be assumed in practice and
- the densities of the expansion resin are usually well above 100 kg/m^3,

the results of the tests allow us to say that under normal traffic loads practically no creep deformation can be expected in expansion resin injections.

If the stress is increased to 0.9 N/mm^2 and the expansion resin has a density of 100 kg/m^3, end deformation increases to 0.7 mm (Figure 12), although around 0.4 mm can be attributed to initial consolidation. With this high stress the material with the lower density no longer exhibits a pure elastic reaction. As can be seen from the pressure tests (Figure 4), a proportion of permanent deformation is activated above 0.77 N/mm^2. In practice this means that even with repeated, very high loads creep deformation occurs only in the 1/10 mm range. However, this interpretation applies only to expansion resin injections with low densities.

With the expansion resin with a higher density (200 kg/m^3) after 20,000 load cycles the cyclic compression test causes total deformation of 0.2 mm (Figure 13), although most of the deformation was caused by the initial consolidation. The actual creep deformation is practically zero. In the laboratory test expansion resin with this density only exhibited any real, irreversible deformation at stresses above 2.2 N/mm^2.

The results of the tests allow us to deduce that in practice, even with high traffic loads, no creep deformation can be expected in expansion resin injections if the density of the expansion resin is above 200 kg/m^3.

Because of this result no tests were carried out with the even higher load-carrying expansion resin with 300 kg/m^3.

Very important for the durability of expansion resins in civil engineering are the properties of the material under dynamic loads with the effects of water. Consequently, cyclic compression tests were carried out on the expansion resin with 100 kg/m^3 under water (Figures 14 and 15).

The impulse creep curve in Figure 14 is practically the same as the creep curve for the similar material in air (Figures 10 and 13). Because of the closed-cell structure of the foamed expansion resin no water can penetrate the internal cavities. The water absorption determined in the laboratory is correspondingly low at approx 2.5% by volume.

The ratios change when the compression test is carried out with a maximum stress in the range of the compression strength of the expansion resin with the lowest density. As shown in Figure 15, this stress causes increased creep deformation, which can be attributed to the destruction of the expansion resin structure by hydraulic pressures. The water absorption after the test was around 13% by volume.

6. Summary and recommendation

Cyclic compression tests were carried out on expansion resin samples with defined densities which were produced in the laboratory. An impulse loading function derived from a standard commonly used in civil engineering was used. The maximum stresses were chosen within the scope of theoretical considerations and justified with the results of FWD measurements.
In terms of a worst case scenario tests were also carried out on expansion resins with low densities in the "overload range".

The aim of the tests was to estimate the behaviour under repeated dynamic loading. The results tend to show that the expansion resin layers beneath concrete slabs should not exhibit any creep deformation under normal traffic loads. Initial orientation tests show that dynamic loading of the expansion resin under water is also not critical.

In interpreting the results of the test it must be considered that the test conditions in the laboratory are much more stringent than under normal conditions, especially in terms of the lateral expansion which is not restricted in the compression test.

The laboratory results confirm the results of measurements with the Falling Weight Deflectometer, in which concrete slabs with expansion resin injected beneath them on the A7 motorway in Germany showed no noticeable changes in their load bearing capacity.

It should also be pointed out that the laboratory tests can only have an orientation character because of the low number of tests that were carried out.

It is recommended that further tests are carried out to back up these first results. The results of the laboratory tests should be supplemented and verified by practical tests, such as removal of material by core drilling, falling weight deflectometer and impulse radar measurements.

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