Temperature impact on sealed mutual overlap strength of bitumen sheets on roof structures.

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Resumo
Este artigo lida com a dependência entre o comprimento da superposição mútua de painéis adjacentes em concreto, na direção longitudinal e a carga de ruptura devido a várias temperaturas. Em razão da grande quantidade de junções e sobreposições de painéis presentes na camada impermeável, é necessário estudar seu comportamento. Vários tipos de superposições ocorrem – em sistemas impermeáveis de camada simples e camada dupla, superposição entre painéis adjacentes e junções de painéis para construções espalhadas ou construções em metal. Esse artigo lida apenas com superposições tencionadas por forças lineares – isso significa estresse de cisalhamento.
Palavras-chave: *Painéis de concreto. Superposição. Resistência.*

Abstract
This article deals with dependency between mutual overlap length of adjacent bitumen sheets in longitudinal direction and tear load due to various temperatures. While there is a large amount of various joints and overlaps of bitumen sheets present on water-proofing layer it is necessary to study their behavior. Various types of overlaps occur – overlaps in single layer or double layer water-proofing systems, overlaps between adjacent bitumen sheets and joints of bitumen sheets to pervading constructions and tinsmith constructions. This article deals only with overlaps strained by linear forces – this means shear stress.
Keywords : *Bitumen sheets. Overlaps. Strength.*

1 Introdução

This article deals with dependency between mutual overlap length of adjacent bitumen sheets in longitudinal direction and tear load due to various temperatures.

Overlaps in longitudinal direction are examined because of extreme loads caused by occurring force effects on roof structure. Technology of manufacturing these overlaps has also influence on final strength. This article deals only with overlaps strained by linear forces – this means shear stress. In some cases tangential stress occurs in these joints – which is called “peeling”. This type of stress occurs with mechanical anchoring of water-proofing layer (bitumen sheet) which is realized directly on overlaps of adjacent sheets. Crucial importance for deciding which type of stress is present depends on the magnitude of **β-**angle which is formed by bitumen sheets in overlap. Stress is tangential (peeling) when the angle is big enough (see Fig. 1), stress is linear (shear) when the angle is small (see Fig. 2) (FAJKOS, NOVOTNY, 2003).

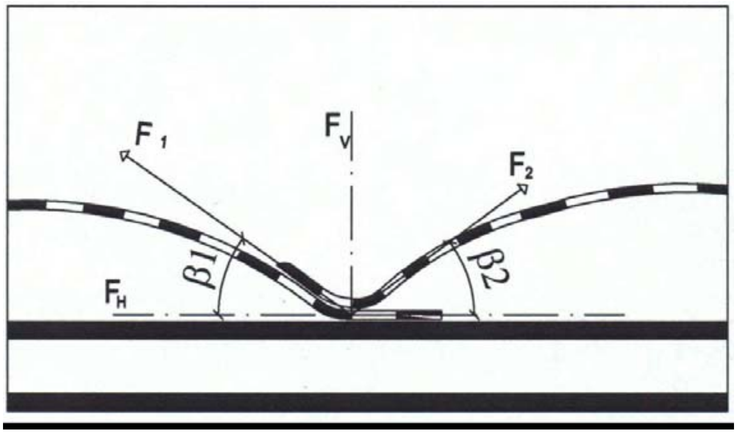

Fig. 1: Tangential forces occurring in overlaps of bitumen sheets

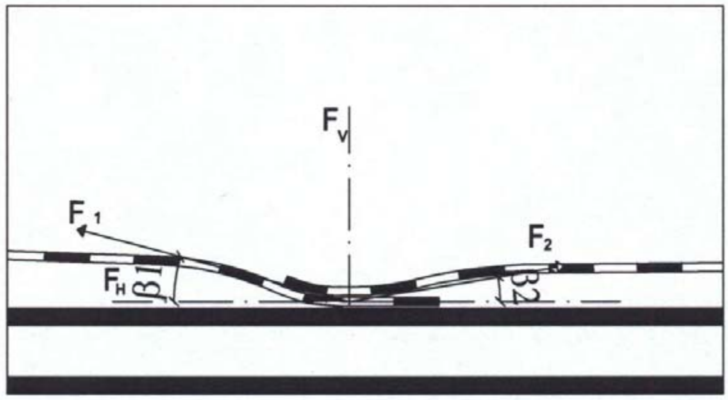

Fig. 2: Linear shear forces occurring in overlaps of bitumen sheets

Bitumen sheet joints in literature and practise

High amount of various joints and overlaps of bitumen sheets are present on water-proofing layer. It contains overlaps in single layer or double layer water-proofing systems, overlaps between adjacent bitumen sheets and joints of bitumen sheets to pervading constructions and tinsmith constructions. Overlaps can be divided according to their position to frontal laps (transversal) and side (longitudinal) – see Fig. 3.

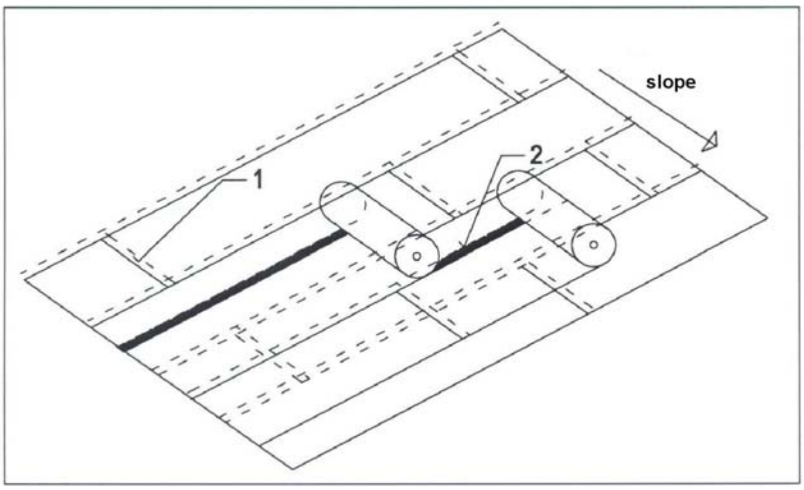

Fig. 3: Types of overlaps (1 - frontal, transversal, 2 – side, longitudinal)

Dimension of bitumen sheet overlaps is not specially defined in presently effective European standards for membrane waterproofing. CSN EN 13707 *Flexible sheets for waterproofing – Reinforced bitumen sheets for* *roof waterproofing – Definition and characteristics*, which is effective in Czech Republic, deals in general way with these overlaps. In related standard CSN P 73 0606 *Waterproofing of buildings – Continuous sheet waterproofing – Basic provisions* paragraph 4.3.1 states: "For membrane water-proofing can be used only products which contain information about application and all necessary parameters and testing methods." Determination of overlap size lays only on manufacturer according to Czech standards.

Another source for information about overlaps is "*General rules for design and realization of flat roofs and water-proofing of below grade structures*" published by Craft for tinsmith, roofers and carpenters in Czech Republic. In this publication we can find in chapter 4.2.1.2 Basic principles of design and realization of membrane water-proofing layers, paragraph 15: "Minimum dimension of water-proof joint of bitumen membranes is 80 mm, for plastic foils 40 mm, if not stated by manufacturer, otherwise" Attempts for mathematical formulation of force effects in bitumen sheet overlaps were made in some European countries including Czech Republic during the 70's of the 20th century. These projects contained definitions of relations among mechanical stress, physical characteristics of bitumen mixture and triggered deformation of bitumen sheets. Complexity of this problematic headed to insertion of various parameters into calculations. In spite of this fact, the result was a rather professional approximation then calculation, which can be used for proper design.

Length of bitumen sheet overlaps is in Czech Republic according to these facts completely in competence of manufacturers. This length is changing according to the type and size of spread as well as whether it is longitudinal or transversal overlap. Length of bitumen sheet overlap is empirically set to 100 mm (minimum 80 mm) for longitudinal and transversal overlaps and fine-grained mineral spread or separating PE foil. Length of bitumen sheet overlap is empirically set to 100 – 150 mm for transversal (frontal) joint and for coarse-grained spread.[1]

General rules from Germany and Slovakia are presented for comparison:

Overlap dimensions are regulated by VDD-Industieverband (Bitumen sheet manufacturers association) - *Technische Regeln - abc der Bitumenbahnen*, where minimum length of 80 mm is set for bitumen sheet overlaps without division of spread or type of overlap (FAJKOS, 2004).

Length 100 mm without division of spread or type of bitumen mass is the parameter set in Slovakia by effective standard *STN 73 33 00 Roof structures*.

2 Methodology

Percentage comparisons of forces transmitted by various overlap lengths is used for determination of relation between overlap lengths and tear stress. Two groups of materials were chosen. Materials with coarse-grained spread where overlap lengths 120 mm and 150 mm are compared and materials with fine-grained spread where overlap lengths 80 mm and 120 mm are compared. The area of the smaller overlap is always approximately 80% of the bigger overlap area.[2] Bitumen sheets from two manufacturers were chosen to ensure maximum objectivity of this research. Representative combinations of various bearing inlays and bitumens modified by various polymers (see Table 1).

Measurements were executed with various temperatures (-20, 0, +20, +50 a +80 °C) [3] with deviation ± 3°C. 10 specimens for each type of bitumen sheet were tested for every set temperature.

Table 1: Overview of tested materials: Specimens A, B, C, F, J, M represents bitumenous sheets with coarse-grained spread. Specimens N, O, P, Y, Z represents bitumenous sheets with fine-grained spread. All bitumen sheets are equipped on reverse side with easily meltable polyethylene foil except sheet R which is equipped with PES nonwoven fleece.

Tag	Bitumen sheet type	Modification type	Bearing inlay	Weight b.i g/m^2	Impregnation of b. inlay
A+B	Modificated	SBS	GF	60	NO
C	Modificated	SBS	PEF	180	YES
F	Modificated	APP	PEF	230	YES
J	Ox		PEF	160	YES
M	Modificated	SBS	PEF	220	NO
N	Modificated	APP	PEF	230	NO
O	Modificated	SBS	GFM	200	NO

[1] It applies for fully sealed bitumen sheets. The term **overlap length** will be used furthermore while joint on testing specimen is 50 mm wide and length is a variable technical parameter.
[2] It is not possible to always maintain the overlap length set. Results from experimental measurements (N/50 mm) were re-calculated using proportionality to nominal values for 120 mm and 150 mm.
[3] Low temperature (-20, 0) °C and high temperature (+50, +80) °C are used furthermore in the text.

P	Ox		GFM	200	NO
R	Modificated	SBS	PEF+GFM	180	YES
Y	Modificated	SBS	GFM	200	YES
Z	Modificated	SBS	PEF	180	YES

(Note: SBS - copolymer styren-butadien-styren, APP – atactic polypropylene, GF – glass fiber fleece, PEF – polyester fleece, GFM – glass fiber mat, b. inlay impregnation – impregnation of bearing inlay in independent manufacturing process.)

Evaluation was made in percentage of comparison of overlap length of 80 (resp. 120) mm. Tear stress transmitted by overlap length of 100 (resp. 150) mm represents 100%. Tear stress transmitted by overlap length of 80 (resp. 120) mm at (–20, 0, +20, +50 a +80°C) is re-calculated in form of percentage value and carried out into graph[4].

3 Experimental part

For creating technological prescript for this test CSN EN 12317-1 was used. Maximum scavage load (shear resistance) until rupture or separation of bitumen sheet in overlap is measured. Tests were executed in Dehtochema Bitumat laboratories using shredding machine LABORTECH 2.050 which complies with the standard mentioned above.

Test specimens were taken from the whole surface area of bitumen sheet only in longitudinal direction. Test specimens are 50 mm wide and 350 mm long. These specimens were tempered for 20 hours in an environment with temperature 21 ± 3 °C and relative humidity 50 ± 20%. 9 (18) specimens were made – count was increased against standard for ensuring higher accuracy and subsequently lower error for evaluation.

For measurements in low and high temperatures specimens were tempered at least 3 hours in demanded temperature. The scheme of testing instrument with installed test specimen is presented in Fig. 4.

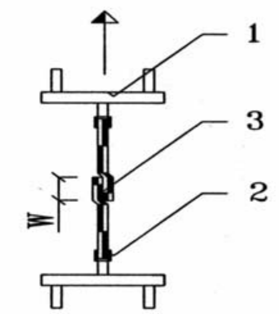

Fig. 4: Overlap shear resistance test, 1- testing instrument's frame, 2 – instrument's jaws, 3 – test specimen

4 Results

Main influence on overlap rupture belongs to bearing inlay, type of bitumen mass and overlap length.

Stress transmission in **low temperatures** lies on bearing inlay and bitumen mass. Rupture of bitumen sheet apart from overlap occurred with bitumen mass modified by polymers. Rupture of bitumen sheet apart from overlap and disengaging in overlap area occurred with oxidized bitumen mass. Both failures occurred with bitumen sheets made with bearing inlay from glass fiber mat and also from polyester mat. With this type of bitumen sheet, de-lamination from bearing inlay occurred. Higher amount of disengaged overlaps occurred by sheets where impregnation of bearing inlay was not made. Disengagement was caused by embrittlement of bitumen mass and subsequent loss of adhesion.

Influence of bearing inlay on sheet resistance and overlap resistance was lowered at **high temperatures**. The problematic of overlap resistance was constricted to adhesion between bitumen mass on reverse side of upper sheet and facing side of lower sheet and on overlap length.

[4] Average from 10 measurements.

Shearing failure always occurred without variance of bitumen mass at +80 °C. Shearing failure was partly present at +50 °C, only with bitumen sheets from bitumen mass modificated by copolymer SBS.

Disengagement in overlaps occurred almost in 100% of cases with bitumen sheets from bitumen mass modified by APP polymer even at +20 °C. Shear resistance accrual between overlap lengths 80 and 100 mm is obvious till this temperature. Some part of specimens with length overlap 100 mm long was ruptured apart from overlap.

Rupture apart from overlap always occurred with bitumen sheets from bitumen mass modified by copolymer SBS.

Disengagement occurred always with bitumen sheets from oxidized bitumen mass.

Results obtained after processing measured data are: descending curve of scavage load percentage value for an overlap of 80 mm long to 100 mm (see Fig. 5) and for overlap 120 mm to 150 mm (see Fig. 6) with respect to temperature occurred by 3 bitumen sheets out of 11. Ascent until temperature 0°C appeared in two cases (until temperature 20°C in one case) with subsequent curve descent. In other 3 cases, the curve descents, eventhough there is a local ascent in some measurements. There is no visible dependence in the last two cases. (see Fig. 5, Fig. 6 and Table 2).

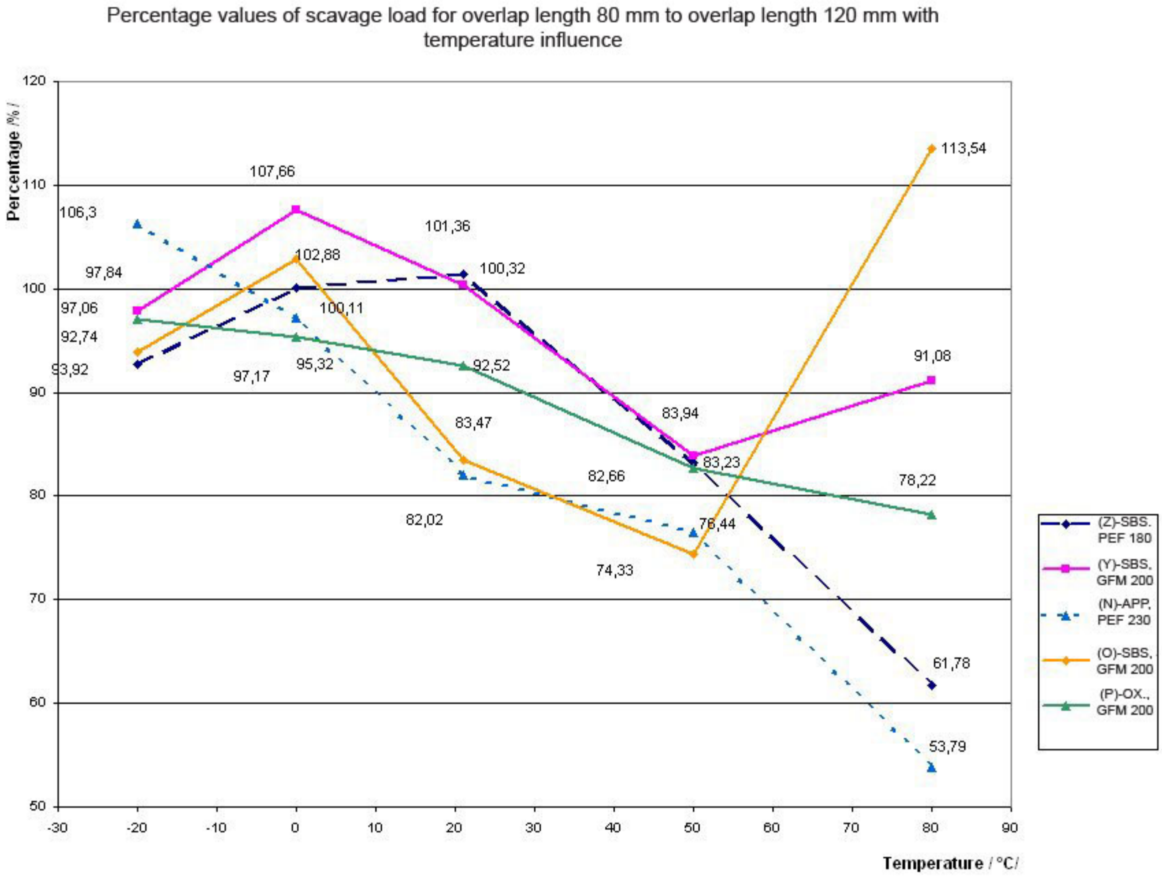

Fig. 5 - Influence of temperature to dependency of ratio between overlap dimension for 80 and 100 mm

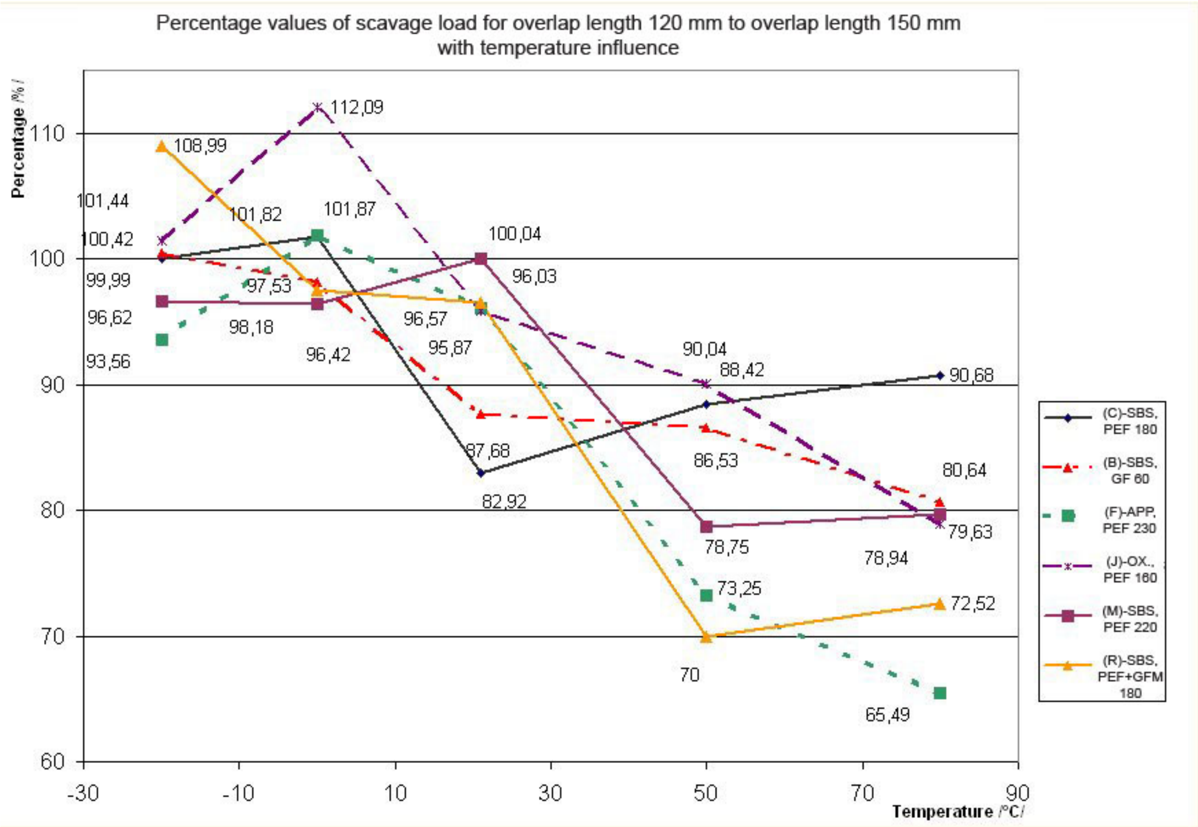

Fig. 6: Influence of temperature to dependency of ratio between overlap dimension for 120 and 150 mm

Table 2: Results overview from experimental measurements

INFLUENCE OF TEMPERATURE TO SCAVAGE LOAD			
Tag	**Modification**	**Bearing inlay**	**Description**
A+B	SBS	GF	Curve descents
C	SBS	PEF	Curve descents, then ascents
F	APP	PEF	Curve ascents, then descents
J	OX	PEF	Curve ascents, then descents
M	SBS	PEF	Curve lightly descents, then ascents, then descents and then lightly ascents
N	APP	PEF	Curve descents
P	OX	GFM	Curve descents
R	SBS	PEF+GFM	Curve descents, then lightly ascents
O	SBS	GFM	Curve ascents, then descents, then steeply ascents
Y	SBS	GFM	Curve ascents, then descents, then ascents
Z	SBS	PEF	Curve ascents, then descents

Evaluation with respect to bearing inlay and used bitumen mass:

Bitumen sheets modificated by copolymer SBS and polyester mat bearing inlay. Curve has irregular progress and influence of temperature on overlap length is small in case of coarse-grained spread. Curve descents with rising temperature in case of fine-grained spread. Influence of temperature on overlap length increases with rise of temperature.

Bitumen sheets modificated by copolymer SBS and glass fiber mat bearing inlay. Curves are descending but between +50°C and +80°C they ascent. Influence of temperature on overlap length is small.

Bitumen sheets modificated by copolymer SBS and glass fiber fleece bearing inlay. Curve descents with rising temperature. Influence of temperature on transmitted force by overlap increases with rising temperature.

Bitumen sheets modificated by copolymer SBS and composite bearing inlay from polyester and glass fiber mat.

Curve descents with rising temperature with slight ascent below +80 °C. Influence of temperature on transmitted force by overlap increases with rising temperature.

Bitumen sheets modificated by polymer APP and polyester mat bearing inlay.

Curve descents with rising temperature with slight ascent below +80 °C. Influence of temperature on transmitted force by overlap increases with rising temperature.

Bitumen sheets from oxidized bitumen and polyester mat bearing inlay.

Curve descents with rising temperature from 0 °C. Influence of temperature on transmitted force by overlap increases with rising temperature.

Bitumen sheets from oxidized bitumen and glass fiber mat bearing inlay.

Curve descents with rising temperature. Influence of temperature on transmitted force by overlap increases with rising temperature.

5 Conclusion

According to the presented results of experimental measurements, the following can be stated:

1. Overlap length gains significance with increasing temperature.
2. Smaller overlaps can be manufactured for bitumen sheets modified by copolymer SBS and bearing inlay from polyester fleece (PEF), glass fiber mat (GFM) and glass fiber fleece (GF).
3. Overlap length does have bigger influence for bitumen sheets modified by polymer APP or for bitumen sheets from oxidized bitumen then for bitumen sheets modified by copolymer SBS.

References

CZECH STANDARD INSTITUTE. *CSN en 13707*: flexible sheets for waterproofing: reinforced bitumen sheets for roof waterproofing: definition and characteristics. Prague: CSN, 2005. 8 p.

CZECH STANDARD INSTITUTE. *CSN P 73 0606*: waterproofing of buildings: continuous sheet waterproofing : basic provisions. Prague: CSN, 2000. 24 p.

FAJKOS, A. Waterproofing for flat roofs. In: INTERNATIONAL CONFERENCE IN MODERN BUILDING MATERIALS, STRUCTURES AND TECHNIQUES, 8., 2004, Vilnius. *Proceedings*... Vilnius: ECCE, 2004. p. 44-45. 1 CD-ROM.

FAJKOS, A.; NOVOTNY, M. *Roofs, basic constructions*. Praha: Grada, 2003. 164 p.

FAJKOS, A.; NOVOTNY, M.; STRAKA, B. *Roofs I, reconstructions*. Praha: Grada, 2000. 138 p.

SOBRE O AUTOR

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Graduated on Faculty of Civil Engineering in Brno in 1973. After undergoing professional service as construction manager he returned to Department of Building Structures on Faculty of Civil Engineering in Brno, where he worked as an assistant, from 1989 as Associated Professor. In 1991 he was designated as expert appointed by court for roof structures. He is author of 10 books dealing with roof deck solutions, author of approx. 50 articles in expert and science journals. Attends and lectures periodically on professional conferences and seminars. Author of many designs of roof structures for various utilization – from family houses, public housing and sporting structures to very challenging designs for swimming pools, airport terminals etc. He is very active in expert activities involved in roof structure failure analysis and reconstruction of roof structures.