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# PLASTIC AND RUBBER WATERPROOFING IN CIVIL ENGINEERING

# MATIERES PLASTIQUES ET CAOUTCHOUCS DANS L'ETANCHEITE DES CONSTRUCTIONS DU GENIE CIVIL

# ABDICHTUNGEN MIT KUNSTSTOFFEN UND KAUTSCHUK IM INGENIEURBAU UND WASSEBAU

INSTITUT DU GENIE CIVIL - UNIVERSITE DE LIEGE
CENTRE BELGE D'ETUDE DES MATIERES PLASTIQUES
ET DES CAOUTCHOUCS (C.E.P.)
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# DEFORMATION INTERACTION OF SOFT ROOFING MATERIALS WITH THEIR BASE

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## SUMMARY

The present-day application of soft roofing materials, modern thermally insulating materials and precast concrete structures results in the development of failures of the roofing materials due to mechanical stresses caused primarily by the volume changes of the individual components of the system.

A stress analysis of the system and its individual components for the different arrangement of the composite as a result of volume changes. Examples of failures. Principles of the correct design of the systems.

## INTRODUCTION

To ensure waterproofing of flat roofs soft roofing materials of pliable insulation bands of a number of types and marks have been used in recent years, mostly based on bituminous materials reinforced with various fabrics. We shall leave aside the problems of suitability of the individual types of roofing materials and their composition with reference to waterproofing, atmospheric resistance, life expectancy and workability and shall deal exclusively with the problems of their stress/strain relations.

Soft roofing materials, however, are but a single component of the roof skin consisting of [illegible] number of components whose joint purpose is to achieve the desired effect, viz. the thermal insulation and waterproofing of the load-bearing roof structure and the space below it which would be of sufficiently permanent character. This requirement necessitates an assessment to be made of every single element, every single layer, also with reference to their mechanics, with reference to their deformation in combination with other components, to deal with their mutual interaction, to analyze the state of stress and strain of the whole system and to consider the whole roof skin as a part of the structure it covers. This approach is a considerable importance particularly in connection with the application of some modern materials to thermally insulating strata. In this complex, composite system only a suitable selection of all components and a suitable design of their joints, taking into account all interaction possibilities /with regard to the properties of the individual components/ during the whole period of their intended application, can ensure their satisfactory performance. Separate assessment of the individual components of the roof skin usually results in the failure of the roof skin as a whole and, consequently, in great financial losses.

## PROPERTIES OF SOFT ROOFING MATERIALS

For the manner of cooperation of the individual parts of a composite system, apart from tensile strength and bond between the individual layers, particularly the modulus of elasticity or the modulus of deformability, ductility /ultimate strain/, the form of the stress/strain diagram and the coefficient of thermal expansion of the individual components are dicisive.

The respective values shown in the specifications of some Czechoslovak-made insulation bands are tabulated in Table 1. /It is worth mentioning that the specifications do not always give all the required charakteristics/. However, in actual practice the waterproofing bands are usually applied in two, more frequently in three perpendicularly laid layers. Average properties of the system consisting, for example, of two layers reinforced with unwoven textile fabric and one layer with a glass mat /marked A/ or one layer of a material reinforces with a glass fabric, one layer with unwoven textile fabric and one layer with a glass mat /marked B/, ascertained by the author s tests, are shown in Table 2. The stress/strain diagrams of such systems are shown in Fig. 1.

Table 1

| Trade mark /producer/ | I | II | III | IV | V |
|---|---|---|---|---|---|
| Type of reinforcement | Unwoven textile fabric | dtto | Glass fibre fabric | Glas fibre mat | dtto |
| Tensile strength in longit. directions | 17,5 | 15 | 25 | 12,5 | 20 |
| Tensile strength in transverse direction | 10 | 7,5 | 10 | 9 | 8 |
| Ultimate strain in longit.dir. % | 17-50 | dtto | approx. 20 | 2-5 | not given |
| Ultimate strain in transv.dir. | 30-60 | dtto | approx. 40 | 2-5 | " |
| Coeff.of thermal exp. +5 to + 60°C | $54.10^{-5}$ | dtto | dtto | dtto | " |

- I - ARABIT S - Izol. závody Brno ; II -ANTPS - ARABIT - Stav. izolace, Praha; III - ASTPS - - SKLOBIT A - Dechtochema, Praha, JCP Štúrovo; IV - BITAGIT S, BITAGIT E - Dechtochema, Svoboda n.Ú; V - PRAPS.

Table 2

| System | A | B |
|---|---|---|
| Tensile strength | 11.01 | 12.09 |
| Deformation initial$^{x/}$ | 0.0345 | 0.0233 |
| Deformation ultimate | 0.220 | 0.284 |
| Modulus of elasticity at $\sigma$ = 6kp/cm2 | 309 | 462 |
| Modulus of deformation at 5% | 202 | 207 |
| " " " at 10% | 106 | 125 |
| " " " at 15% | 71 | 86 |

x/ at the time of origin of first cracks

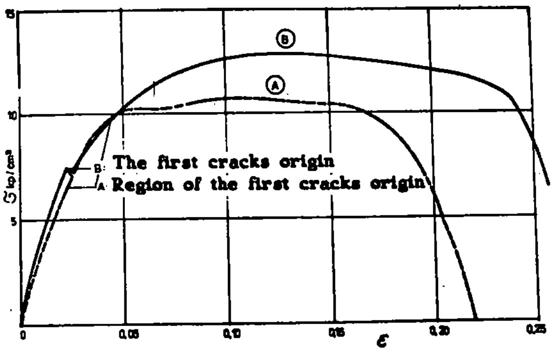

Fig. 1: Stress/strain diagram of a waterproofingroof system: A - consisting of two layers with a textile unwoven reinforcement and one layer with a glass fibre mat; B - consisting of one layer with glass fibre fabric, one layer with a textile unwoven reinforcement and one layer with a glass fibre mat.

## ROOF SKIN AS A WHOLE

The insulation bands are usually placed on top of a cement screed covering thermal insulation. The deformation and physical properties of the waterproofing materials and those of the base are considerably different. As a result of volume changes due to the changes of temperature considerable stresses originate in the system which may result even in local or overall failures of the roof skin.

Complete separation of the waterproof insulation from the base would enable entirely independent behaviour of both elements of the system and, with a great probability /regardless of the distance of expansion joints in the concrete base and its effective bond with underlying strata/ would prevent the origin of harmful stresses in any part of the system and the origin of failure. Unfortunately, however, such design is impossible for a number of other reasons /the wrinkling of insulation bands due to inclination of roof surface, disturbances due to the suction of wind, etc./ and a close connection of both parts of the system must be ensured in one way or another.

On the other hand, perfect fastening of waterproofing bands on the cement screed along its whole suraface, if the latter is divided into small panels by expansion joints and the former is well bonded to its base, would ensure effective cooperation of both parts and would limit the origin of failures to a minimum. Actually, however, such a case is not typical of practical applications.

In actual practice two cases usually occur:

a/ if thermal insulation consists in a rigid material /e.g. light-weight concrete/ firmly connected with the load-bearing structure, the deformations of the base /e.g. due to the changes of temperature/ are negligible. Of decisive importance in this case is the shear stress in the contact joint between the roofing material and the base; to prevent the failure of this contact and the separation of both layers, it is recommended to apply easily deformable transponent systems, such as perforated cardboard, permanently elastic /or pliable/ mastics, etc. When a suitable technology is adhered to and the insulation concrete and the screed have been properly cured to ensure a good bond of both parts and their good bond with the load-bearing structure, the provision of expansion joints in the base can be dispensed with.

b/ If modern thermally insulating materials are used, such as foamed polystyrene, foamed PVC, etc., placed "dry", without any bond with the structure, an entirely new design of the roof skin originates: the waterproofing layer with the cement screed, on top of which it is placed, is entirely separated from other parts of the roof skin and from the load-bearing structure, and a so-called "floating waterproofing system" originates. The design of this type enables relatively easy deformation of the waterproofing system /which will include, in this particular case, also the cement screed/ independently of the expansion of the structure and its thermally insulating layers. The cement screed /base/ can react relatively quickly to all changes of temperature; when the roofing material is well bonded with the base, both components act as a composite and adjust to the changes of temperature jointly. Above the expansion joints of the base /which are indispensable in this design/ considerable stresses in the roofing material may originate.

## STATE OF STRESS OF THE ROOF SKIN

### Rigid Base Connected with the Load-Bearing Structure

As a result of unequal coefficients of thermal expansion of the waterproofing material and its base as well as the temperature gradient and, consequently, different temperatures of both parts - provided a perfect ceonnection /bond/ of the roofing material and the base has been ensured - shearing stresses originate which are identical along the whole surface and change only at the end of one of the parts. In the proximity of every expansion joint of the cement screed, therefore, concentration of shearing stresses /the boundary effect/ occurs in accordance with Fig. 2, and every expansion joint becomes thus a potential source of failures due to the failure of bond between the two parts. Important guide in this respect is the magnitude of the shearing stress which may be attained in the contact joint between the waterproofing material and the cement screed base within the boundaries of the practically occurring temperature changes.

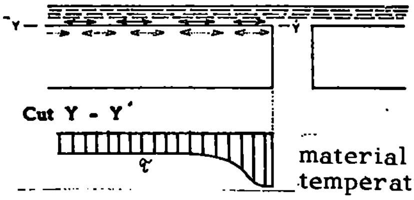

Fig. 2: History of shear stresses at the joint between cement screed and waterproof roofing material plotted against temperature changes.

The coefficient of thermal expansion of bituminous bands /with regard to the percentage of bituminous bonding agent and reinforcing material in the product/ will be determined predominantly by the bituminous material. If the coefficient of thermal expansion of asphalt is given within the limits of 65 and 67.$10^{-5}$ for the temperature range of 20-60°C, this coefficient of waterproofing bands /with regard to the volume representation of the individual phases in the product/ may be considered about 20% lower. This is in good agreement also with the data given in the specifications of these insulation bands concerning the "shrinkage due to a temperature reduction by 55°C /from 60°C to 5°C/", which should not exceed 3%. According to this $\alpha_k = 0.03/55 = 54,6.10^{-5}$. In our further considerations we can consider $\alpha_k = 54.\ 10^{-5}$. The coefficient of thermal expansion of cement concrete is $\alpha_b = 1,2\ .\ 10^{-5}$. The coefficients of thermal expansion of used materials are graphically represented in Fig. 3.

For the cooling from a temperature of 60°C to that of 15°C /sudden rain/ it is possible - -neglecting a certain thermal inertia of the system and under the favourable assumption of equal cooling of the concrete base, it is possible to consider a relative deformation at the contact of the waterproof material and the base

$$\Delta \mathcal{E} = /54 - 1,2/\ 10^{-5}\ .\ 45 = 0.0237$$

which would produce, for the/long-term/ modulus of deformation in shear of the roofing material

$$= \frac{E}{2/1+\mu/} = \frac{202}{2/1+0,5/} = 67 \text{ kp/cm2}$$

a shearing stress of

$$\sigma = 0.0237\ .\ 67 = 1,6 \text{ kp/cm2}$$

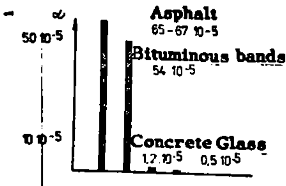

Fig.3: Comparison of coefficients of thermal expansion of used materials

An extrapolation of the short-term modulus of elasticity into the originating deformations due to an extremely quick change of temperature would yield in the joint a stress of

$$\sigma_{ext} = 0,0237\ .\ \frac{309}{2/1+0.4/} = 2.5 \text{ kp/cm2}\ .$$

The magnitude of the average shearing stress will increase /as we have already said/ in the proximity of expansion joints approximately twice /Fig. 2/. The bond strength /shearing strength/ between the roofing material and its base does not attain the above values as a rule, even if the bond has been ensured by good workmanship. Nevertheless, under current performance circumstances no failure of bond in the contact surface should occur as a result of these stresses.

The roofing material alone, which connot deform in accordance with the changes of temperature in a way corresponding to its characteristics, is stressed in tension /when cooled/ or compression /when the temperature rises/. The magnitude of these stresses may attain /over a short period/ at the most /at sudden drop of temperature by 45°C/ approximately

$$\sigma = 0.0237\ .\ 300 = 7.11 \text{ kp/cm2}$$

which is lower than the strength of the roofing material.

Another situation arises, if the concrete base is provided with expansion joints. If we assume, once again, a perfect bond of the roofing material and its base /and the connection of the base with the structure/and an expansion joint 2 cm wide, the stress of 7.11 kp/cm2 is increased by the stress due to the increase /reduction/ of the width of the expansion joint /at the upper surface of the base/ resulting from the linear change of base panel between the expansion joint due to the change of temperature. If we consider, with regard to the connection of the base with the structure, the change of temperature by only 10°C, the stress of the roofing material above the expansion joints would be

$$\sigma = 1/2\ .\ 1,2\ .10^{-5}.\ 10.100.202 = 1.2 \text{kp/cm2 per m}'$$

so that for major panels between expansion joints /over 3,5 m/ the overall stress would exceed the strength of the roofing material. Fortunately the origin of high bond stresses /or the exceeding of the bond strength/ in the proximity of expansion joints in the base /and the shear creep or failure/ increases the part of the roofing material participating in the transmission of the latter effect, markedly reducing the stresses thus originating. As a result of this action in the systems of this type a certain balancing of stresses occurs due to the partial separation of the roofing material from its base /which has no exterior effects/ and the roofing system continues to perform successfully as a whole, regardless of the dimensions of the panels between expansion joints.

Intended ensurement of the same state as the system creates spontaneously in time, results from the connection of the roofing material by means of perforated roofing cardboard /Perbitagit/ in which the individual connecting bridges of the asphalt mass are so flexible as to permit, without major stresses in the roofing material or its base, mutually different expansion movements of both parts. Apart from that perforated cardboard contributes in no small measure to the ventilation of the whole system in the very place, where it is most needed.

## Rigid Base Not Connected with the Structure /"Floating Base"/

When thermal insulation consists of slabs placed dry on top of the load-bearing structure or slope concrete, cement screed as a rigid base is not connected with the load-bearing structure and its expansion movements are enabled without any major resistance /hence "floating base"/.

## Shearing Stress

Shearing stress due to different coefficients of thermal expansion of the waterproofing material and its base as well as the temperature gradient and, consequently, the different temperatures of both parts of the system, provided a complete bond between the roofing material and its base has been ensured, is the same as in the preceding case. Under current performace conditions, therefore, this stress should not cause the failure of the contact joint, provided the bond were perfectly ensured.

## Stresses Above Expansion Joints

Let us examing the stresses /or strains/ above expansion joints /which - in contradistinction to the first system of rigid base connected with the structure - are indispensable in this system/. Provided a perfect bond between the roofing material and its base has been ensured, it is possible to consider the assumption that the roofing material, with a considerably lower modulus of elasticity, will generally follow the linear temperature deformations of its base, as justified. The deformation of every expansion panel would have to be transmitted, once again, by a part of free roofing material above the expansion joint whose length would equal the width of the joint, i.e. 2 cm for example /Fig. 4/. If we consider a change /reduction/ of temperature by 30°C, the relative deformation would attain - in dependence on the length of the expansion panel - the values in accordance with Fig.5.

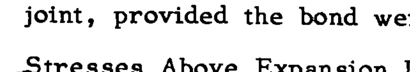

Fig. 4: Stressing the waterprof roofing material in plain tension above the expansion joint of the base due to the drop of temperature, if the insulation is fully bonded to the base and the joints of the latter are not filled.

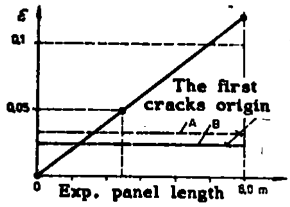

Fig.5: Changes of longitudinal deformations of waterproof insulation above the expansion joint in the base due to temperature changes /full bond, no joint filler/.

It can be observed that for a length of the panel a little in excess of 1 m the ensueing deformations exceed the critical deformations originating at the moment of origin of the first cracks in the roofing material.

## Flexural Stresses

In the case of perfect bond between the roofing material and the cement screed the latter is stressed, as a result of unhomogeneous thermal expansions, by a flow of shearing stresses along its upper contact surface. These stresses produce a concave or convex curvature of the cement screed along the length of the expansion panel /Fig. 6/. Under the justified assumption that the curvature follows a circular arch, the only unknown quantity required for the calculation of vertical deformations of either the middle of the expansion panel of cement screed or its boundaries /convex curvature during cooling/ is the effectiveness of stress /or strain/ transmission by the contact joint. Objectively this effectiveness cannot yet be determined in any way, as it is the function of not only mechanical, deformation and rheological parameters of both adjoining materials, but also that of the temperature gradient, speed of temperature change, weight as well as, to a considerable extent, the quality of workmanship and type of materials use.

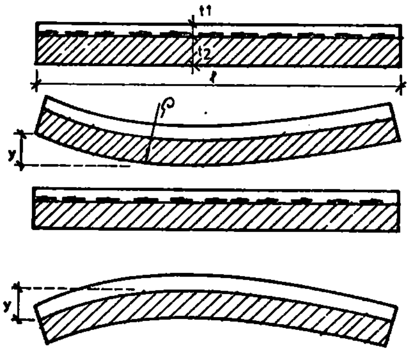

Fig. 6: Curvature of expansion panels of cement screed due to temparature changes

For the purpose of an aproximate calculation of vertical deformations due to the curvature we shall assume the thickness of insulating materials $t_1$ = 1.2 cm, the thickness of the cement screed $t_2$ = 4 cm, temperature change ΔT=45°C, modulus of deformation of cement screed E= 50 000 kp/cm2, modulus in shear G =20 000 kp/cm2 /for a Poisson´s coefficient 0.25/, /long-term/ modulus of deformation of the roofing material 67 kg/cm2, and the relative deformations at the contact of both materials reduced in the ratio of the shear moduli of elasticity of both materials. The relative shortening /or elongation/ of the upper surface of cement screed may vary, accordingly, within the limits of

$$\frac{67}{20\,000} \cdot 0{,}0237 = 0{,}0793 \cdot 10^{-3} \leqq \varepsilon \leqq \frac{110}{20\,000} \cdot 0{,}0237 =$$

$$= 0.0130 \cdot 10^{-2}$$

The vertical deformations v, shown in Fig. 7 plotted against the length of the panel between expansion joints, correspond with a smaller, but more realistic strain.

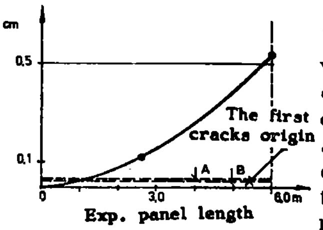

Fig. 7: Changes of vertical deformations of expansion panels of concrete base plotted against the length of the expansion panel due to the cooling of the roofing material

When the temperature increases, the panels of the cement screed deform concavely. The origin of failure of the roofing material due to this curvature is practically eliminated/Fig.8/. During cooling, on the other hand, the curvature is convex, as a result of which the ends of the panel are raised by the above mentioned value in a dish-shaped manner /Fig. 9/. The length of the panel exerts a great influence on the magnitude of vertical displacement in this case /see Fig. 7/. Such curvature occurs when, as a result of low temperature, the modulus of deformation of the roofing material is higher and the viscous creep minimum; the stresses /or strains/ originating above the expansion joint at the considered change of the panel curvature can be determined approximately under the assumption that the arch or the deformation is circular of the same central angle as that of the panels; its radius /the radius of curvature/ is proportionate with the ratio of the length of the panel [illegible] the width of the expansion joint. For the calculation the width of the arch above the joint was considered at 5 cm. By a simple procedure it is possible to determine that the stress of the roofing material above the joint due to curvature will attain, under the given circumstances, the magnitude of about 1 kp/cm2.

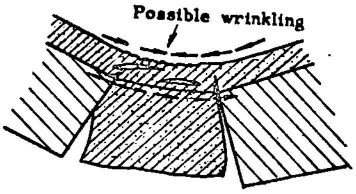

Fig.8: Possible failures of the roof skin due to the cooperation of the individual parts of the composite system of the roofing material due to temperature increase./Separation of the asphalt joint filler from the concrete, cracks on the lower face of the roofing material at the edge of the joint, shearing cracks, separation of the individual insulating layers above the joints, wrinkling of the surface/.

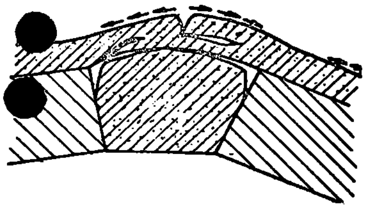

Fig.9: Possible failures of the roof skin due to the cooperation of the individual parts of the composite system of the roofing materials during its cooling /separation of asphalt filler from the concrete, cracks on the upper surface of the roofing material in the middle above the expansion joints in concrete, shear cracks, separation of the individual layers of roofing materials/.

## Filling of the Joints with Asphalt

In some cases the expansion joints in the cement screed are filled with asphalt prior to the placing of the roofing material. This circumstance, however, may considerably change the possible states of stress in the roofing system.

## Influence of the Joint Filler Volume on the Roofing Material

Asphalt which fills the expansion joints is also subjected to volume changes due to the changes of temperature. Apart from that it is alternately compressed and tensioned by the expansion movements of the cement screed /Fig.10/. For example, an increase of temperature by 30°C corresponds with a linear change of every metre of the length of the screed panel at the rate of

$$\Delta l = 30 \ . \ 1,2 \ . \ 10^{-5} \ . \ 100 = 0,036 \text{ cm/m} .$$

The volume of asphalt in the joint per 1 cm of its length is considred with the value of

$$4 \ . \ 2 \ . \ 1 = 8 \text{ cm3} .$$

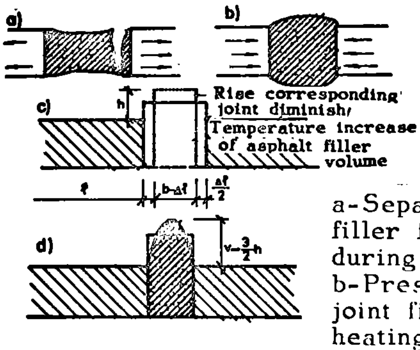

Fig.10 : Volume changes of asphalt joint filler due to the temperature change of the roofing material.
a-Separation of the joint filler from the concrete during cooling
b-Pressing out of the joint filler during heating
c- Overall change of the dimensions of the joint filler
d- Formation of an ashpalt roll above the joint.

The respective increase of temperature would change its linear dimensions so that its new overall volume would be

$$4,072 \ . \ 2,036 \ . \ 1,018 = 8,45 \text{ cm3}$$

Since the deformations of the asphalt filler may be directed mostly only upwards /against the relatively yielding roofing material/ an asphalt roll appears above the joint. Provided its circumference be circular, its maximum height /see Fig. 10/ will be

$$v = \left[ \frac{8.45}{/2 - \Delta l/ . 1,0} - 4,0 \right] . \frac{3}{2}$$

Fig. 11 shows the change of the roll height with the length of the expansion panel.

The roofing material must follow the shape of this roll. When the temperature sinks to its original value, however, the roll does not disappear entirely. When the cement screed shrinks, it is torn off the joint filler /due to embrittlement and low tensile bond/ and the roofing material is subjected to flexure over the roll /Fig. 12/.

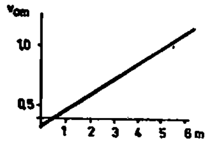

Fig. 11: Change of the height of the asphalt roll with the length of the expansion panel

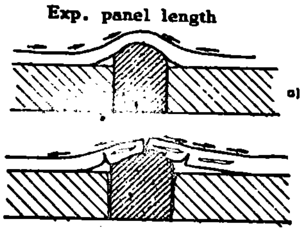

Fig. 12: Origin of failures above the asphalt joint filler of the base during the cooling of the roofing material.
a - State during heating
b-- State during cooling after preceding heating

Under the assumption of constraint of the roofing material over a span of 5 cm, loading by a single solitary load in the middle of this span, roofing material thickness of 1,2 cm and the height of the roll of only 1/3 of the value calculated above /Fig. 13/ we obtain the relative deformation of the upper surface of the roofing material above the middle of the joint and that of the lower surface in the proximity of the joint in accordance with Fig. 14, where the

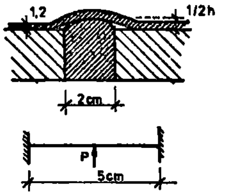

Fig.13: Calculation diagram of flexural stresses of the roofing material above the asphalt joint filler roll in the base

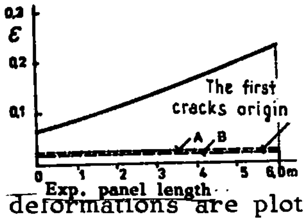

Fig. 14: Relative deformation of the upper face of the roofing material above the asphalt roll plotted against the length of the expansion panel of the base

deformations are plotted against the panel length. It can be seen that under the given assumptions the roofing material is always disturbed above the asphalt roll by cracks, regardless of the panel length. The formation of the roll alone due to the increased volume of the asphalt joint filler /regardless of the linear expansion of the base/ would cause relative deformations of the order of ultimate deformations of the materials use.

### Influence of Bonding the Roofing Material to the Joint Filler Alone

If the bond between the roofing material and the base along the whole contact surface imperfect /which is usual in actual practice/ and the joints are filled with asphalt, the bond between the roofing material and the base is most perfect in the very place of expansion joints. When the temperature drops, the roofing material between the joints is subjected to tension uniformly distributed along the height of the cross section in the whole expansion panel. When the temperature slowly decreases by 30°C, this stress /using the modulus of deformation of the order of 60 kp/cm2/ is about 1 kp/cm2; at a sudden temperature change /using the modulus of deformation of the roofing material of the order of 309 kp/cm2/ it attains the value of 5.1 kp/cm2. Most unfavourable effect of this stress will manifest itself, naturally, in the places of additional stresses, e.g. in the proximity of expansion joints.

### Stresses in the Roofing Material Unconnected with the Floating Base in the Proximity of and in the Expansion Joint

If it has been ensured that the roofing material may not be connected permanently to the expansion joint and its vicinity, e.g. by the use of a rubber underlay, the deformations due to the afore described causes would be considerably lower /even if the joints were filled with asphalt/. The width of the underlay ensuring permissible deformation of the roofing material under load depends, naturally, on the dimensions of the expansion panels of the base.

If the roofing material were not connected with the base above the expansion joints of the latter over a width of 30 cm, a temperature change of 30°C would produce the following deformations per 1 m run of the base:

- as a result of linear changes of the base with perfect bond between the roofing material and the base all over the remaining surface

$$\varepsilon = 1{,}2 \;.\; 10^{-5} \;.\; 30 \;.\; 100 \;.\; 1/30 = 1{,}2 \;.\; 10^{-3}/m$$

- as a result of curvature

$$\varepsilon = 1{,}6 \;.\; 10^{-3}/m$$

together:

$$\varepsilon = 2{,}8 \;.\; 10^{-3}/m.$$

Should the joint be filled with asphalt, these deformations would be increased by that due to the asphalt roll, viz.

$$\varepsilon = 2{,}4 \;.\; 10^{-3}/m$$

which makes a total of

$$\varepsilon = 5{,}2 \;.\; 10^{-3}/m$$

Fig. 15 shows the changes of relative deformations with the length of the expansion panels in either last case in comparison with the ultimate deformation of the roofing material at the moment of origin of cracks.

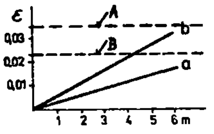

Fig. 15: Change of the relative deformation with the length of expansion panels with the covering of the expansion joint over a width of 30 cm.
a- Without asphalt joint filler
b- With asphalt joint filler

## SUMMARY AND PRINCIPLES OF CORRECT DESIGN

The considerations presented in the paper are based on relatively high temperature differences. In actual practice such great differences may really be encountered in the systems with a floating base and effective thermal insulation as a result of the low thermal capacity and, consequently, small heat accummulation and transfer.

Although the used assumptions are not always and entirely fulfilled in actual practice and the system "helps itelf" in the most varied manner /by the redistribution of stresses from more to less stressed places, by the relaxation of stresses, etc./, the above considerations testify sufficiently to the fact that the state of stress of the roofing material above the expansion joints of its base is considerable and considerably more unfavourable than in any other place of the roof skin, and that these places are always prone to failure. These failures may originate most easily in winter /mostly as a result of the changes which took place in summer/. They would originate even if the thickness of the roofing materials were inferior to the considered value of 1.2 cm and are the result of combined effects of tensile and flexural stresses.

Fig. 16 shows charakcteristic examples of failures of this type of a roofing system whose roof skin consisted of the following components:, load-bearing structure, slope concrete, vapour barrier, foam polystyrene 6.5 cm /with vents mounted on the upper face of the polystyrene layer/, wood wool and cement slabs 5 cm, type A 400 cardboard /unbonded/, cement screed 3 cm, 2 layers of Arabit, 1 layer of Bitagit, with 2 coats of type Rubol aluminium paint.

An analysis of the individual causes of the origin of failures and their location creates solid prerequisites for the determination of the principles of correct design of the roof skin comprizing soft roofing materials and for the prevention of unsuccessful application:

1. When waterproof roofing is applied to a ridig base firmly connected with the structure /light weight concrete, etc./, it is necessary to ensure, above all, perfect bond of the roofing material with its base along its whole surface. More advantageous /less sensitive to the quality of workmanship/ is the use of a transponent layer of a perforated cardboard.

II. When using new materials for thermal [illegible]ulation /placed dry in the form of slabs without any mortar bed/ and a "floating base" [illegible]r the application of the waterproof roofing materials, it is necessary to ensure primarily;

- effective ventilation of the entire system of thermal insulation along its whole thickness;

- avoid the filling of the expansion joints of the base with asphalt or any other material;

- always connect the waterproof roofing material to the base by means of a transponent layer consisting in either perforated cardboard /with flexible bridges of connecting asphalt/ or a permanently elastic or pliable mastic with sufficient adhesion to both the insulating bands and to the concrete of the base;

- covering of the expansion joints with an underlay ensuring permanent separation of the waterproof roofing material from the base over a width dependent on the dimensions of the expansion panels of the base;

using the waterproof roofing materials with the highest possible ultimate strain /ductility/ for the upper layer of the waterproof system.

It need not be accentuated that the application of the waterproof skin should be effected as soon as the completed base has been finished and that the placing of the individual layers should follow immediately one another to minimize the possibility of inclusion of moisture into the roofing system /which is another frequent source of failure/. Also immediate provision of the surface of the roof skin with a reflexive paint coat effectively reduces the stresses in the whole roofing system and should become an integral part of the whole technology.

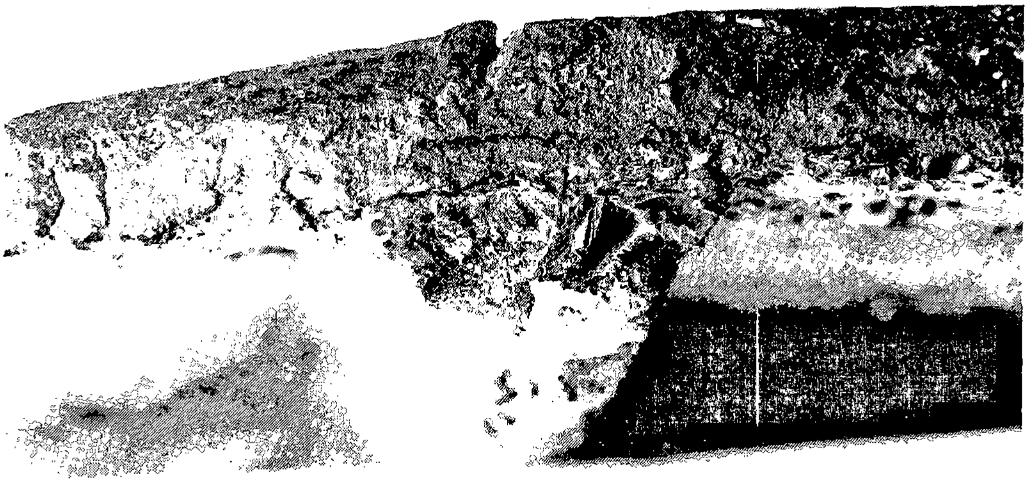

Fig. 16 a

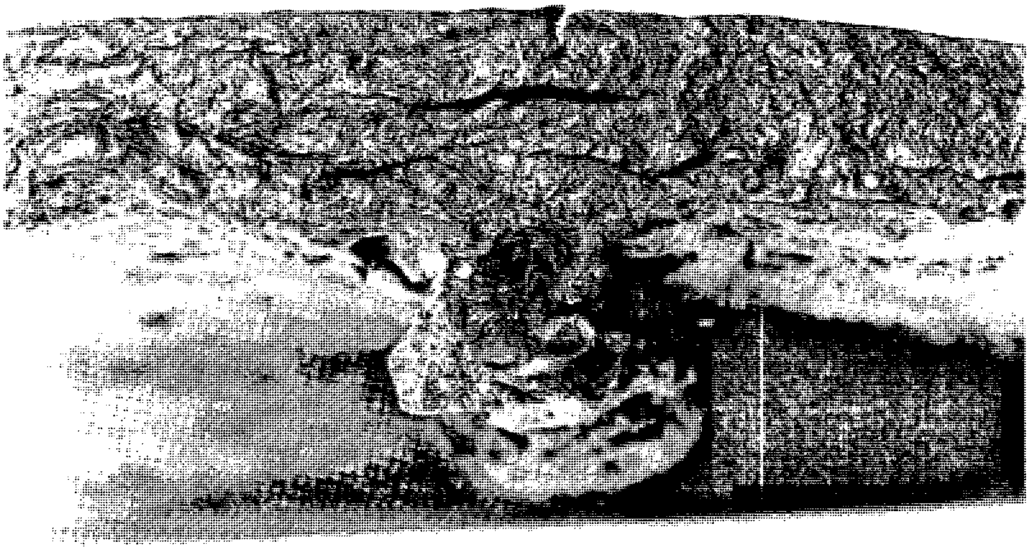

Fig. 16 b

Fig. 16 : Characteristic examples of failures of soft roofing materials above na expansion joint filled with asphalt.