GRISPE

Guidelines and **R**ecommendations for **I**ntegrating **S**pecific **P**rofiled steel sheets in the **E**urocodes (**GRISPE**)

Working Package 1

WP1 Background guidance for EN 1993-1-3 to design of sheeting with embossments and indentations

30th June 2015

Deliverable D 1.5

Guidelines and Recommandations for Integrating Specific Profiled Steels sheets in the Eurocodes (GRISPE)

Project co-funded under the Research Fund for Coal and Steel
Grant agreement No RFCS-CT-2013-00018
Proposal No RFS-PR-12027

Author(s)
Palisson Anna, Sokol Palisson Consultants

Drafting history	
Draft Version 1	*2nde July 2015*
Draft Version 2	*4th July 2015*
Final Version Revision 01	*14th February 2016*
Final Version Revision 02	*31st May 2016*
Final Version Revision 03	*29th August 2016*

Dissemination Level		
PU	*Public*	
PP	*Restricted to the Commission Services, the Coal and Steel Technical Groups and the European Committee for Standardisation (CEN)*	
RE	*Restricted to a group specified by the Beneficiaries*	
CO	*Confidential, only for Beneficiaries (including the Commission services)*	***x***

Verification and Approval
Coordinator David Izabel, SNPPA
WP1 Leader SOKOL PALISSON CONSULTANTS
Other Beneficiaries SNPPA, Bac Acier, IFL, Joris Ide, KIT

Deliverable	
D 1.5 WP1 Background guidance for EN 1993-1-3 (embossments & indentations)	***Due date : 30.06.2015*** ***Completion date: 30.06.2015***

1. INTRODUCTION

Due to its many construction advantages steel decking is frequently used in steel-framed construction for both roofs and floors for interior design, commercial and industrial refurbishments and for the building trade. In order to increase the shear connection between the steel and the concrete in the composite slabs, steel decks are reinforced with connectors such as embossments or indentations (Fig. 1).

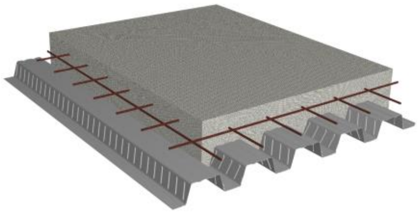


Fig. 1 - Indentations in a composite slab

As we could see in the state of the art [1] completed within GRISPE project, at the composite stage the behavior of composite slabs with embossments has been determined by numerous studies [2] to [8], embossments increase for the composite steel-concrete slab shear connection, moment capacity, mid-span deflections and end slips whereas at the construction stage there is a real lack of data and knowledge about the effect of embossments and indentations on the steel deck resistance and stiffness. The European Standard EN 1993-1-3 dealing with design rules for cold-formed members and sheeting doesn't cover profiles with embossments and indentations. Moreover the existing studies and researches on this type of profile [9], [10], [11] don't allow to quantify precisely by calculation the effect of embossments and indentations. This lack is even more disturbing and serious, as these studies have shown that the effect is unfavorable to certain criteria as bending resistance. Therefore the one way to design sheeting with embossments / indentations is to determine resistance values by testing, which takes a long time and is expensive.

The aim of this study is to develop a calculation method for steel decks with embossments / indentations based on a huge testing program performed within GRISPE project [12], [13]

2. ACQUIRED DATA THROUGH GRISPE PROJECT

2.1. Steel sheeting test analysis

A huge program of 144 tests was performed on steel trapezoidal sheeting in order to determine and compare resistance values of steel decks without and with embossments and indentations [12], [13]. Two different profiles PCB 60 and PCB 80 from BACACIER, France, with different shapes of embossments/indentations (decking 1 and decking 2) were tested. The same profiles were tested with and without embossments/indentations, with two different thicknesses of the sheets.

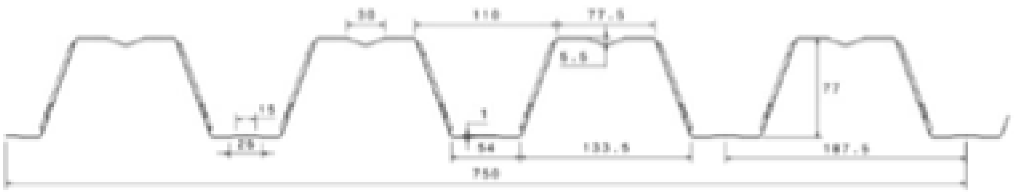


Figure A.1: Cross-section of PCB 80

Fig. 2.1.1: PCB 80 from BACACIER SAS

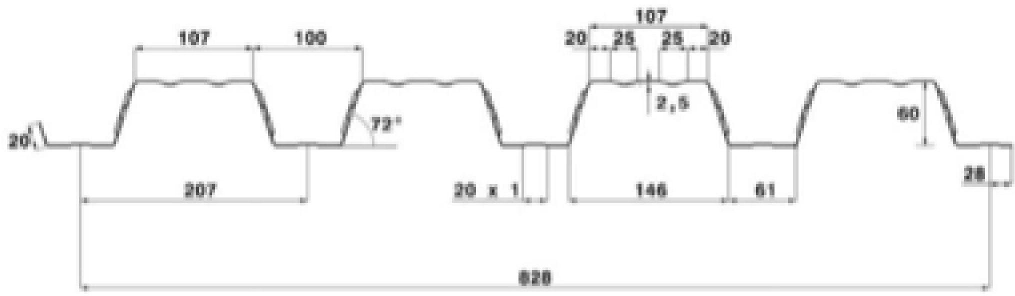


Figure A.2: Cross-section of PCB 60

Fig. 2.1.2: PCB 60 from BACACIER SAS

The profiles were tested according to EN 1993-1-3, Annex A:

- <u>single span tests</u>

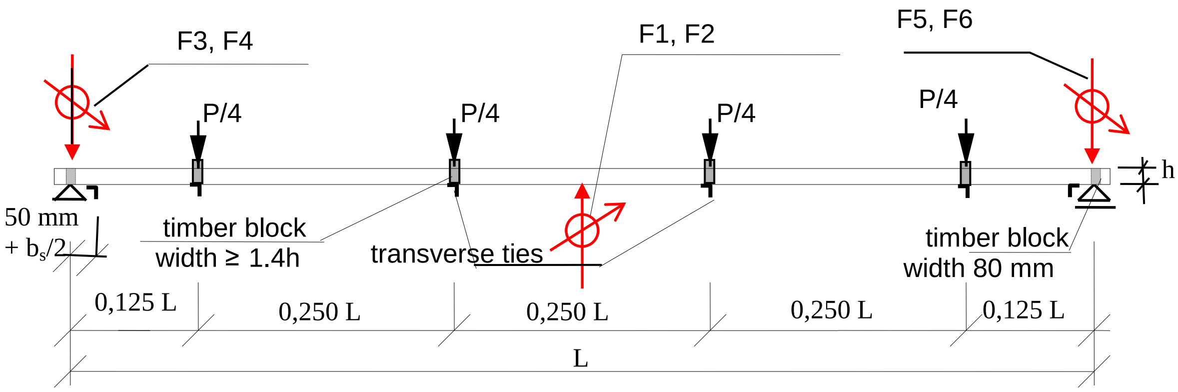
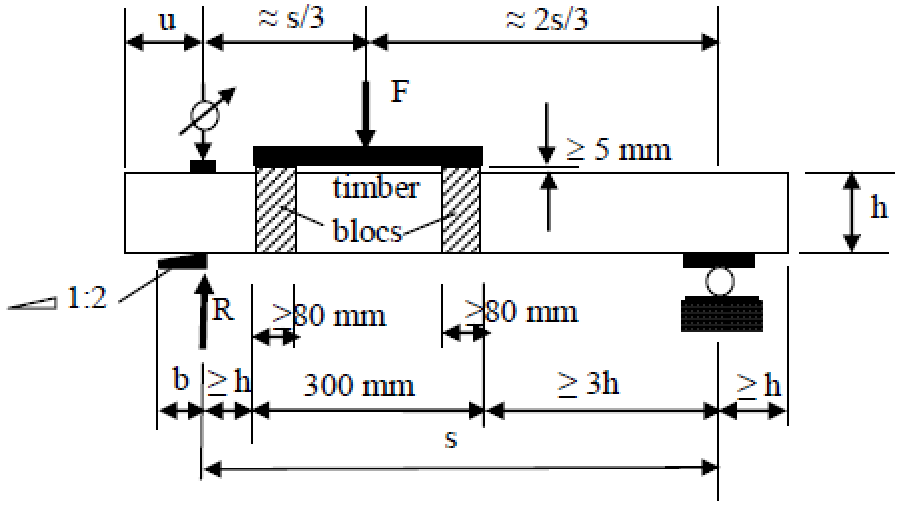


Fig. 2.1.3. – Test set-up for single span tests

- <u>end support tests</u>



Key:
b_s = support length
u = length from internal edge of end support to end of sheet

Fig. 2.1.4 – Test set-up for end support test

- <u>internal support tests</u>

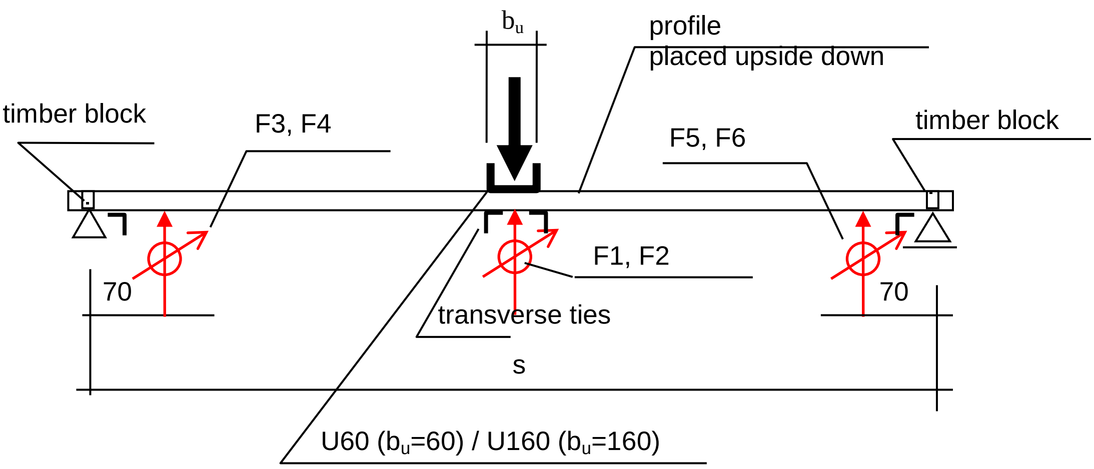


Fig. 2.1.5 – Test set-up for internal support tests

The analysis of those tests allowed us to conclude:

- for the moment resistance: the <u>embossments and indentations decrease moment resistance</u> from 3,5% up to 9,7%, and decrease inertia moment from 1,4% up to 10,7%. The study performed by P. Luure and M. Crisinel [9] which showed a decrease of about 10% on the resistance and the study performed by J. M. Davies [10] who found in his finite element analysis a decrease of 3 to 10% of the bending strength are consistent with our study.

- for the end support resistance (web crippling) <u>the embossments and indentations increase the web crippling resistance</u> from 5,5% up to 20,3%. P. Luure and M. Crisinel [9] found an increase of about 10%, which is consistent with our values.

- for the moment-reaction interaction, it is observed that in general tendency:
  - for smaller span s values, the interaction resistance of profile with embossments / indentations is equal or bigger than without embossment
  - for bigger span s values, the interaction resistance of profile with embossments / indentations is equal or smaller than without embossment

This observation may be logically explained by the following:

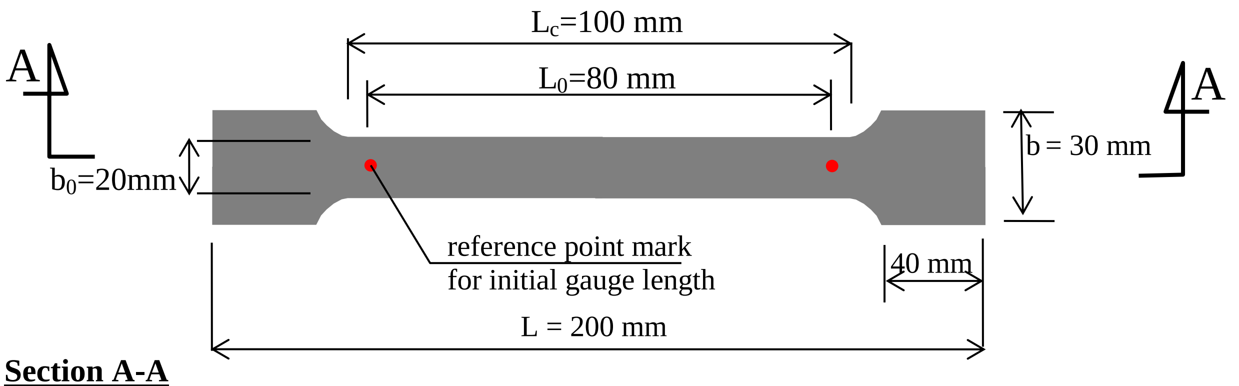
- from end support and simply span tests it results that the embossments decrease the moment resistance and increase the reaction resistance

. for smaller s values (right side of the M-R diagram) the interaction resistance is governed by the reaction resistance (that is higher)

. - for bigger s values (left side of the M-R diagram) the interaction resistance is governed by the moment resistance (that is lower)

2.2. Coupon tensile test analysis

54 tensile testing on coupons with and without embossments were performed with two different thicknesses in order to determine the influence of embossments on the yield stress.



<u>Section A-A</u>

a) plate coupons

b) coupons with indentations

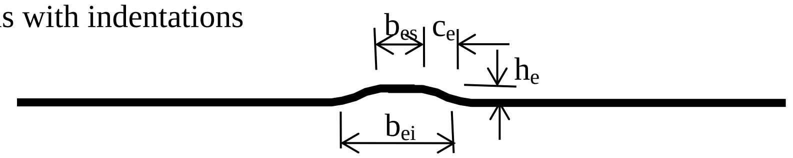


Fig. 2.2.1 Dimensions of coupons

<u>Key:</u>

L = total length
L_c = parallel length
L_0 = initial gauge length
b = total width

b_0 = width of the parallel reduced part

Values of h_e: 0 mm; 1 mm; 2 mm; 3 mm; 4 mm
Values of b_e: 0 mm; 10 mm
Thickness: 0.75 mm; 1 mm

The stress decreases in accordance with the embossments. The more important the embossment is the more important the stress decrease is.

2.2.1. Yield stress with and without embossments

a) 0.75 mm

Plate samples

Complete tensile traction diagrams
A detailed analysis allowed us to determine the ratios between the yield stress of the coupon plate without embossment and the yield stress of the coupon plate with embossment.

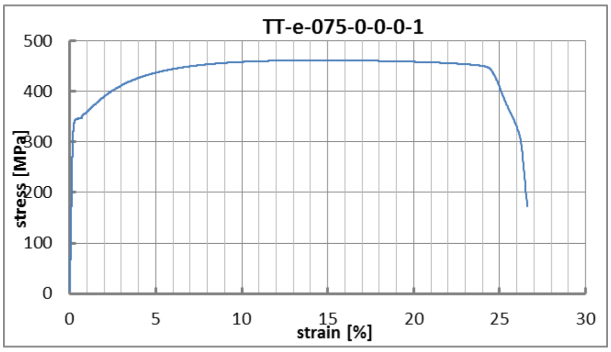


Fig. 2.2.1.1

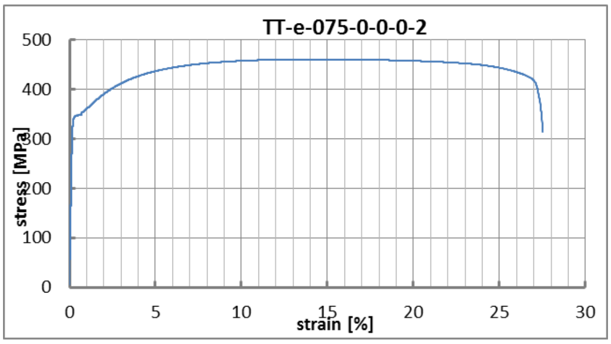


Fig. 2.2.1.2

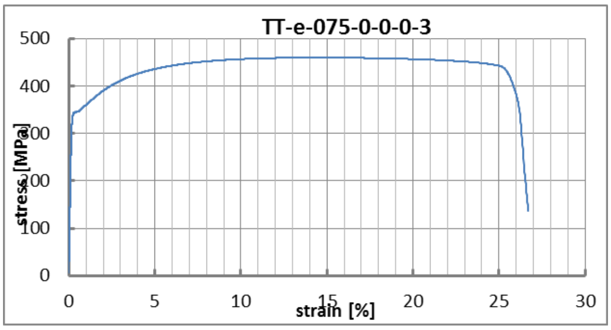


Fig. 2.2.1.3

Truncated diagrams until 0,5% strain in yield stress area

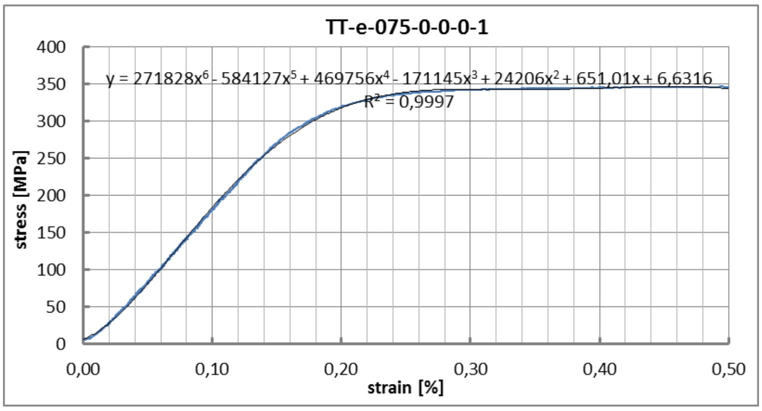


Fig. 2.2.1.4

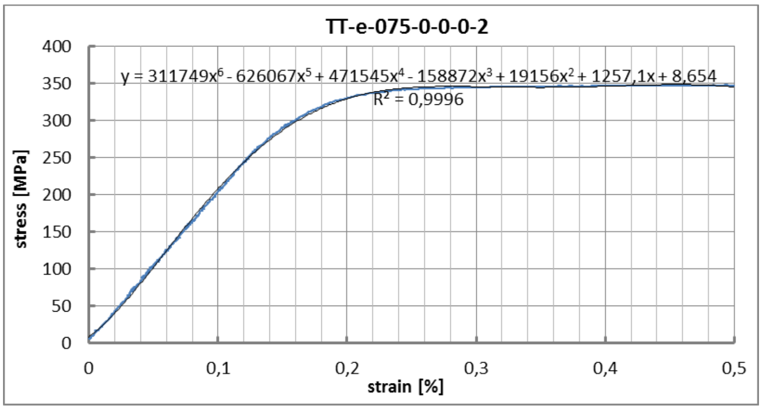


Fig. 2.2.1.5

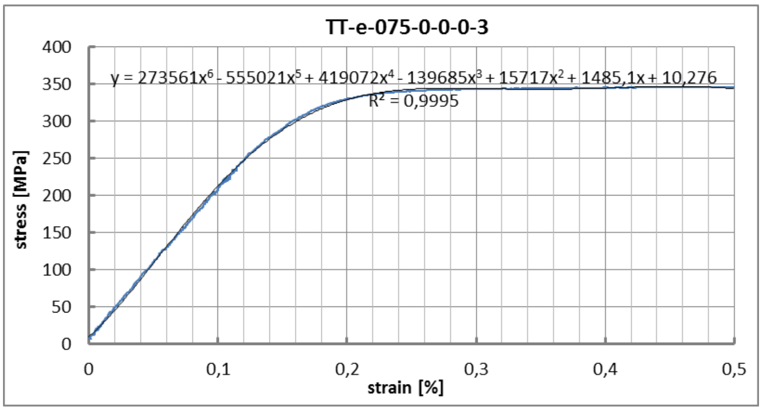


Fig. 2.2.1.6

Average equation curve:

y = 285713.667*x^6-588405*x^5+453457.6666*x^4-156567.3*x^3+19693.07*x^2+1131.7*x+8.52

Determination of the yield strength value

Principle

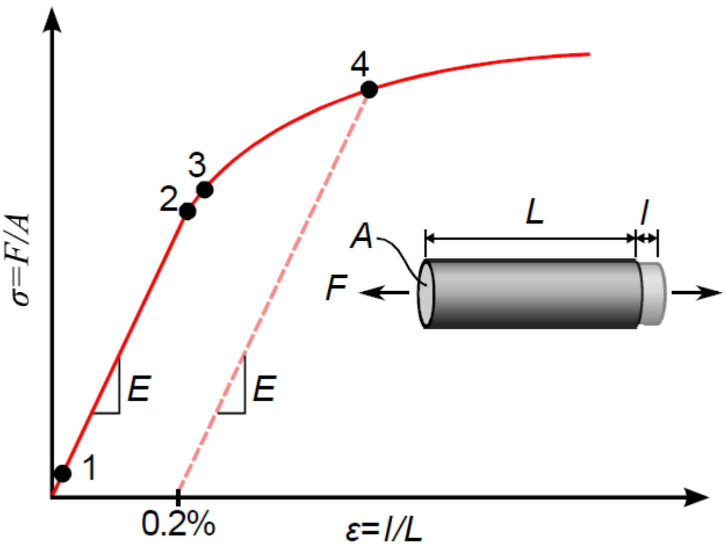


Fig. 2.2.1.7

Stress–strain curve showing typical yield behavior. Stress (σ) shown as a function of strain (ϵ).

- 1: True elastic limit
- 2: Proportionality limit
- 3: Elastic limit
- 4: Offset yield strength

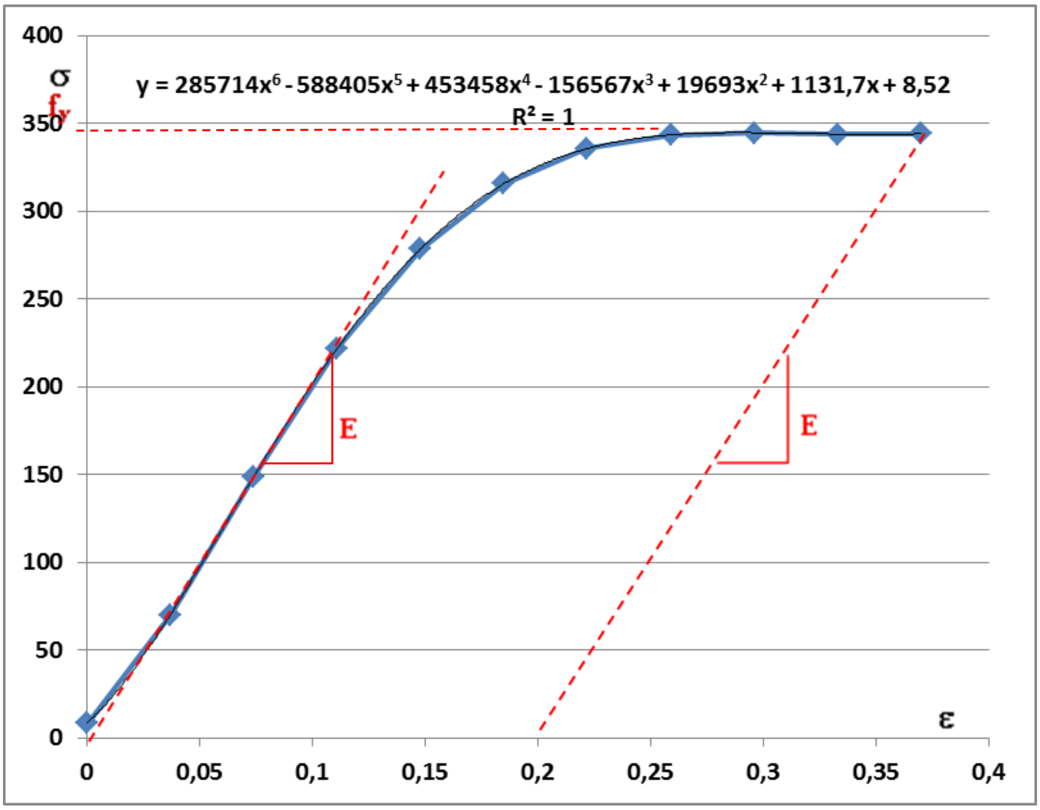


Fig. 2.2.1.8 Determination of the f_y value

The f_y value is defined by the 2 equations system:

$y = 285714x^6 - 588405x^5 + 453458x^4 - 156567x^3 + 19693x^2 + 1131.7x + 8.52$

$y = E*(x-0.2)$

The solution of the above equation system gives:

$y = 343.976177 = f_y$

$x = 0.36973 = \varepsilon_y$

The elastic limit σ_p (see Fig. 2.2.1.7, point "3" on the curve) is assumed as being defined by 0.05% strain, as shown in the Fig. 2.2.1.9.

This is performed by solution of the two equations system:

$y = 285714x^6 - 588405x^5 + 453458x^4 - 156567x^3 + 19693x^2 + 1131.7x + 8.52$

$y = E*(x-0.05)$

The solution of the above equation system gives:

$y = 333.881491 = \sigma_p$
$x = 0.21729 = \varepsilon_p$

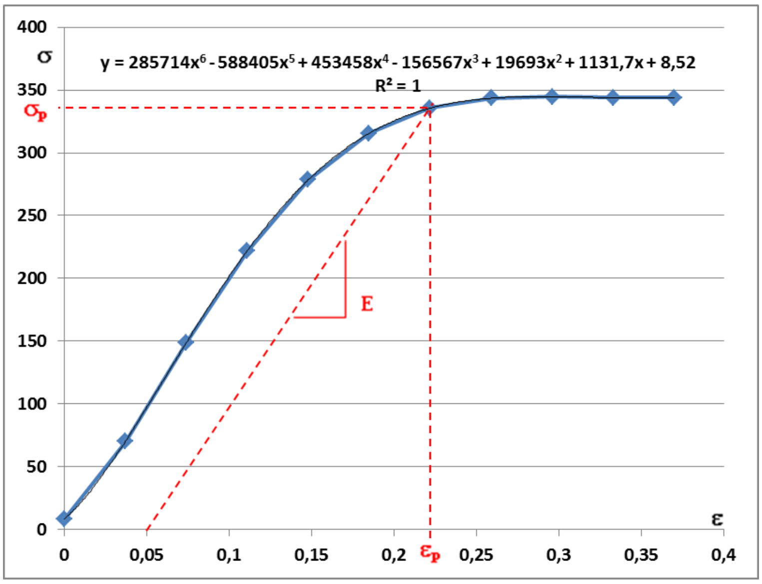


Fig. 2.2.1.9 Determination of the proportionality limit

The curve σ - ε diagram is replaced by two broken lines diagram:

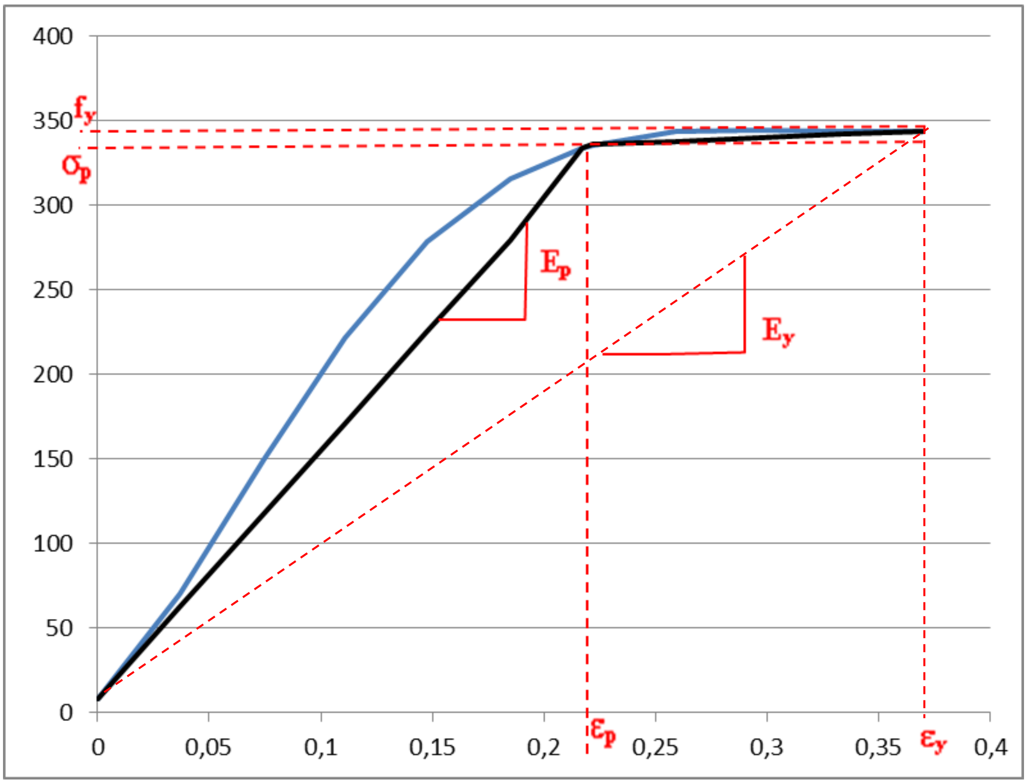
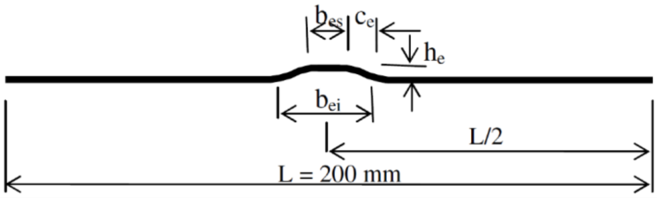


Fig. 2.2.1.10 Simplified bi-linear diagram (black line)

The E_p is to be used in the area 0 - σ_p
The E_y is to be used in the area σ_p - f_y

Embossed samples



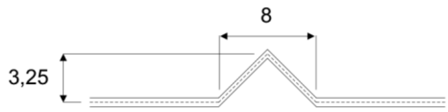
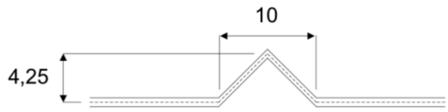
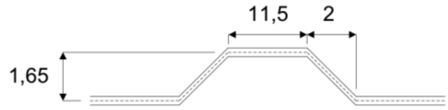
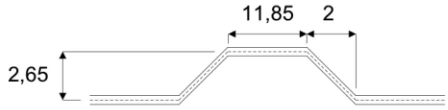
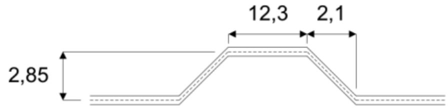
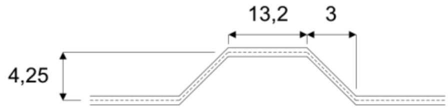
Test	Core thickness t_K [mm]	Measured height $h_e + t_N$ [mm]	Geometry according to Joris Ide [mm]
TT-e-075-0-0-0-1	0.698	-	
TT-e-075-0-0-0-2	0.701	-	
TT-e-075-0-0-0-3	0.702	-	
TT-e-075-1-1-0-1	0.701	2.14	-
TT-e-075-1-1-0-2	0.701	2.12	
TT-e-075-1-2-0-3	0.700	2.12	
TT-e-075-2-2-0-1	0.699	3.31	-
TT-e-075-2-2-0-2	0.705	3.25	
TT-e-075-2-2-0-3	0.702	3.30	
TT-e-075-3-3-0-1	0.694	4.00	
TT-e-075-3-3-0-2	0.698	3.96	
TT-e-075-3-3-0-3	0.679	3.94	
TT-e-075-4-4-0-1	0.701	4.85	
TT-e-075-4-4-0-2	0.700	4.85	
TT-e-075-4-4-0-3	0.696	4.91	
TT-e-075-1-1-10-1	0.693	2.40	
TT-e-075-1-1-10-2	0.699	2.41	
TT-e-075-1-1-10-3	0.695	2.40	
TT-e-075-2-2-10-1	0.699	3.39	
TT-e-075-2-2-10-2	0.699	3.35	
TT-e-075-2-2-10-3	0.700	3.34	
TT-e-075-3-3-10-1	0.698	3.57	
TT-e-075-3-3-10-2	0.698	3.57	
TT-e-075-3-3-10-3	0.702	3.56	
TT-e-075-4-4-10-1	0.691	5.06	
TT-e-075-4-4-10-2	0.699	5.11	
TT-e-075-4-4-10-3	0.698	5.10	

Table 2.2.1.1 – Results of tensile tests with embossments, nominal thickness $t_N = 0.75$ mm

Diagrams in the area 0 - ε_{ye}

TT-e-075-1-1-0

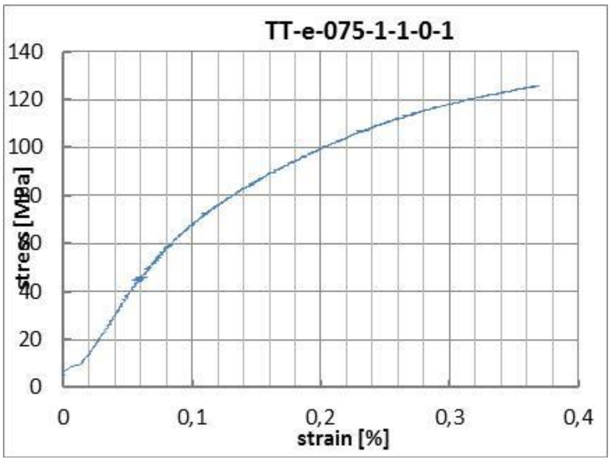


Fig. 2.2.1.11

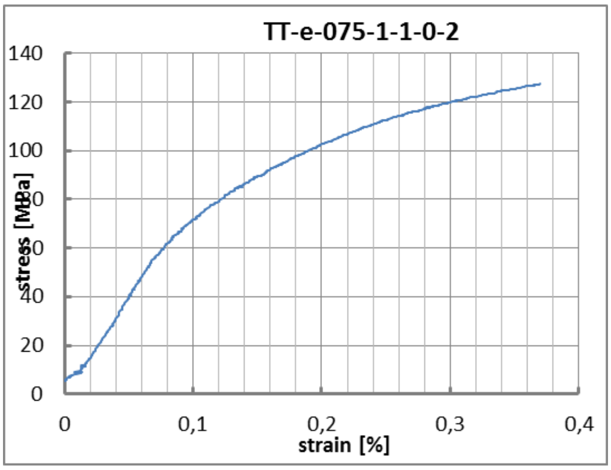


Fig. 2.2.1.12

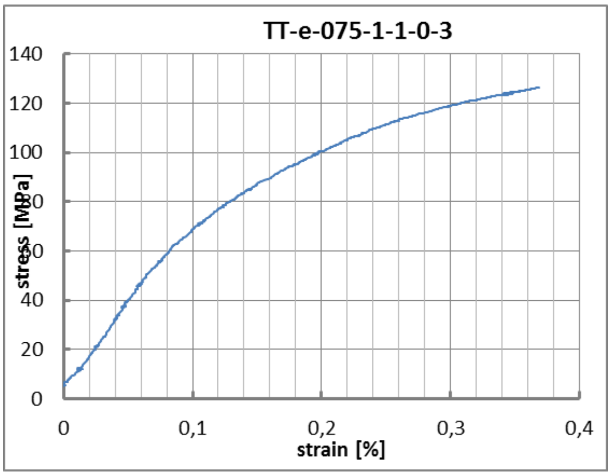


Fig. 2.2.1.13

TT-e-075-1-1-10

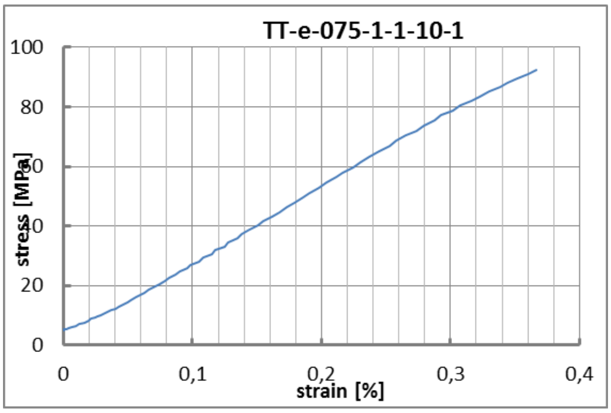


Fig. 2.2.1.14

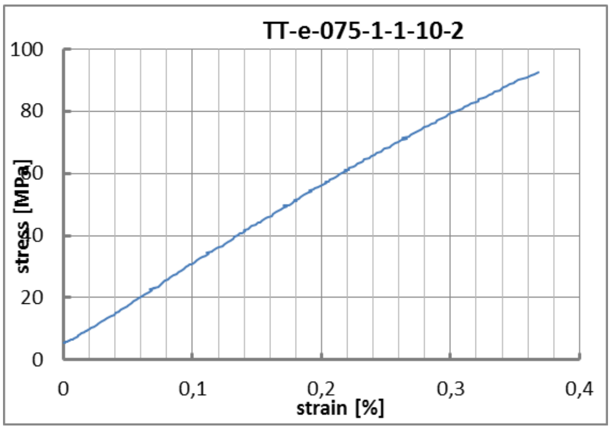


Fig. 2.2.1.15

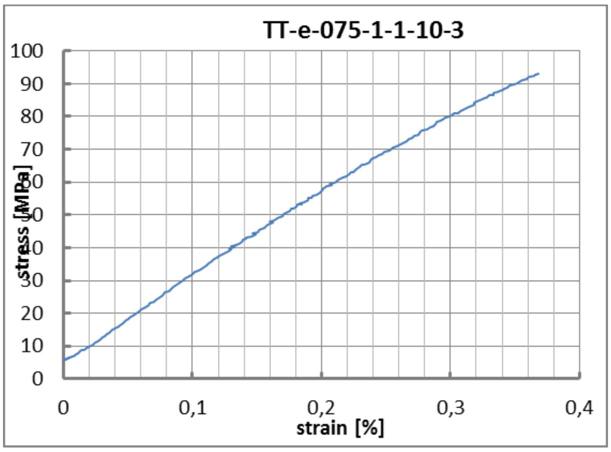


Fig. 2.2.1.16

TT-e-075-2-2-0

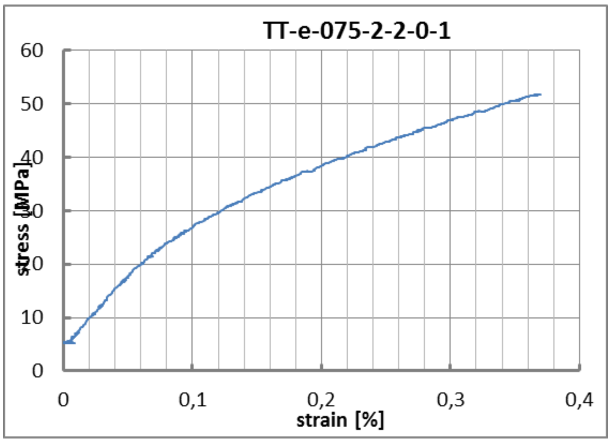


Fig. 2.2.1.17

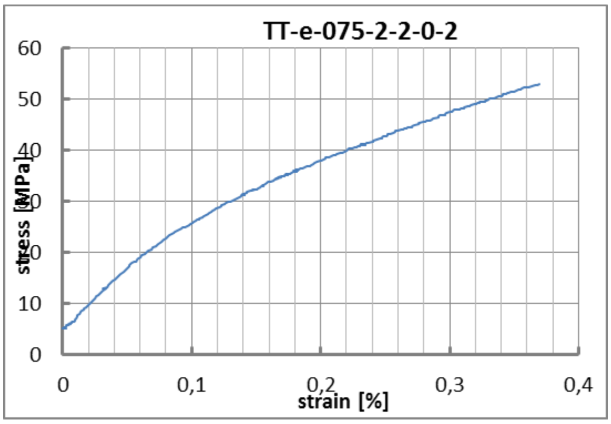


Fig. 2.2.1.18

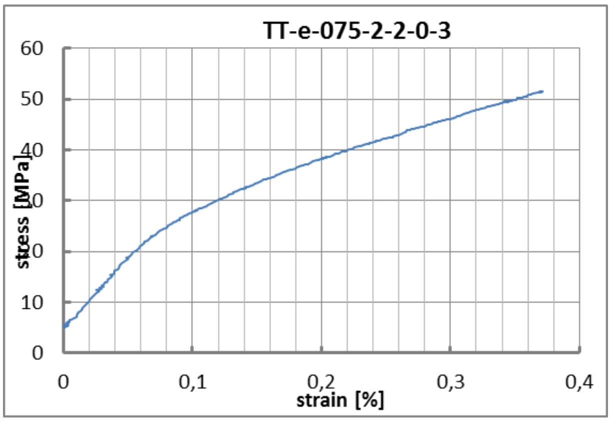


Fig. 2.2.1.19

TT-e-075-2-2-10

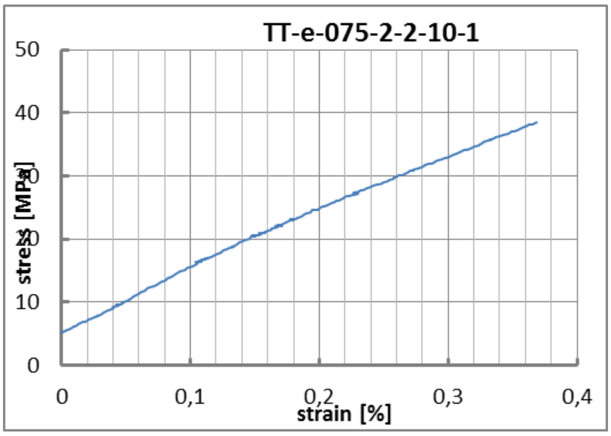


Fig. 2.2.1.20

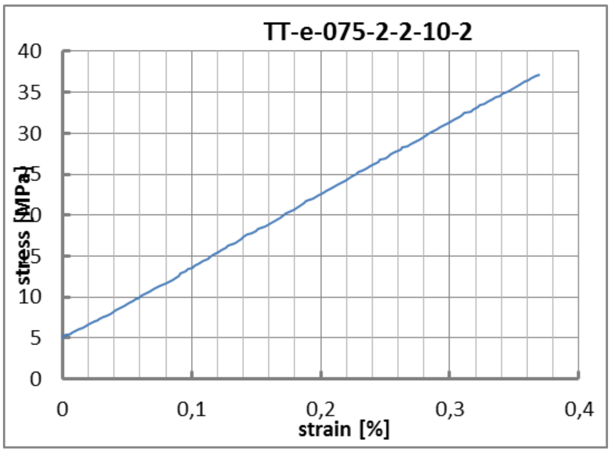


Fig. 2.2.1.21

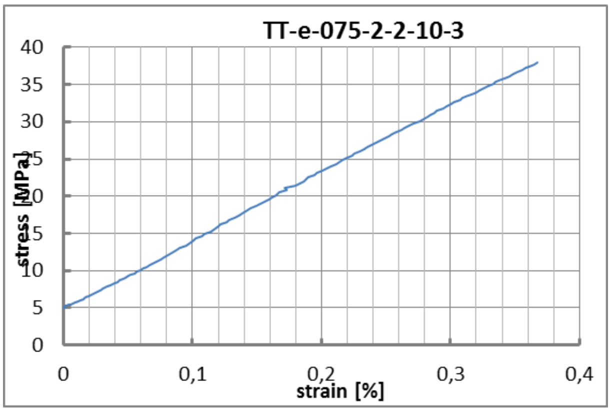


Fig. 2.2.1.22

TT-e-075-3-3-0

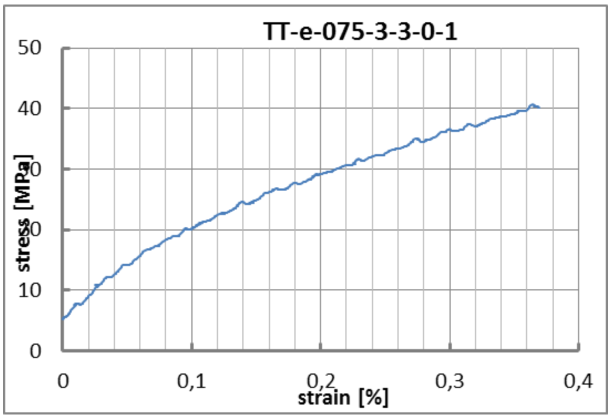


Fig. 2.2.1.23

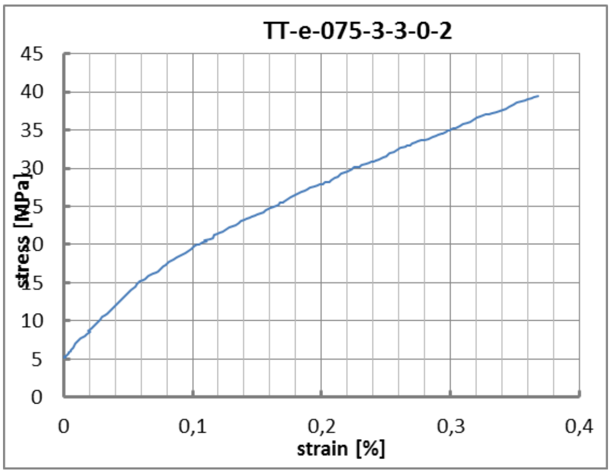


Fig. 2.2.1.24

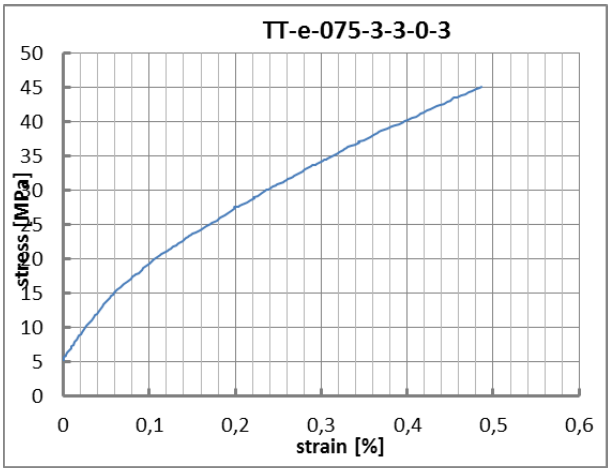


Fig. 2.2.1.25

TT-e-075-3-3-10

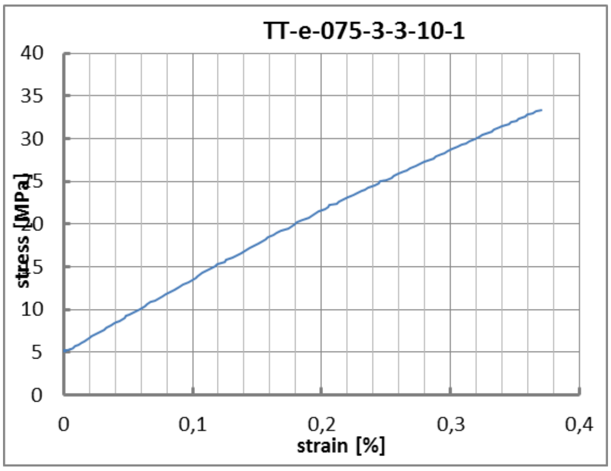


Fig. 2.2.1.26

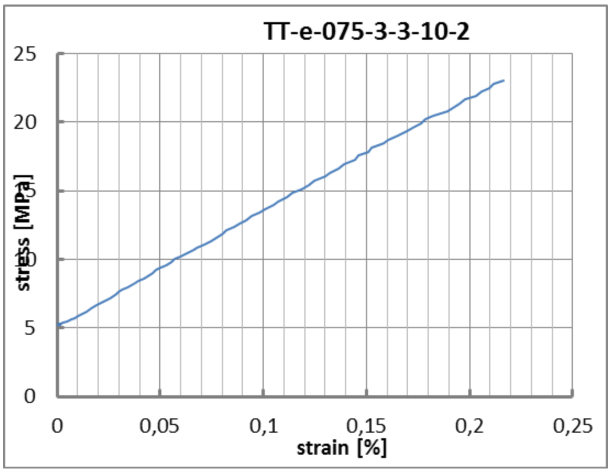


Fig. 2.2.1.27

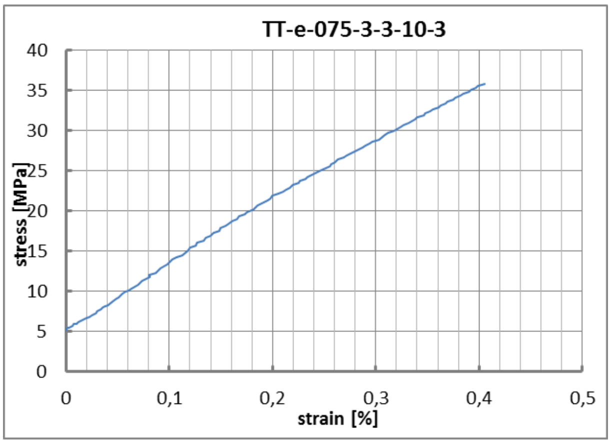


Fig. 2.2.1.28

TT-e-075-4-4-0

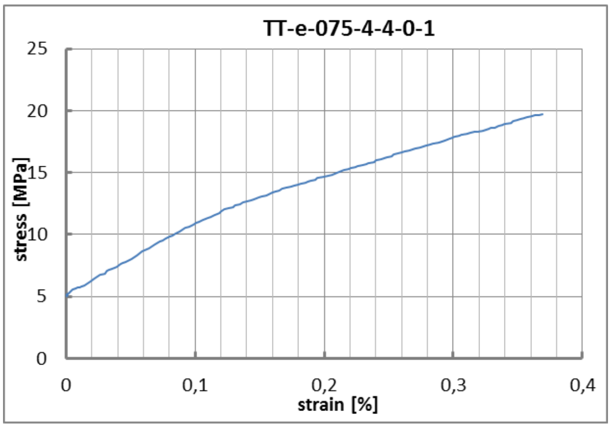


Fig. 2.2.1.29

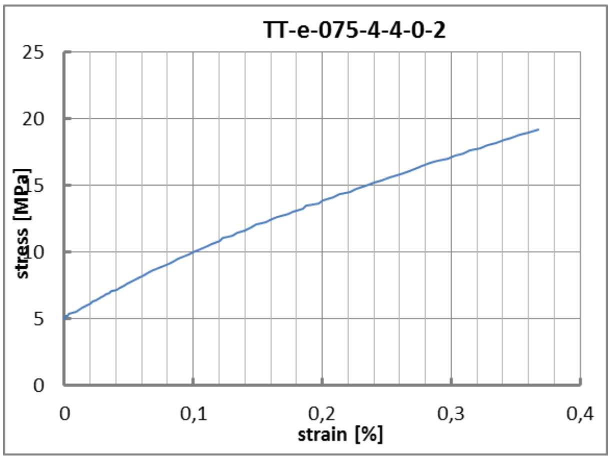


Fig. 2.2.1.30

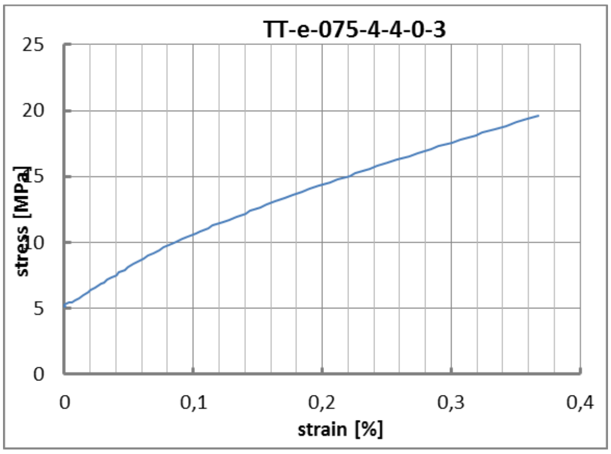


Fig. 2.2.1.31

TT-e-075-4-4-10

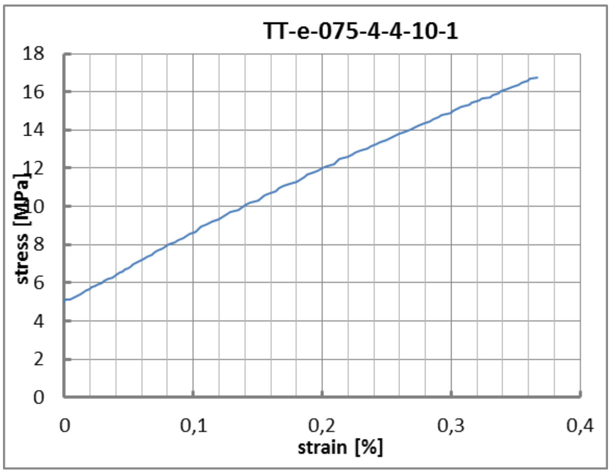


Fig. 2.2.1.32

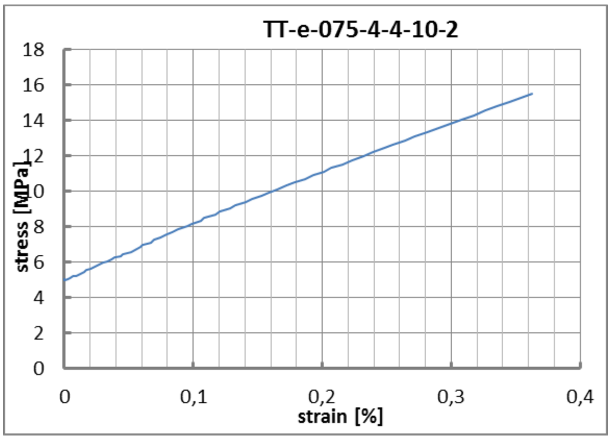


Fig. 2.2.1.33

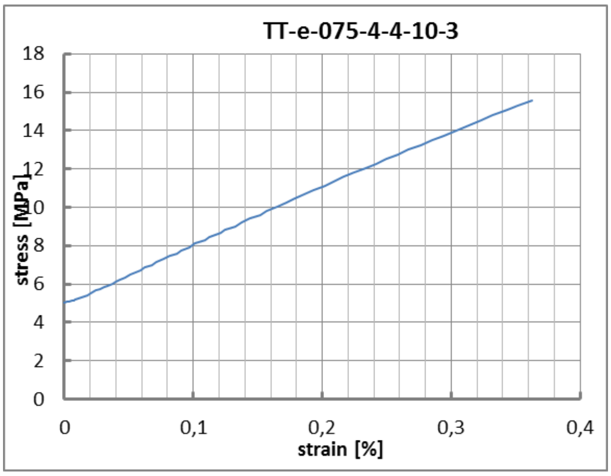


Fig. 2.2.1.34

The above diagrams corresponding to the folded samples are interpreted in the similar manner as the diagram corresponding to the plate samples (see Fig. 2.2.1.8) illustrated on the example of the sample TT-e-075-1-1-0-1:

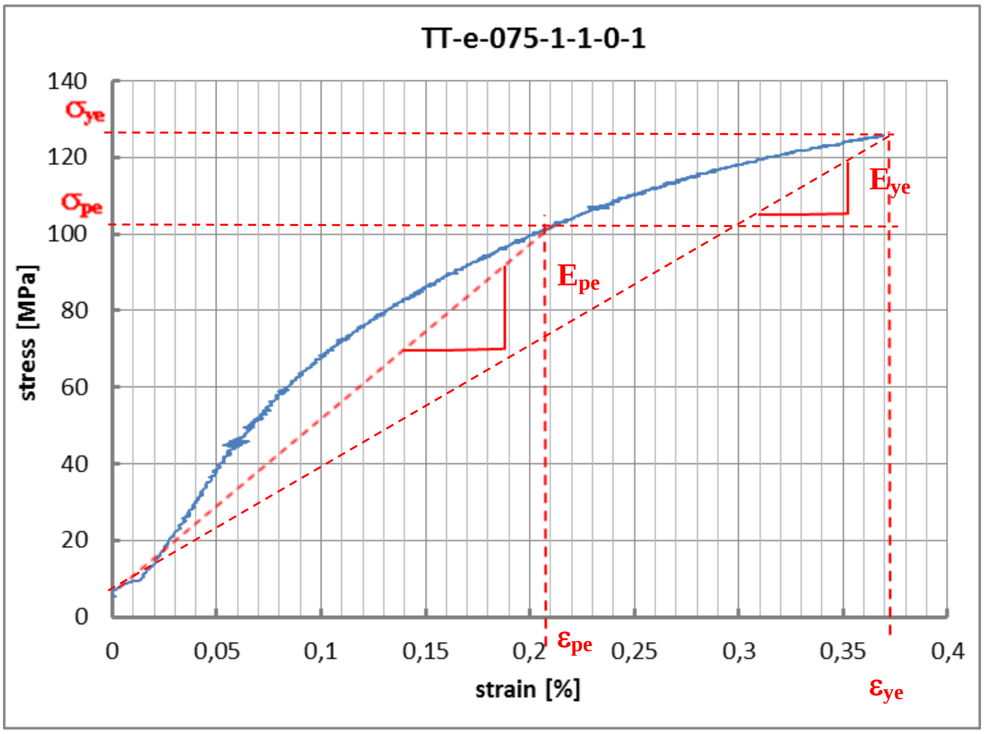


Fig. 2.2.1.35

Remark:
In the Figure 2.2.1.35 ε_{pe} and ε_{ye} are those defined for the plate samples:
$\varepsilon_{pe} = \varepsilon_p = 0.21729$
$\varepsilon_{ye} = \varepsilon_y = 0.36973$

the σ_{pe} and σ_{ye} are the actual stresses in the given folded sample corresponding to ε_{pe} and ε_{ye} strains

b) 1mm

<u>Plate samples</u>

Complete tensile traction diagrams

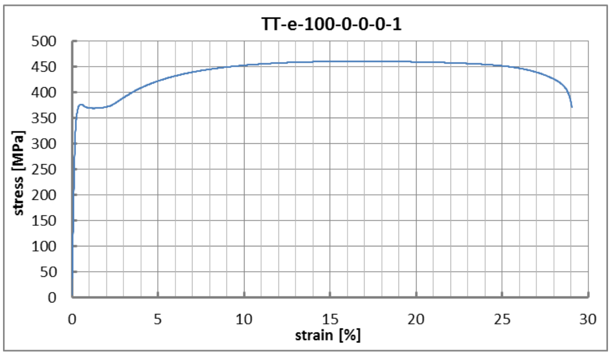


Fig. 2.2.1.36

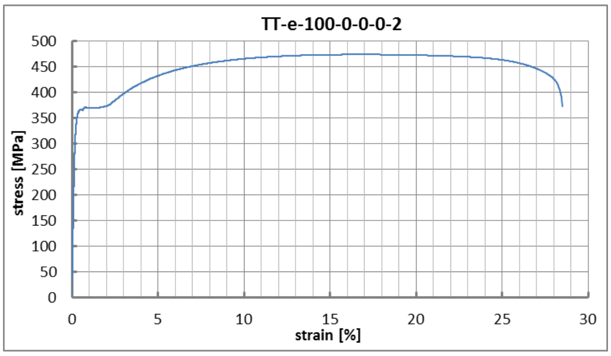


Fig. 2.2.1.37

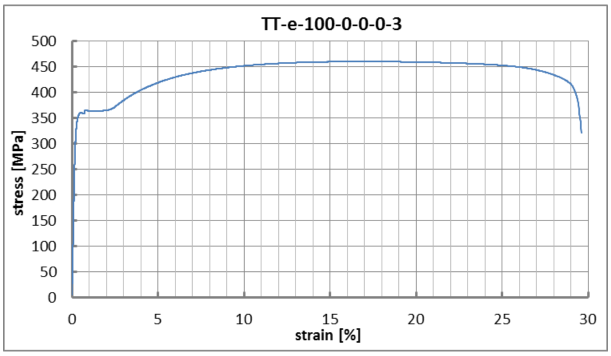


Fig. 2.2.1.38

Truncated diagrams until 0,5% strain in yield stress area

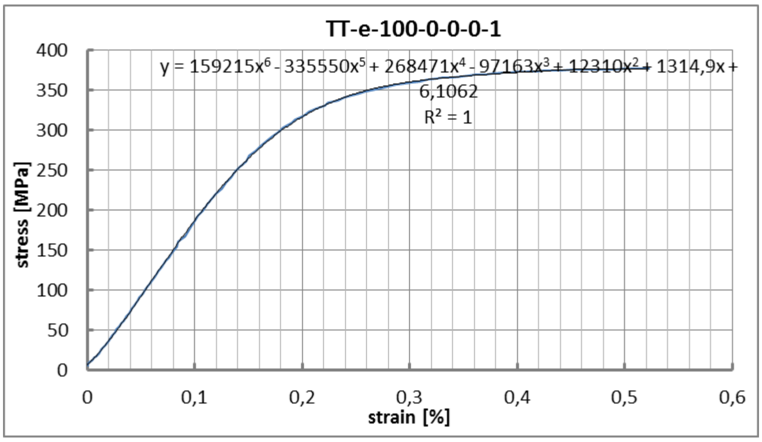


Fig. 2.2.1.39

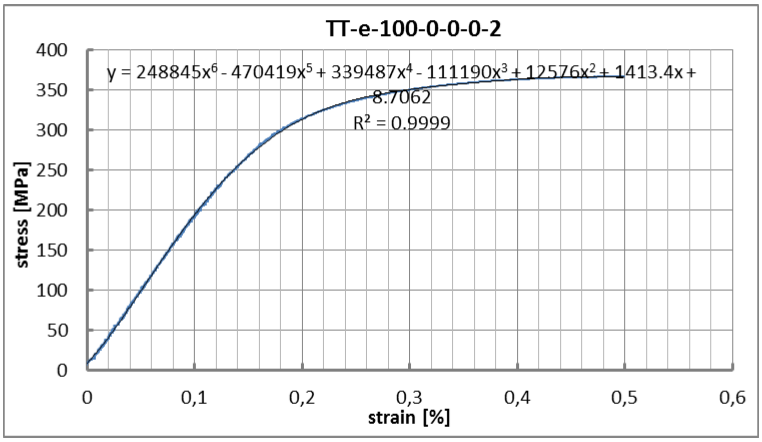


Fig. 2.2.1.40

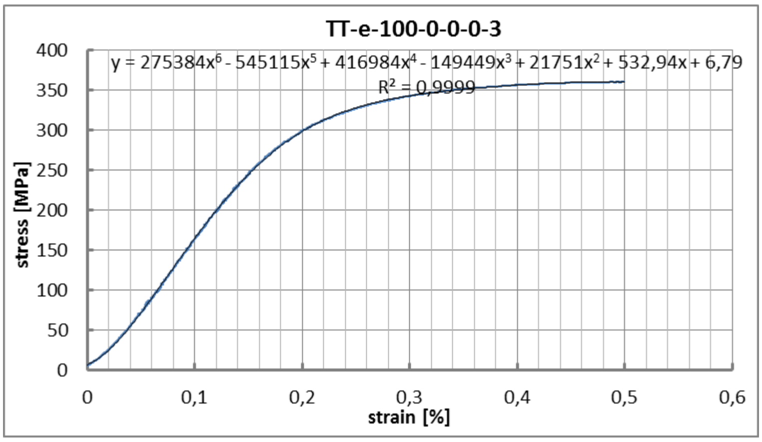


Fig. 2.2.1.41

Average equation curve:

y=227814.666*x^6-450361.333*x^5+341647.333*x^4-119267.333*x^3+15545.667*x^2+1087.08*x +7.201

Determination of the yield strength value (see. Fig. 2.2.1.42)

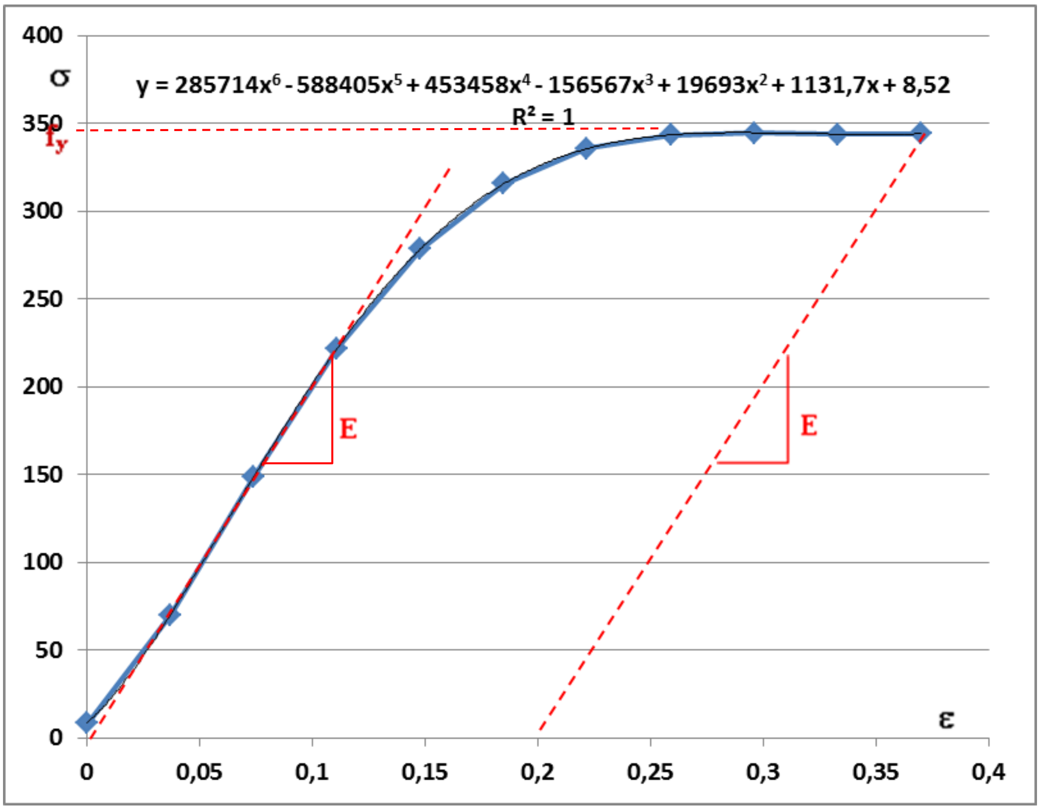


Fig. 2.2.1.42

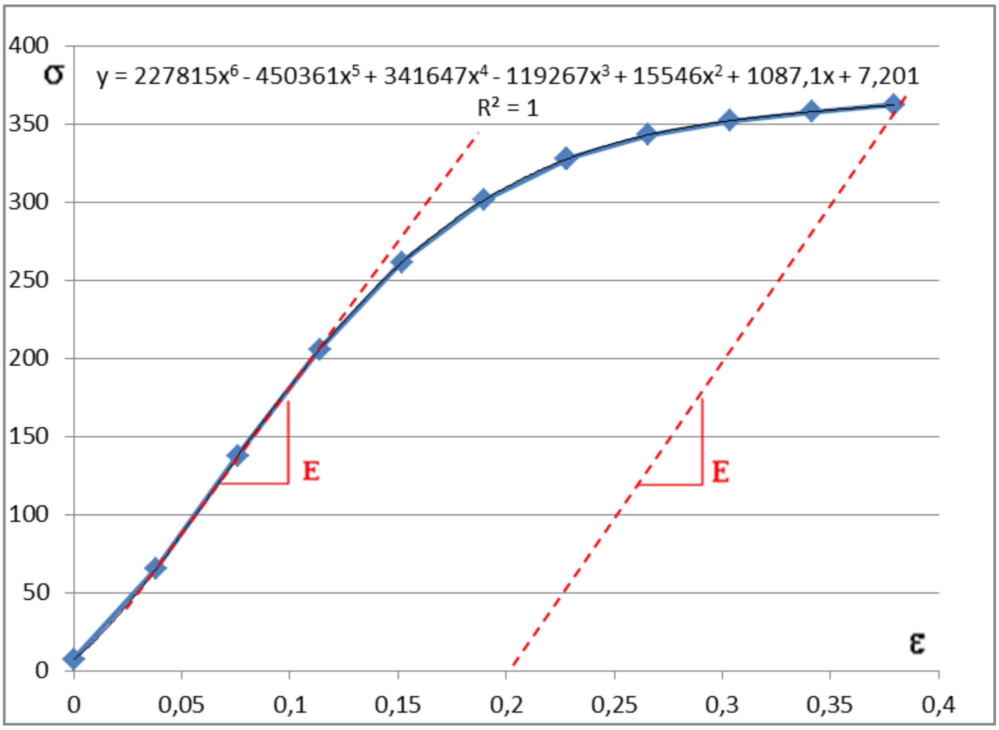


Fig. 2.2.1.43

Determination of the f_y value

The f_y value is defined by the 2 equations system:

$y = 227815x^6 - 450361x^5 + 341647x^4 - 119267x^3 + 15546x^2 + 1087.1x + 7.201$

$y = E*(x-0.2)$

The solution of the above equation system gives:

$y = 361.911991 = f_y$
$x = 0.37962 = \varepsilon_y$

The proportionality limit σ_p (see Fig. 2.2.1.7, point "3" on the curve) is assumed as being defined by 0.05% strain, as shown in the Fig. 2.2.1.44.

This is performed by solution of the two equation system:

$y = 227815x^6 - 450361x^5 + 341647x^4 - 119267x^3 + 15546x^2 + 1087.1x + 7.201$

$y = E*(x-0.05)$

The solution of the above equation system gives:

$y = 361.911991 = \sigma_p$
$x = 0.22859 = \varepsilon_p$

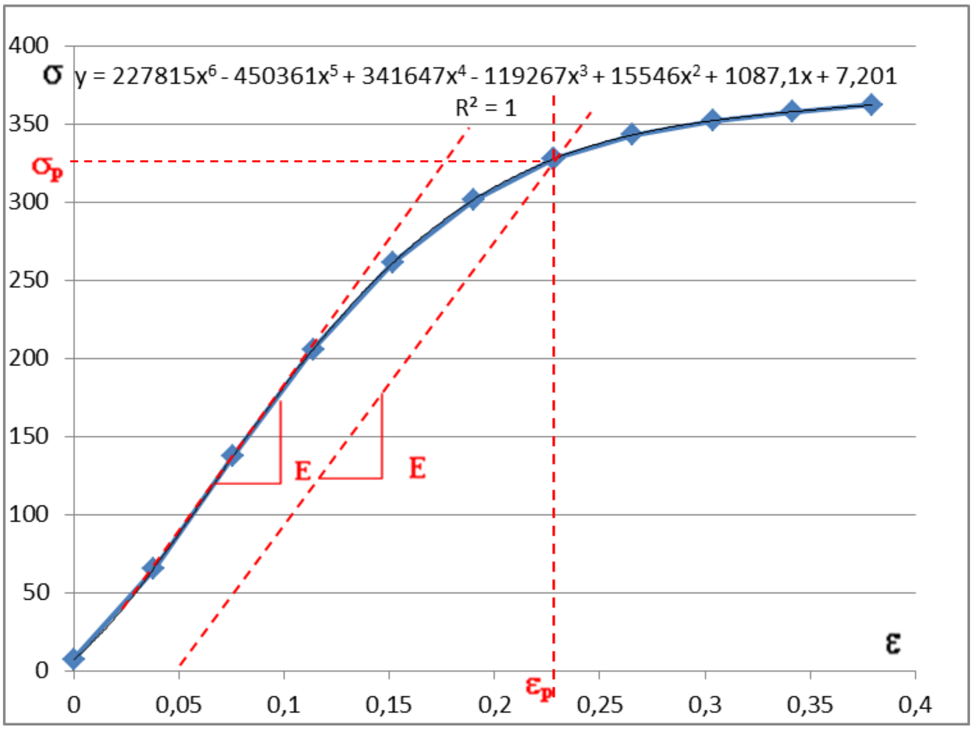


Fig. 2.2.1.44 Determination of the proportionality limit

The curve σ - ε diagram is replaced by two broken lines diagram:

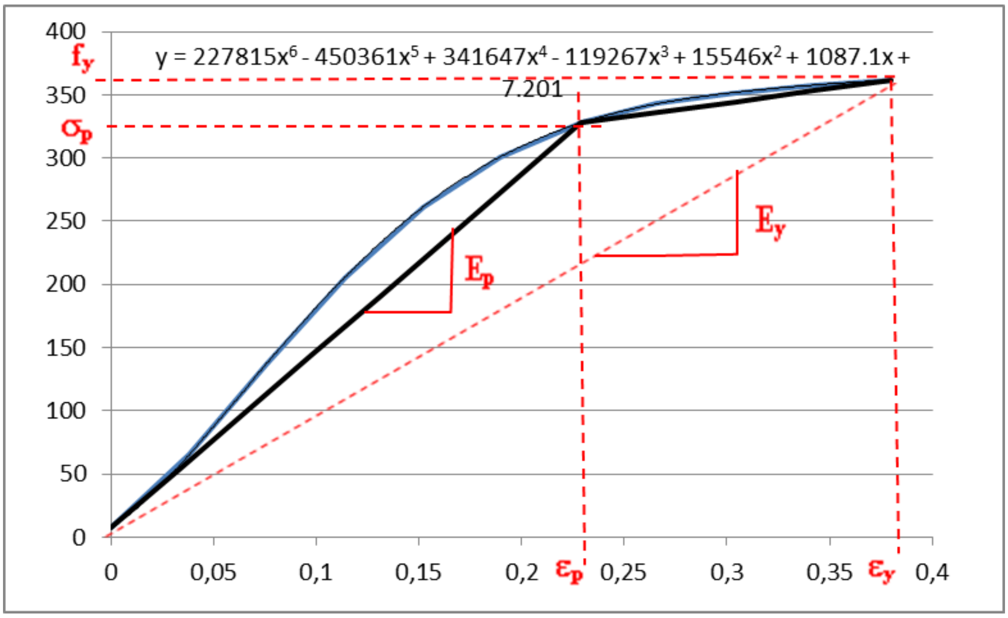
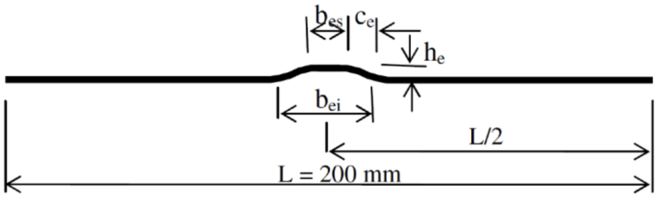


Fig. 2.2.1.45 Simplified bi-linear diagram (black line)

The E_p is to be used in the area 0 - σ_p
The E_y is to be used in the area σ_p - f_y

Folded samples



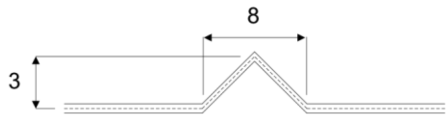
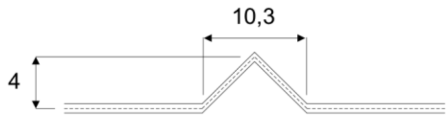
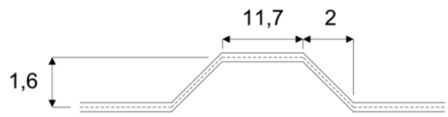
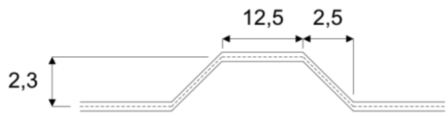
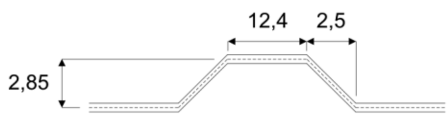
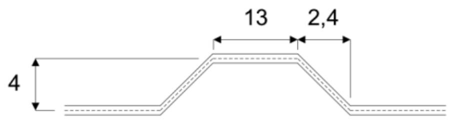
Test	Core thickness t_K [mm]	Measured height $h_e + t_N$ [mm]	Geometry according to Joris Ide [mm]
TT-e-100-0-0-0-1	0.934	-	
TT-e-100-0-0-0-2	0.931	-	
TT-e-100-0-0-0-3	0.934	-	
TT-e-100-1-1-0-1	0.935	2.31	-
TT-e-100-1-1-0-2	0.928	2.31	
TT-e-100-1-2-0-3	0.938	2.33	
TT-e-100-2-2-0-1	0.930	3.24	-
TT-e-100-2-2-0-2	0.933	3.25	
TT-e-100-2-2-0-3	0.935	3.24	
TT-e-100-3-3-0-1	0.931	4.00	
TT-e-100-3-3-0-2	0.934	3.96	
TT-e-100-3-3-0-3	0.927	3.94	
TT-e-100-4-4-0-1	0.930	4.85	
TT-e-100-4-4-0-2	0.934	4.85	
TT-e-100-4-4-0-3	0.933	4.91	
TT-e-100-1-1-10-1	0.934	2.40	
TT-e-100-1-1-10-2	0.927	2.41	
TT-e-100-1-1-10-3	0.934	2.40	
TT-e-100-2-2-10-1	0.928	3.39	
TT-e-100-2-2-10-2	0.933	3.35	
TT-e-100-2-2-10-3	0.934	3.34	
TT-e-100-3-3-10-1	0.934	3.57	
TT-e-100-3-3-10-2	0.931	3.57	
TT-e-100-3-3-10-3	0.928	3.56	
TT-e-100-4-4-10-1	0.934	5.06	
TT-e-100-4-4-10-2	0.933	5.11	
TT-e-100-4-4-10-3	0.934	5.10	

Table 2.2.1.2 – Results of tensile tests with embossments, nominal thickness $t_N = 1$ mm

Diagrams in the area 0 - ε_y

TT-e-100-1-1-0

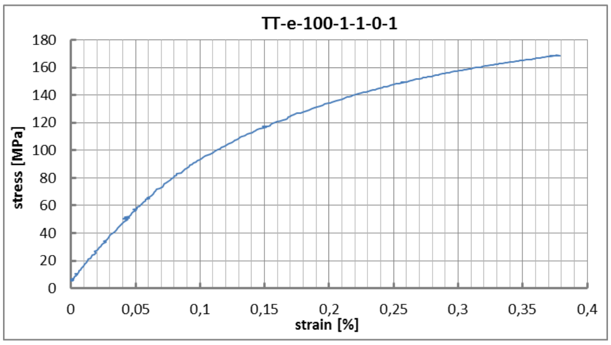


Fig. 2.2.1.46

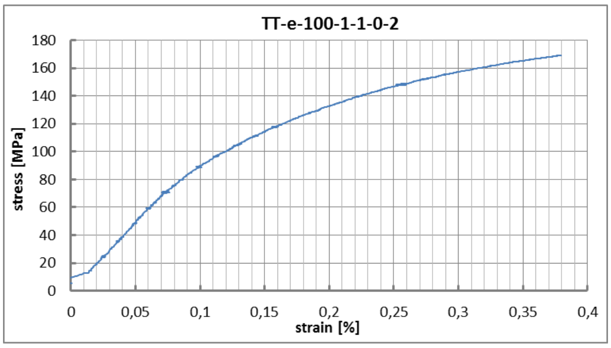


Fig. 2.2.1.47

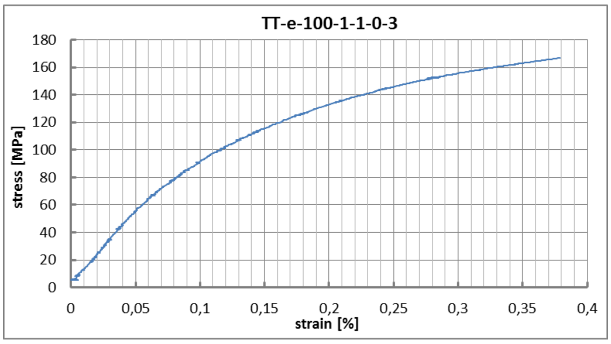


Fig. 2.2.1.48

TT-e-100-1-1-10

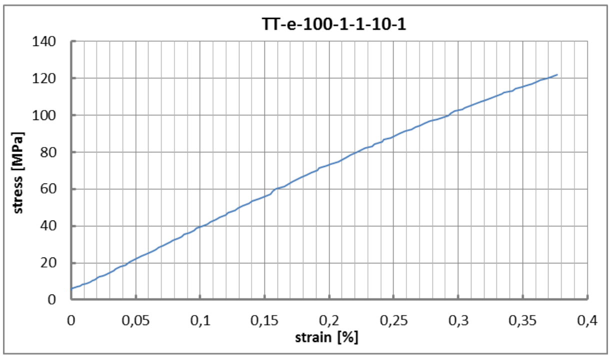


Fig. 2.2.1.49

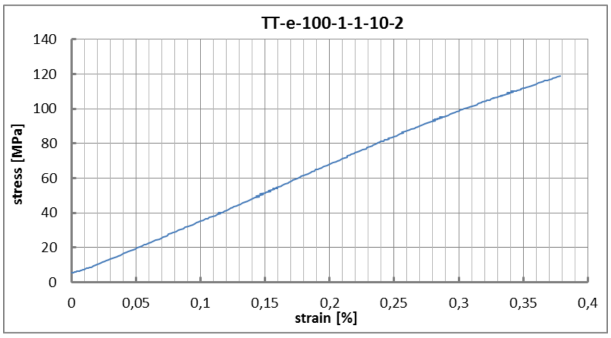


Fig. 2.2.1.50

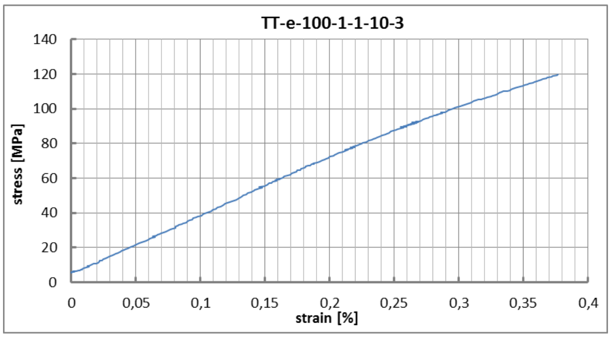


Fig. 2.2.1.51

TT-e-100-2-2-0

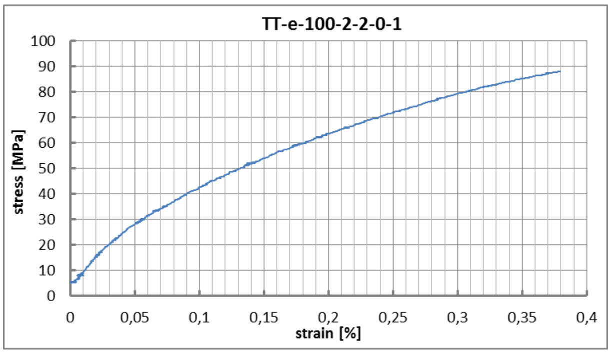


Fig. 2.2.1.52

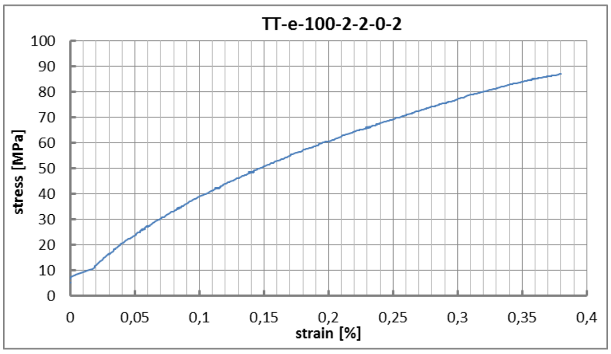


Fig. 2.2.1.53

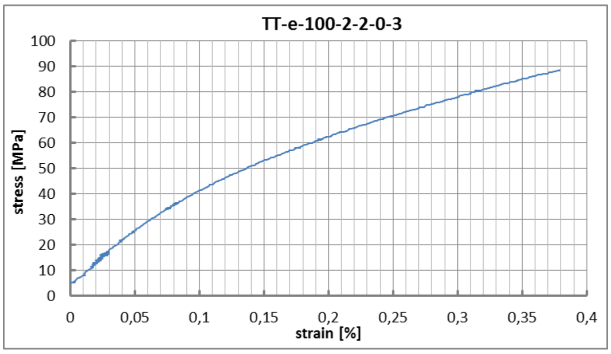


Fig. 2.2.1.54

TT-e-100-2-2-10

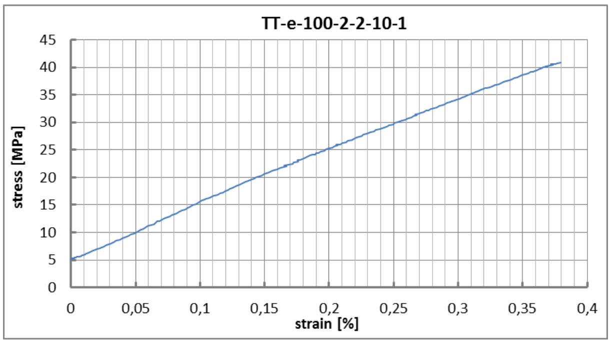


Fig. 2.2.1.55

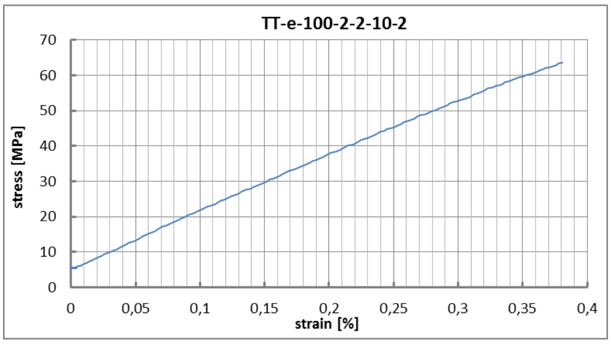


Fig. 2.2.1.56

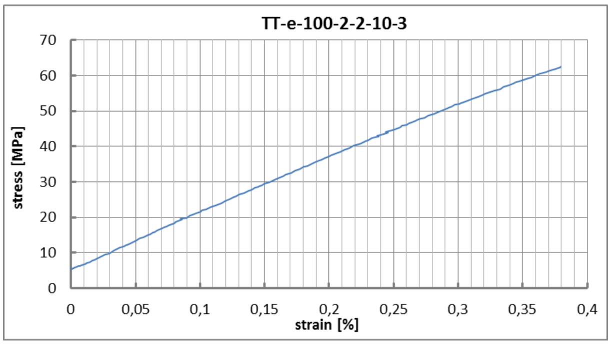


Fig. 2.2.1.57

TT-e-100-3-3-0

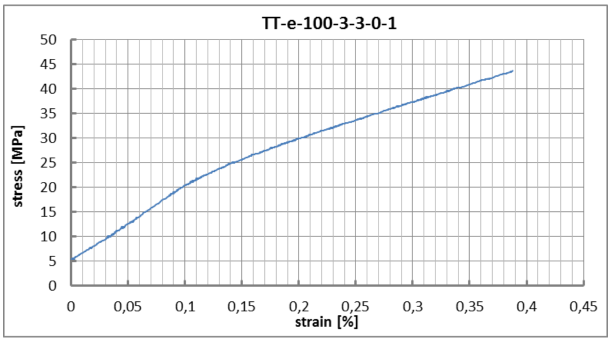


Fig. 2.2.1.58

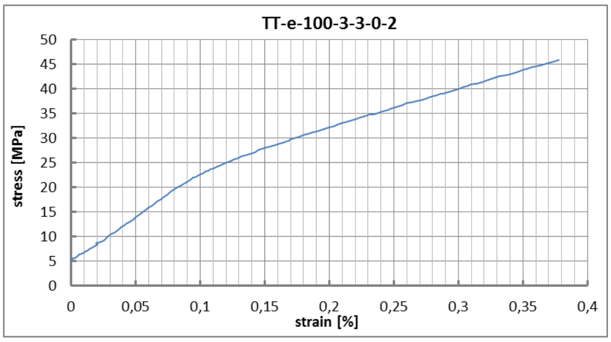


Fig. 2.2.1.59

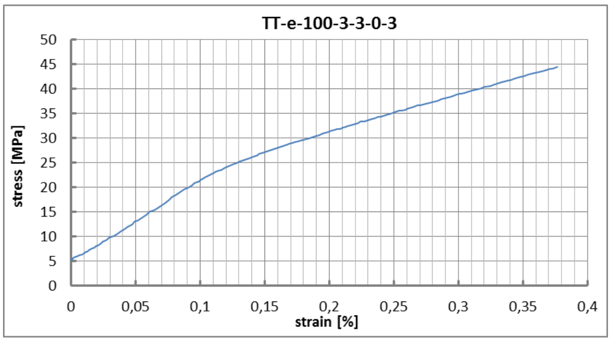


Fig. 2.2.1.60

TT-e-100-3-3-10

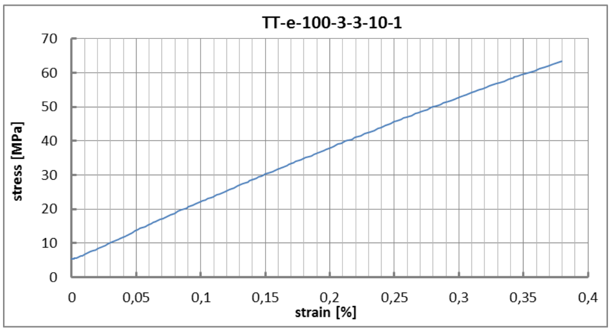


Fig. 2.2.1.61

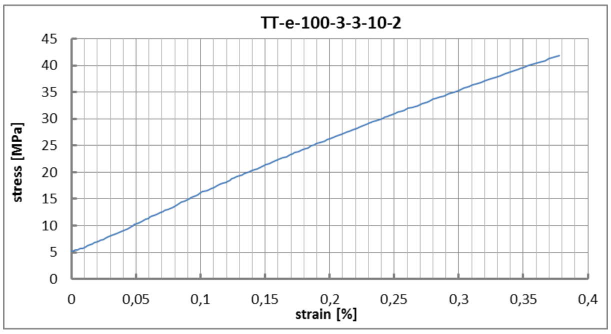


Fig. 2.2.1.62

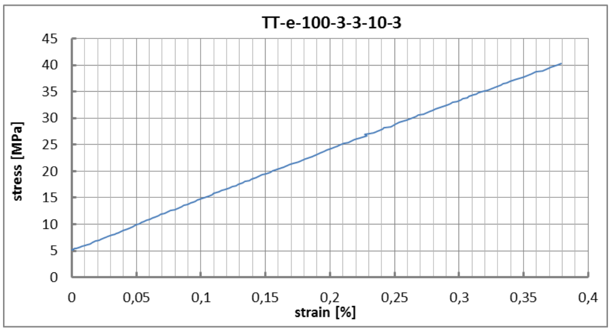


Fig. 2.2.1.63

TT-e-100-4-4-0

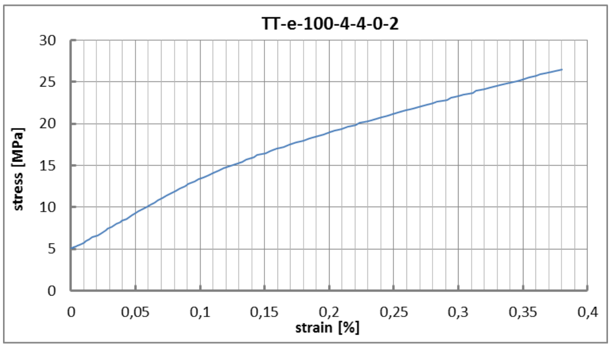


Fig. 2.2.1.64

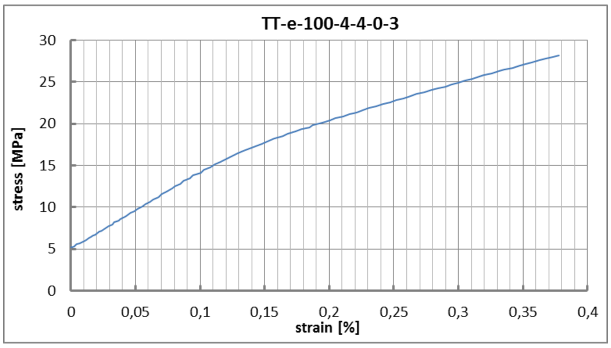


Fig. 2.2.1.65

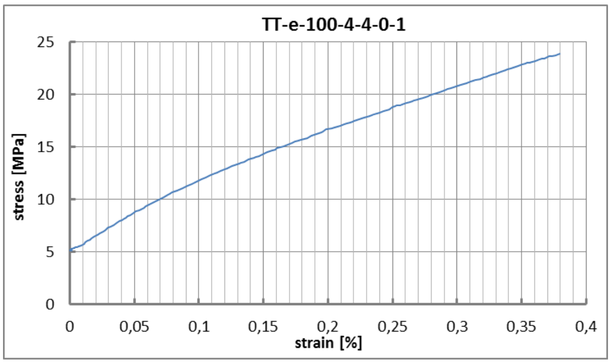


Fig. 2.2.1.66

TT-e-100-4-4-10

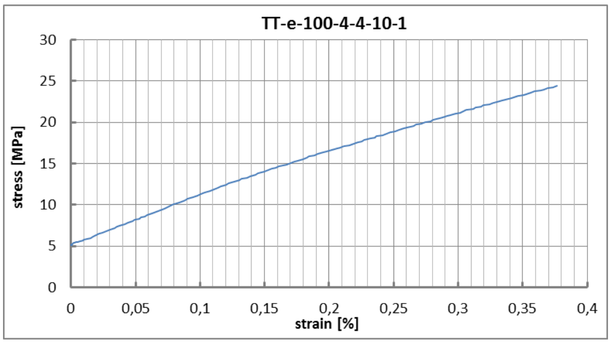


Fig. 2.2.1.67

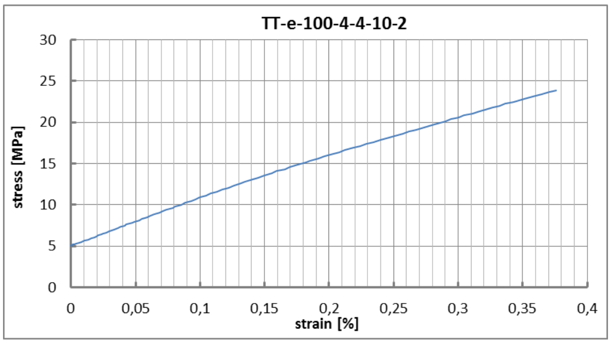


Fig. 2.2.1.68

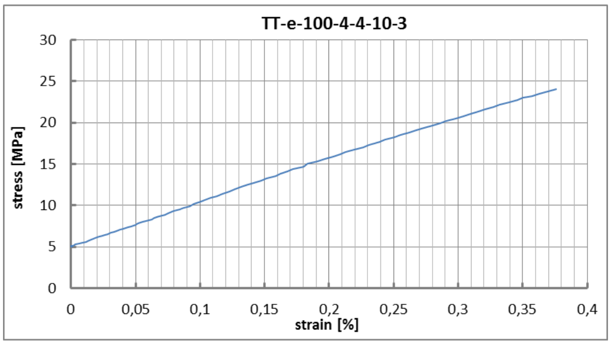


Fig. 2.2.1.69

The above diagrams corresponding to the folded samples are interpreted in the similar manner as the diagram corresponding to the flat samples (see Fig. 2.2.1.45) illustrated on the example of the sample TT-e-075-1-1-0-1:

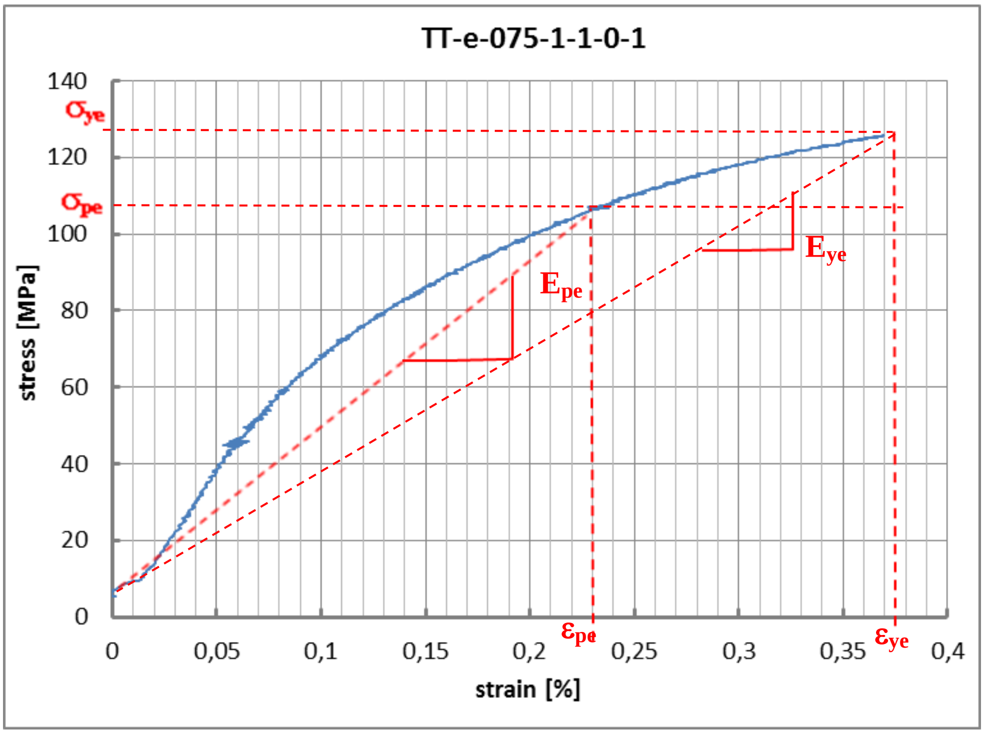


Fig. 2.2.1.70

Remark:
In the Figure 2.2.1.70 ε_{pea} and ε_{yea} are those defined for the plate samples:
$\varepsilon_{pea} = \varepsilon_{pa} = 0.22859$
$\varepsilon_{yea} = \varepsilon_{ya} = 0.37962$

the σ_{pe} and σ_{ye} are the actual stresses in the given folded sample corresponding to ε_{pa} and ε_{ya} strains.

The evolution of the stress depending on the strain simultaneously for both types of samples: flat (blue line) and embossed (black line), is shown in the Fig. 2.2.1.71:

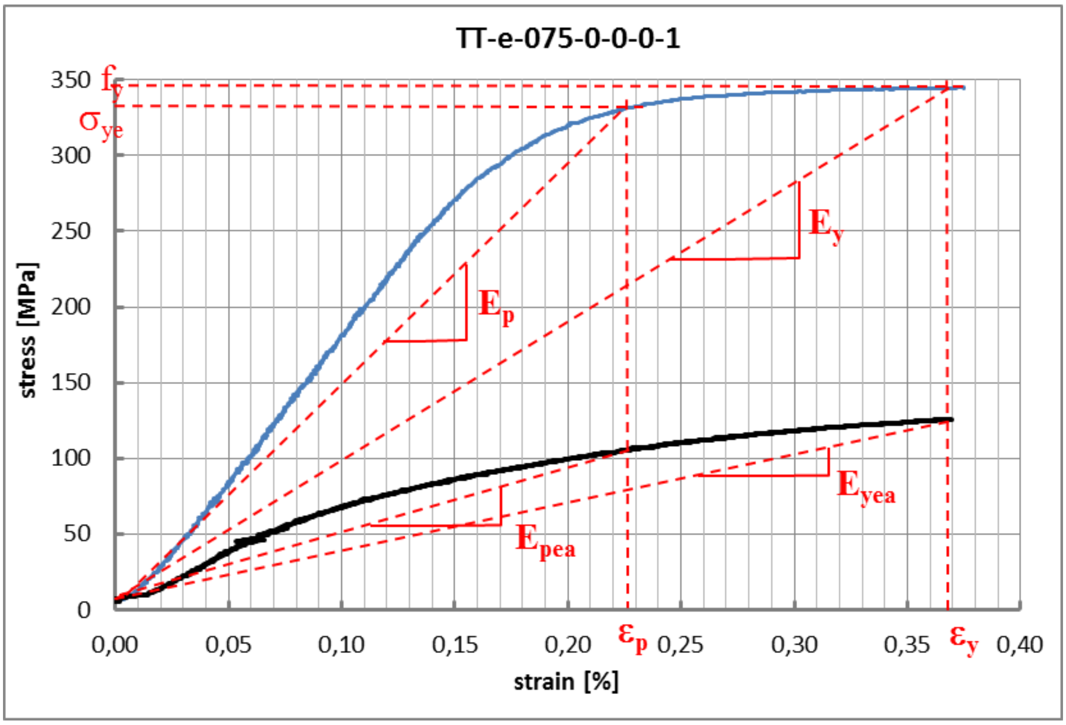


Fig. 2.2.1.71

2.2.2. Determination of the effectiveness of embossed part of the section

From the above tests results, using the Navier's plane strain section hypothesis we can now derive the effective stress in the embossed part of the section wall (see the Fig. 2.2.1)

In the first step is defined the relation between the stiffness of the flat coupon and the global stiffness of the embossed coupon tests for the same strain ε.

The elongation of the flat coupon under stress σ_f is:

$$\Delta L_f = \frac{L_0}{E_f}\sigma_f = \frac{\sigma_f}{K_f} \qquad (2.1)$$

The elongation of the embossed coupon under stress σ_{ea} is:

$$\Delta L_{ea} = \frac{L_0}{E_{ea}}\sigma_{ea} = \frac{\sigma_{ea}}{K_{ea}} \qquad (2.2a)$$

where:

E_f is the Young's modulus measured on the flat coupon
E_{ea} is the Young's modulus measured on the embossed coupon
K_f is the stiffness constant of the flat coupon = L_0/E_f
K_{ea} is the stiffness constant of the embossed coupon = L_0/E_{ea}
The "a" index is used to point out that this is an average value obtained on the embossed coupon containing the embossed and flat parts

The same strain in both coupons occurs when $\Delta L_f = \Delta L_{ea}$, so comparing (2.1) and (2.2a) we obtain:

$$K_{ea} = \frac{s_{ea}}{s_f} K_f$$

In the second step is defined the relation between the stiffness of the flat coupon and the local stiffness of the embossment for the same strain ε.

For this, we observe that the elongation ΔL_{ea} can be also expressed as:

$$\Delta L_{ea} = \frac{\sigma_{ea}}{K_f} + \frac{\sigma_{ea}}{K_e} \qquad (2.2b)$$

Comparing (2.2a) and (2.2b) we obtain the equation defining the local stiffness factor of the embossment:

$$K_e = \frac{K_f K_{ea}}{K_f - K_{ea}} \qquad (2.3)$$

This behaviour model leads to a notion of the effective (equivalent) thickness

$$t_{eff} = \rho * t \qquad (2.4)$$

of the embossment, where:

$$\rho = \frac{K_e}{K_f} \qquad (2.5)$$

This ratio is variable depending on the stress level.
In the Tables 2.2.2.1 and 2.2.2.2 are presented the ρ ratios for the two stress levels shown in the Fig. 2.2.1.7:
- σ_{ye} (elastic limit stress)
- f_y (yiel stress)
and for different thickness t=0.75 mm and t=1.00 mm.

	K_p	K_{pea}	K_{pe}	K_y	K_{yea}	K_{ye}	ratio ρ	
	N/mm²/mm						K_{pe}/K_p	K_{ye}/K_y
TT-e-075-1-1-0	1893	573	821	1133	411	645	0.4339	0.5690
TT-e-075-1-1-10		315	378		297	403	0.1995	0.3553
TT-e-075-2-2-0		199	223		158	184	0.1177	0.1624
TT-e-075-2-2-10		115	123		111	123	0.0650	0.1088
TT-e-075-3-3-0		138	149		117	130	0.0788	0.1150
TT-e-075-3-3-10		103	109		95	104	0.0575	0.0920
TT-e-075-4-4-0		57	59		49	51	0.0310	0.0451
TT-e-075-4-4-10		40	41		37	39	0.0214	0.0341

Table 2.2.2.1 – Ratios ρ for the different coupons t = 0,75 mm

	K_p	K_{pea}	K_{pe}	K_y	K_{yea}	K_{ye}	ratio ρ	
	N/mm²/mm						K_{pe}/K_p	K_{ye}/K_y
TT-e-100-1-1-0	1768	745	1288	1172	535	984	0.7283	0.8396
TT-e-100-1-1-10		408	531		380	563	0.3003	0.4806
TT-e-100-2-2-0		338	418		273	357	0.2362	0.3044
TT-e-100-2-2-10		174	193		166	194	0.1092	0.1653
TT-e-100-3-3-0		153	167		129	145	0.0947	0.1240
TT-e-100-3-3-10		117	125		111	122	0.0709	0.1044
TT-e-100-4-4-0		81	85		69	74	0.0480	0.0630
TT-e-100-4-4-10		68	71		63	67	0.0400	0.0570

Table 2.2.2.2 – Ratios ρ for the different coupons t = 1,00 mm

Another presentations of ρ values depending on the h_e (Table 2.2.2.1 and Table 2.2.2.2) and b_{ei} dimensions are given in the Table 2.2.2.3 and 2.2.2.4.

h_e		$\rho_p = K_{pe}/K_p$		$\rho_y = K_{ye}/K_y$	
b_{ei}=0	b_{ei}=10	b_{ei}=0	b_{ei}=10	b_{ei}=0	b_{ei}=10
1,38	1,65	0,4339	0,1995	0,5690	0,3553
2,54	2,61	0,1177	0,0650	0,1624	0,1088
3,22	2,82	0,0788	0,0575	0,1150	0,0920
4,12	4,34	0,0310	0,0214	0,0451	0,0341

Table 2.2.2.3 Ratios ρ depending on the h_e et b_{ei} dimensions for t = 0,75 mm

h_e		$\rho_p = K_{pe}/K_p$		$\rho_y = K_{ye}/K_y$	
b_{ei}=0	b_{ei}=10	b_{ei}=0	b_{ei}=10	b_{ei}=0	b_{ei}=10
1,32	1,4	0,7283	0,3003	0,8396	0,4806
2,24	2,36	0,2362	0,1092	0,3044	0,1653
2,97	2,57	0,0947	0,0709	0,1240	0,1044
3,87	4,09	0,0480	0,0400	0,0630	0,0570

Table 2.2.2.4 Ratios ρ depending on the h_e et b_{ei} dimensions for t = 1,00 mm

Considering the variation of the ratios ρ depending of the stress level, the question arises as to the choice ρ value for the determination of the effective thickness t_{eff} .

Three cases are regarded:
1. Section under axial normal force (traction of compression): in this case the stress are constant over whole section so the representative safe value is $\rho_p=K_{pe}/K_p$
2. Section under bending: the stress level is varying, depending on the distance of the embossment to the neutral axis
3. Section under combiner action under normal force and bending: the stress level is varying, depending on the distance of the embossment to the neutral axis, as in the case 2.

It is obvious that taking into account of the ratio ρ depending on the stress level in the embossment is excessively complex and not adapted for a current practice.
The practical solution is then to take a constant safe ρ value, regardless the stress level in the embossment.
One observes that in the cases 1 and 2 the bigger is distance to the neutral axis, the bigger is the influence of the t_{eff} variation on the inertia moment. In conclusion, also in this case the adoption of the $\rho_p=K_{pe}/K_p$ seems to be the most rational safe choice.

We observe that the sheeting with embossment is designated to the composite slabs, where it is working under simultaneous action of bending and traction: near the support the predominant action is bending and increasing the distance from the support the tension gradually becomes predominant.
In conclusion the $\rho_p=K_{pe}/K_p$ is proposed (taking the minimum value of ρ between ρ (b_{ei} = 0 mm) and ρ (b_{ei} = 10 mm) for safety reason) to be generally adopted for the evaluation of the effective thickness of the embossment: $t_{eff} =\rho_p *t$. This ratio is then calculated for the height of the embossment, making an interpolation between the h_e bracketing the value (Table 2.2.2.5 and Table 2.2.2.6)

t = 0,75 mm	
h_e (mm)	$\rho_p = K_{pe}/K_p$
0	1.000
1.5	0.221
2	0.150
2.5	0.080
2.75	0.060
3	0.053
3.5	0.041
4	0.029

Table 2.2.2.5 Ratios ρ depending on the h_e dimensions for t = 0,75 mm

t = 1 mm	
h_e (mm)	$\rho_p = K_{pe}/K_p$
0	1.000
1.5	0.280
2	0.181
2.5	0.084
2.75	0.067
3	0.062
3.5	0.052
4	0.042

Table 2.2.2.6 Ratios ρ depending on the h_e dimensions for t = 1 mm

3. STUDY ON CALCULATION METHOD OF STEEL DECKS WITH EMBOSSMENTS / INDENTATIONS

Resistances of the profiles PCB 60 and PCB 80 without and with embossments / indentations are calculated in order to be compared to the test results presented in § 2.2.

The profiles (with and without embossments / indentations) resistance is calculated according to EN 1993-1-3.
The geometrical proportions *b/t*, *h/t*, *c/t* and *d/t* are inside the range of width to thickness given in Table 3.1. (Table 5.1 of EN 1993-1-3)

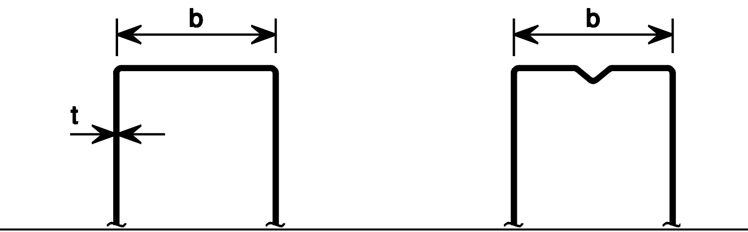
	$b/t \leq 500$
	$45° \leq \phi \leq 90°$ $h/t \leq 500 \sin\phi$

Table 3.1 - Maximum width to thickness ratios

For the comparison the tests results are not adjusted and the calculation are made with the actual observed properties and geometry of the test specimen.

3.1. Span moment resistance

3.1.1. Resistance values of profiles without embossments / indentations

The moment resistances of the effective section are calculated according to EN 1993-1-3 and are compared to the values defined by testing for PCB 60 in Table 3.1.1.1 and for PCB 80 in Table 3.1.1.2.

PCB 60:

The tested profile properties are:
t= 0,698 mm and f_{yb} = 341 N/mm^2
t= 0,932 mm and f_{yb} = 364 N/mm^2

PCB 60			
t_{nom}	M_R (kN*m/m)		
mm	Test	Calculation	
0.75	5.03	4.85	**3.8%**
1.00	7.40	7.23	**2.3%**

Table 3.1.1.1 – Comparison between calculated and defined by testing resistances moment for PCB 60

PCB 80:

The tested profile properties are:
t= 0,684 mm and f_{yb} = 363 N/mm^2
t= 0,961 mm and f_{yb} = 370 N/mm^2

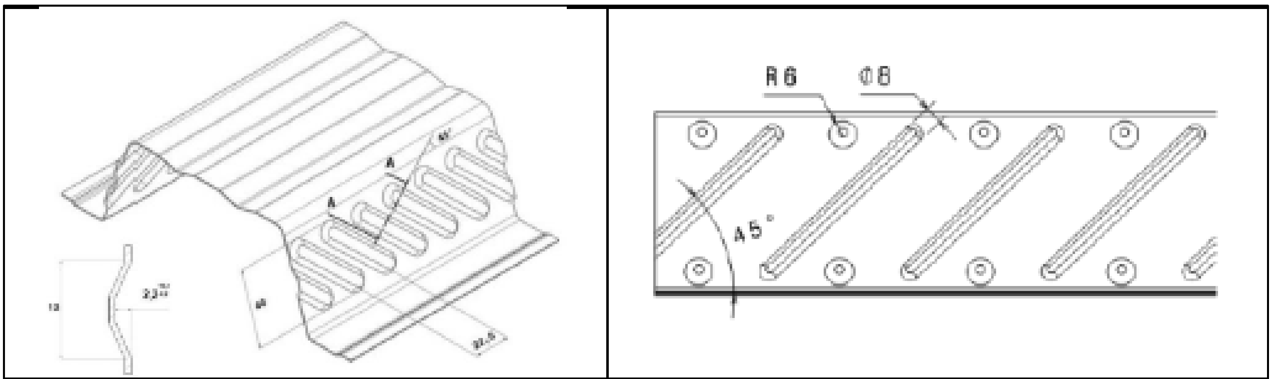
PCB 80			
t_{nom}	M_R (kN*m/m)		
mm	Test	Calculation	
0.75	9.00	8.45	**6.1%**
1.00	13.62	12.24	**10.1%**

Table 3.1.1.2 – Comparison between calculated and defined by testing resistances moment for PCB 80

The calculated resistance moments are lower than the tested ones, from 2,3% to 3,8% for PCB 60 and from 6,1% to 10,1% for PCB 80.

3.1.2. Resistance values of profiles with embossments / indentations

The moment resistances of the effective section are calculated according to EN 1993-1-3, considering the embossments / indentations (Fig. 3.1.2.1) as plate elements with a reduced thickness $t_{red} = \rho * t$ where the ratio ρ defined according to § 2.2.2 .



PCB 60	PCB 80

Fig. 3.1.2.1- Embossments / indentations

For both PCB 60 and PCB 80 the calculation is performed in different cross sections in order to determine the section which induces the most important reduction of the resistance moment.

PCB 60:

Ratio ρ is defined according to Tables 2.2.2.5 and 2.2.2.6 for thickness t = 0,75 mm and t = 1 mm., considering the height of embossments "h_e"

Ratio ρ values defined in this way are presented in Table 3.1.2.1:

t (mm)	0,75	1
ratio ρ for PCB 60	0,150	0,201

Table 3.1.2.1 - Ratio ρ values of embossments of PCB 60

The tested profile properties are:
t= 0,698 mm and f_{yb} = 341 N/mm^2
t= 0,932 mm and f_{yb} = 364 N/mm^2

In Table 3.1.2.2 the calculated resistance moments and the defined by testing resistance moments are presented. The calculation of M_R = 4,42 kN*m/m for t=0,75mm is explained in Annex A.

PCB 60 with embossments			
t_{nom}	M_R (kN*m/m)		
mm	Test	Calculation	
0.75	4.54	4.42	**2.7%**
1.00	7.07	6.69	**5.3%**

Table 3.1.3.2 – Comparison between calculated and defined by testing resistance moment for PCB 60 with embossments

	Embossment influence	
	Test	Calculation
0.75	-9.7%	-8.8%
1.00	-4.4%	-7.4%

Table 3.1.2.3 – Embossment influence on resistance moment defined by testing and calculation for PCB 60

As shown in the tables 3.1.2.2 the calculated resistance moments are lower than the tested ones from 2,7% to 5,3%.

PCB 80:

Ratio ρ is defined according to Tables 2.2.2.5 and 2.2.2.6 for thickness t = 0,75 mm and t = 1 mm., considering the height of the embossments "h_e" (the height of the conical embossment = the height of the longitudinal embossment Fig. 3.1.2.2)

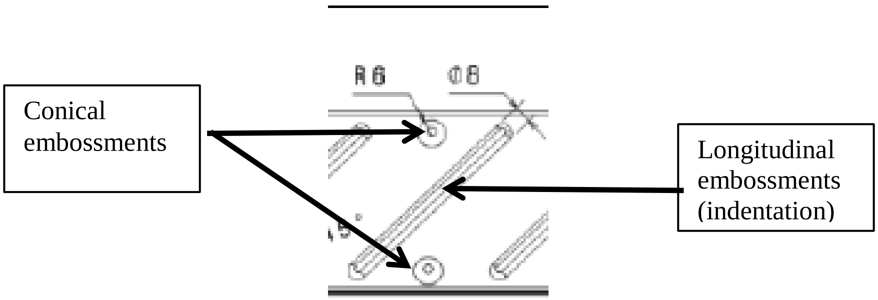


Fig. 3.1.2.2 Conical embossments and longitudinal embossments (indentation) of PCB 80

t (mm)	0,75	1
ratio ρ for PCB 80	0,179	0,221

Table 3.1.2.4 - Ratio ρ values of embossments of PCB 80

The tested profile properties are:
t= 0,684 mm and f_{yb} = 363 N/mm^2
t= 0,961 mm and f_{yb} = 370 N/mm^2

In Table 3.1.2.5 are presented calculated resistance moments (with Ratio ρ from Table 3.1.2.4) and resistance moments defined by testing

PCB 80 with embossments			
t_{nom}	M_R (kN*m/m)		
mm	Test	Calculation	
0,75	8,69	7,13	18,0%
1,00	13,06	10,42	20,2%

Table 3.1.2.5 – Comparison between calculated and defined by testing resistance moment for PCB 80 with embossments

Based on these ρ values, the calculated resistance moment is underestimated comparing to resistance moment defined by testing. Therefore the assumption is made that a conical embossment has an influence less important than a longitudinal indentation, therefore for the conical embossments ratio ρ is calibrated on the mean value between 1 (corresponding to the case without embossment) and the value for the height "h_e" of a longitudinal embossment

ratio ρ conical =(1+ratio ρ longitudinal)/2

Ratio ρ values defined in this way are presented in Table 3.1.2.6:

t (mm)	0,75	1
ratio ρ for longitudinal embossments	0,179	0,221
ratio ρ for conical embossments	0,589	0,610

Table 3.1.2.6 - Ratio ρ values of conical embossments and longitudinal embossments (indentation) of PCB 80

In Table 3.1.2.7 are presented calculated resistance moments (with ratio ρ from Table 3.1.2.6) and resistance moments defined by testing

PCB 80 with embossments			
t_{nom}	M_R (kN*m/m)		
mm	Test	Calculation	
0.75	8.69	7.77	**10.6%**
1.00	13.06	11.28	**13.6%**

Table 3.1.2.7 – Comparison between calculated and defined by testing resistance moment for PCB 80 with embossments

	Embossment influence	
	Test	Calculation
0.75	-3.5%	-8.1%
1.00	-4.1%	-7.8%

Table 3.1.2.8 – Embossment influence on resistance moment defined by testing and calculation for PCB 80

As shown in the tables 3.1.2.7, taking for the conical embossments ratio ρ equal to the mean value between 1 and the value for the height "h_e" and for the longitudinal embossment ratio ρ value for the height "h_e" gives results closer to the test results and still lower, from 10,6% to 13,6%.

We can conclude that for PCB 60 with embossments and for PCB 80 with embossments the differences between calculation and testing are similar to the differences observed for the profiles without embossments.

Moreover the decrease induced by embossments defined by calculation for PCB 60 and for PCB 80 varies from 7,4% to 8,8% which is consistent with the decrease defined by testing (from 3,5% to 9,7%) (Table 3.1.2.3 and 3.1.2.8).

This comparison confirms that the calculation method for the resistance moment of the steel sheeting with embossments / indentations adopted in the present study gives the results that are coherent and in the same time safe in relation with the testing results.

3.2. Web crippling resistance

3.2.1. Web crippling resistance values of profiles without embossments / indentations

The web crippling resistances, calculated according to equation (6.18) EN 1993-1-3, are compared to the values defined by testing for PCB 60 in Table 3.2.1 and for PCB 80 in Table 3.2.2.

$$R_{w,Rd} = \alpha t^2 \sqrt{f_{yb} E} \left(1 - 0{,}1\sqrt{r/t}\right)\left[0{,}5 + \sqrt{0{,}02\, l_a / t}\right]\left(2{,}4 + (\phi/90)^2\right)/\gamma_{M1} \qquad (6.18)$$

PCB 60:

The tested profile properties are:
t= 0,698 mm and f_{yb} = 341N/mm^2
t= 0,932 mm and f_{yb} = 364 N/mm^2

PCB 60			
t_{nom}	R_R (kN/m)		
mm	Test	Calculation	
0,75	22,41	6,64	**70,4%**
1,00	37,03	11,99	**67,6%**

Table 3.2.1 – Comparison between calculated and defined by testing web crippling resistances for PCB 60

PCB 80:

The tested profile properties are:
t= 0,684 mm and f_{yb} = 363 N/mm^2
t= 0,961 mm and f_{yb} = 370 N/mm^2

PCB 80			
t_{nom}	R_R (kN/m)		
mm	Test	Calculation	
0.75	16.05	7.97	**50.4%**
1.00	29.84	15.14	**49.3%**

Table 3.2.2 – Comparison between calculated and defined by testing web crippling resistances for PCB 80

The calculated web crippling resistance at the end support is much lower than the tested one: about 50% for PCB 80 and about 70% for PCB 60.

This confirms the already noticed fact by M. Bakker [14] that web crippling prediction formula gives results different from test results.

3.2.2. Web crippling resistance values of profiles with embossments / indentations

As seen at § 3.1.2 the calculated web crippling resistance is much lower than the tested one. Moreover the difference between resistances with and without embossments is much lower than the difference between resistances calculated and tested (D1.4) therefore seek a fine solution would be illusory, and would not bring any practical advantage. Consequently, it is proposed to calculate web crippling resistance at support for profiles with embossments / indentations to take the usual formula (6.18) EN 1993-1-3

$$R_{w,Rd} = \alpha\, t^2 \sqrt{f_{yb} E}\, \left(1 - 0{,}1\sqrt{r/t}\right)\left[0{,}5 + \sqrt{0{,}02\, l_a / t}\right]\left(2{,}4 + (\phi/90)^2\right)/\gamma_{M1} \qquad (6.18)$$

3.3. Moment-Reaction interaction

The web crippling reaction is calculated according to EN 1993-1-3.

For the purposes of the present study, theoretical resistance to combined action of moment M_{Ed} and reaction R_{Ed}, (M-R theor.) used in the calculation model defined by the eq. (6.28c), EN 1993-1-3 is transformed in the following form:

$$\frac{M_E}{M_0} + \frac{R_E}{R_0} \leq 1 \qquad (1a)$$

$M_0 = 1.25M_{c,Rd}$ (1b)
$R_0 = 1.25R_{c,Rd}$ (1c)

These relations are presented in the Fig. 3:3.1

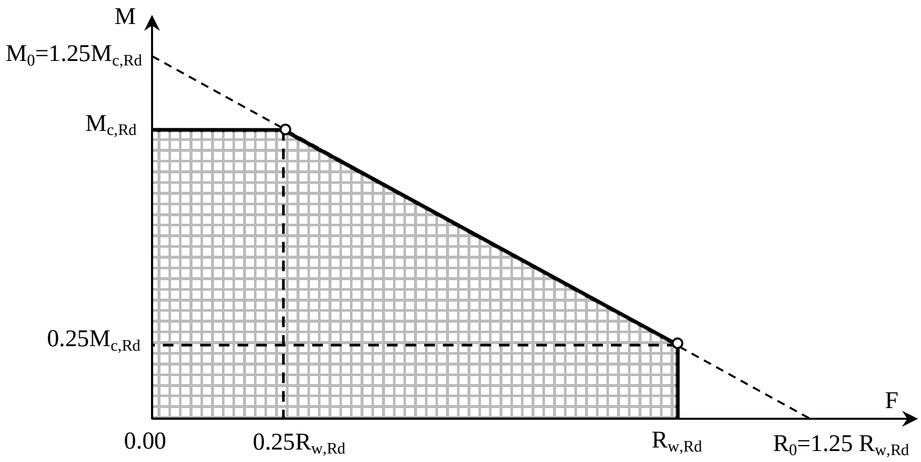


Fig. 3.3.1 Graphical presentation of the equation (1)

PCB 60:

The tested profile properties are:
t= 0,698 mm and f_{yb} = 341N/mm^2
t= 0,932 mm and f_{yb} = 364 N/mm^2

Ratio ρ is defined according to Tables 2.2.2.5 and 2.2.2.6 for thickness t = 0,75 mm and t = 1 mm., considering the height of embossments "h_e"

Ratio ρ values defined in this way are presented in Table 3.3.1:

t (mm)	0,75	1
ratio ρ for PCB 60	0,150	0,201

Table 3.3.1 - Ratio ρ values of embossments of PCB 60

In the Fig. 3.3.2 to 3.3.9 the results of theoretical calculation (black lines) according to the EN 1993-1-3 eq. (6.28) for profiles without embossment are compared to the results of testing without embossment (blue lines). On these graphs are also superposed the results of testing with embossments (green lines).

PCB 60 0.75mm, b_u=60mm without embossments

M_{Rk_max}	R_{Rk_min}
3,64	9,66

M_{Rk_min}	R_{Rk_max}
2,05	20,52

PCB 60 0.75mm, b_u=60mm with embossments

M_{Rk_max}	R_{Rk_min}
3,51	9,33

M_{Rk_min}	R_{Rk_max}
2,08	20,75

without embossment	
$M_{calculated}$	$R_{calculated}$
4,43	23,25

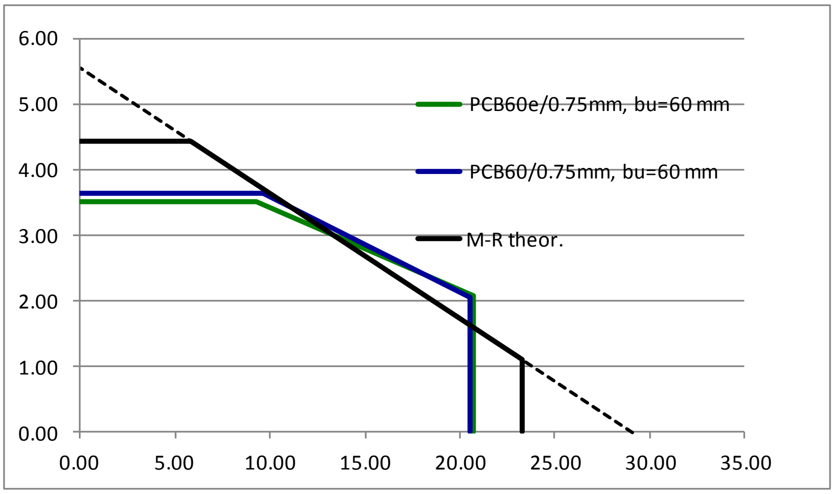


Fig. 3.3.2. Results for the profiles PCB60/0.75 mm, at the support width bu=60 mm

PCB 60 0.75mm, b_u=160mm without embossments

M_{Rk_max}	R_{Rk_min}
4,54	12,06

M_{Rk_min}	R_{Rk_max}
3,22	32,14

PCB 60 0.75mm, b_u=160mm with embossments

M_{Rk_max}	R_{Rk_min}
4,22	11,21

M_{Rk_min}	R_{Rk_max}
3,34	33,43

without embossment	
$M_{calculated}$	$R_{calculated}$
4,43	33,90

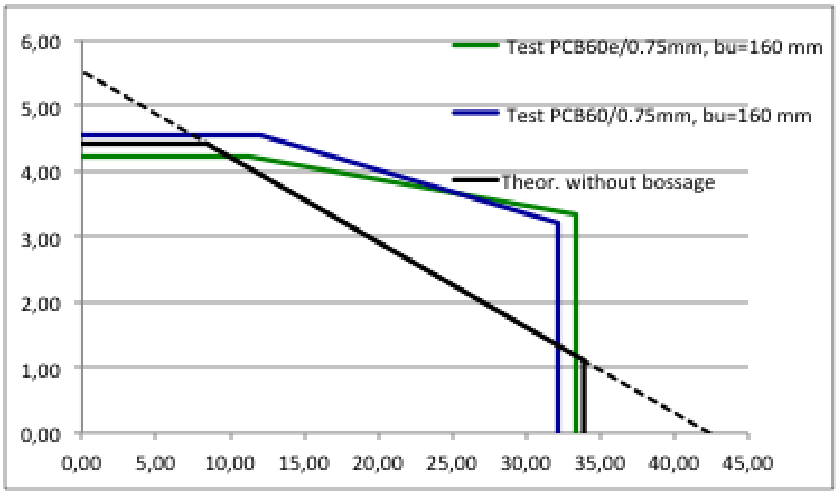


Fig. 3.3.3. Results for the profiles PCB60/0.75 mm, at the support width bu=160 mm

PCB 60 1.00mm, b_u=60mm without embossments

M_{Rk_max}	R_{Rk_min}
5,91	15,71

M_{Rk_min}	R_{Rk_max}
3,30	33,00

PCB 60 1.00mm, b_u=60mm with embossments

M_{Rk_max}	R_{Rk_min}
5,59	14,86

M_{Rk_min}	R_{Rk_max}
3,31	33,08

without embossment	
$M_{calculated}$	$R_{calculated}$
6,80	40,69

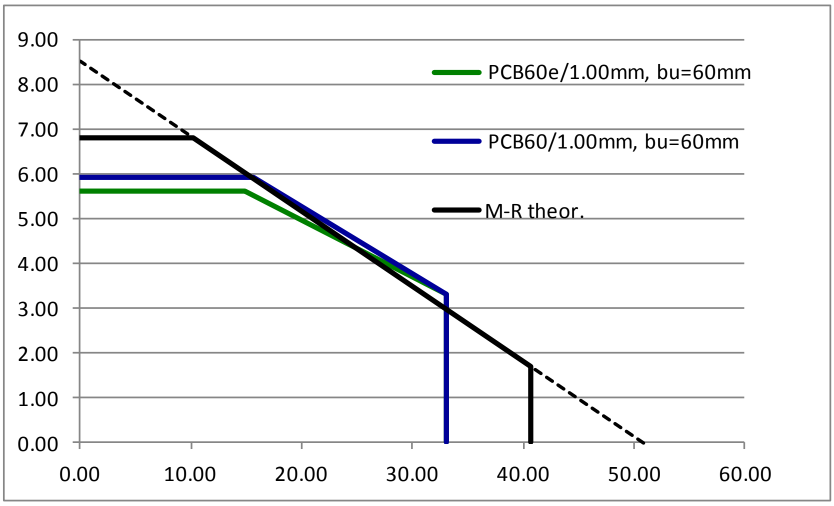


Fig. 3.3.4. Results for the profiles PCB60/1.00 mm, at the support width bu=60 mm

PCB 60 1.00mm, b_u=160mm without embossments

M_{Rk_max}	R_{Rk_min}
7,18	19,10

M_{Rk_min}	R_{Rk_max}
5,37	53,67

PCB 60 1.00mm, b_u=160mm with embossments

M_{Rk_max}	R_{Rk_min}
6,72	17,86

M_{Rk_min}	R_{Rk_max}
5,48	54,75

without embossment	
$M_{calculated}$	$R_{calculated}$
6,80	58,57

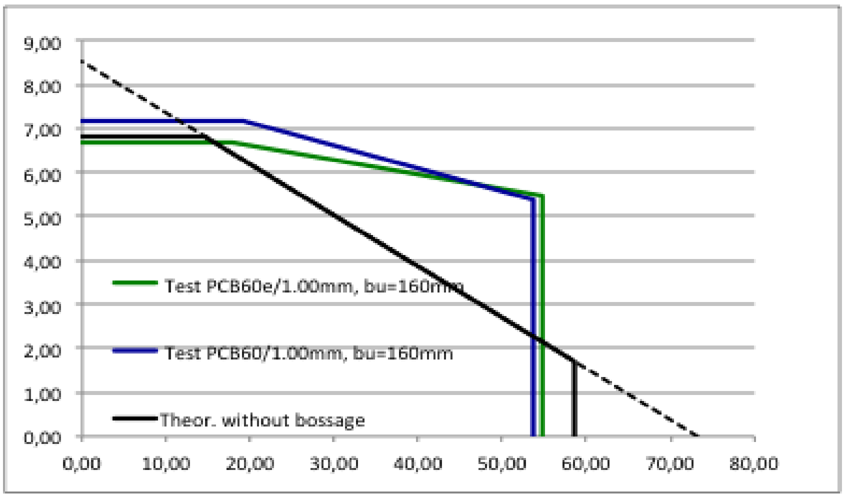


Fig. 3.3.5. Results for the profiles PCB60/1.00 mm, at the support width bu=160 mm

PCB 80:

The tested profile properties are:
t= 0,684 mm and f_{yb} = 363 N/mm^2
t= 0,961 mm and f_{yb} = 370 N/mm^2
Ratio ρ values defined in this way are presented in Table 3.3.2:

t (mm)	0,75	1
ratio ρ for longitudinal embossments	0,179	0,221
ratio ρ for conical embossments	0,589	0,610

Table 3.3.2 - Ratio ρ values of conical embossments and longitudinal embossments (indentation) of PCB 80

PCB 80 0.75mm, b_u=60mm
without embossments

M_{Rk_max}	R_{Rk_min}
4,58	10,72

M_{Rk_min}	R_{Rk_max}
2,98	23,82

PCB 80 0.75mm, bu=60mm
with embossments

M_{Rk_max}	R_{Rk_min}
4,56	10,69

M_{Rk_min}	R_{Rk_max}
2,99	23,94

without embossment	
$M_{calculated}$	$R_{calculated}$
5,86	29,34

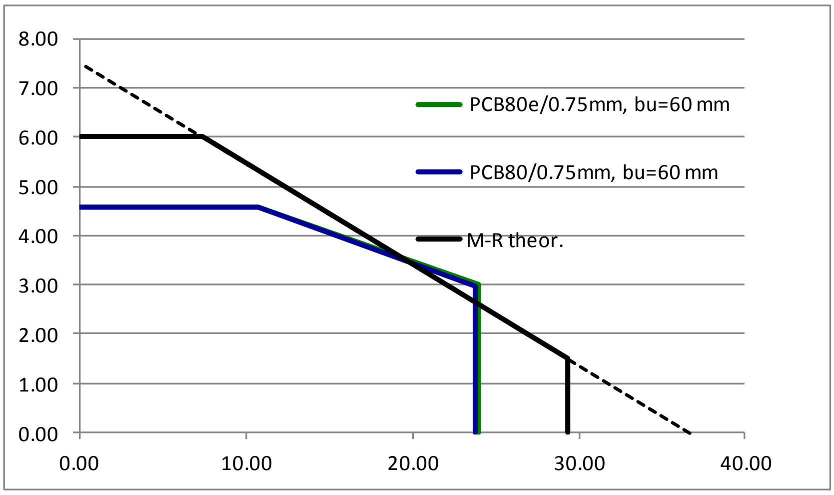


Fig. 3.3.6 Results for the profiles PCB80/0.75 mm, at the support width bu=60 mm

PCB 80 0.75mm, bu=160mm
without embossments

M_{Rk_max}	R_{Rk_min}
5,591	13,111

M_{Rk_min}	R_{Rk_max}
4,395	35,144

PCB 80 0.75mm, b_u=160mm
with embossments

M_{R_max}	R_{R_min}
5,38	12,62

M_{R_min}	R_{R_max}
4,72	37,75

without embossment	
$M_{calculated}$	$R_{calculated}$
5,86	42,77

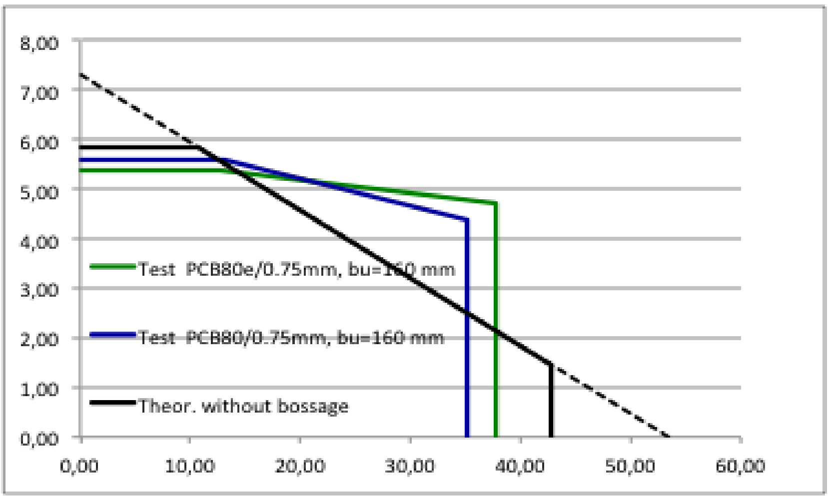


Fig 3.3.7 Results for the profiles PCB80/0.75 mm, at the support width bu=160 mm

PCB 80 1mm, b_u=60mm
without embossments

M_{Rk_max}	R_{Rk_min}
7,86	18,44

M_{Rk_min}	R_{Rk_max}
5,14	41,09

PCB 80 1mm, b_u=60mm
with embossments

M_{Rk_max}	R_{Rk_min}
7,90	18,52

M_{Rk_min}	R_{Rk_max}
5,36	42,83

without embossment	
$M_{calculated}$	$R_{calculated}$
9,99	53,80

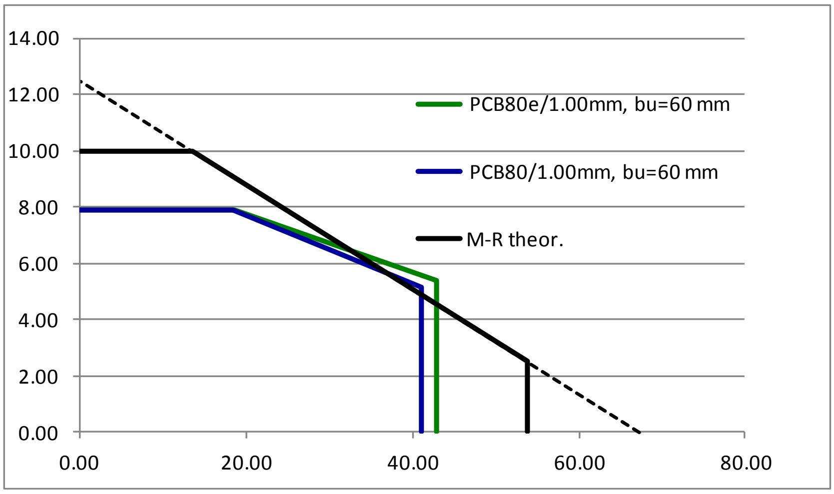


Fig. 3.3.8. Results for the profiles PCB80/1.00 mm, at the support width bu=60 mm

PCB 80 1mm, b_u=160mm
without embossments

M_{Rk_max}	R_{Rk_min}
9,38	22,02

M_{Rk_min}	R_{Rk_max}
7,86	62,83

PCB 80 1mm, b_u=160mm
with embossments

M_{Rk_max}	R_{Rk_min}
9,32	21,87

M_{Rk_min}	R_{Rk_max}
8,16	65,23

without embossment	
$M_{calculated}$	$R_{calculated}$
9,99	77,23

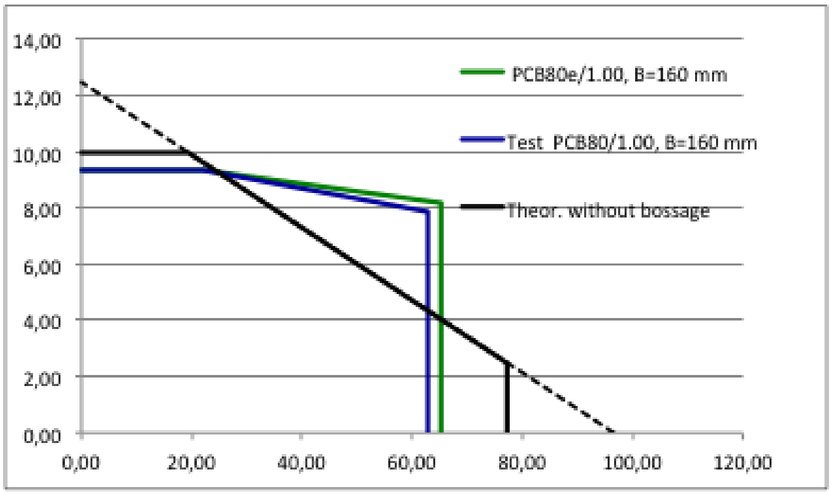


Fig. 3.3.9. Results for the profiles PCB80/1.00 mm, at the support width bu=160 mm

<u>Adaptation of the eq. (6.18), EN 1993-1-3 for the calculation of the web crippling resistance of the profiles with embossment.</u>

The moment resistance is calculated according to EN 1993-1-3, considering the embossments / indentations as plate elements with a reduced thickness $t_{red} = \rho * t$ as in § 3.1.2

As a reminder, below is presented the eq. (6.18), EN 1993-1-3 for the theoretical calculation of the web crippling resistance of the profiles with embossment:

$$R_{w,Rd} = \alpha t^2 \sqrt{f_{yb} E} \left(1 - 0{,}1\sqrt{r/t}\right)\left[0{,}5 + \sqrt{0{,}02 l_a / t}\right]\left(2{,}4 + (\phi/90)^2\right) / \gamma_{M1} \qquad (4)$$

where:

- h_w is the web height between the midlines of the flanges;
- r is the internal radius of the corners;
- φ is the angle of the web relative to the flanges (degrees)
- l_a is the effective bearing length, in the present case $l_a = b_u$
- α is the coefficient for the relevant category, in the present case $\alpha = 0.15$
- t is the design thickness of the section
- γ_{M1} partial safety coefficient, in the present case we take $\gamma_{M1} = 1.0$

This equation is used for the determination of the web crippling resistances of the profiles without embossments, presented in the Fig. 3.3.2 to 3.3.9.
However, the results obtained with this equation are in some cases, especially for the large support widths, not accurate. This confirms the already observed tendency pointed out in § 3.2.1 and by M. Bakker [14] that web crippling prediction formula give results different from test results.

In this study we tested a possibility of a safe adaptation of this equation for the profiles with embossments, searching an equivalent design thickness to put in the equation (4).
One difficulty lies in the fact that the thickness t appears in different members of the eq. (4), where its role is different as to the mechanical behaviour.
For instance, firstly used t value (r^2), corresponds to the buckling resistance of the web.
The next one (r/t) corresponds to the influence of the transversal bending of the web depending on the internal angle of the corners r.
The next one (l_a/t) corresponds probably to the spread of the stress on neighbouring zones.
In this study, we tested a possibility of adaptation of the eq. (4), by calculating the equivalent thickness t_{eff} depending on the inertia of the indentations in the web, and replacing the firstly and thirdly used t with the effective thickness t_{eff}, and leaving the secondly used t without changing.
The results of this test was excessively incoherent with the test results, and in some case very unsafe, therefore this way was given up
However, the performed tests prove that in case of the section with embossments the resistance at the support decreases in case of long test spans s and increases, less or more in case of short test spans s.

This observation is used for the proposed safe adaptation of the equation (4) which is the following:

1) First step:

Calculation of the two extreme points of the segment corresponding to the interaction M-R:
$M_{max} = M_{r,c,e}$; $-R_{max} = R_{r,c,n}$
$M_{min} = 0.25M_{r,c,n}$; $R_{min} = 0.25R_{r,c,n}$
where:

$M_{r,c,e}$ is the moment resistance calculated for the section with embossment
$M_{r,c,n}$ is the moment resistance calculated for the section without embossment
$R_{r,c,n}$ is the web crippling resistance calculated for the section without embossment

2) Second step:

Calculation of the values M_0 and R_0 from the equations (2) and (3)

3) Third step:

Use of the equation (1) for verification of the interaction M_E - R_E
The graphical presentation of this adaptation is shown in the Fig. 3.3.10a and 3.3.10b

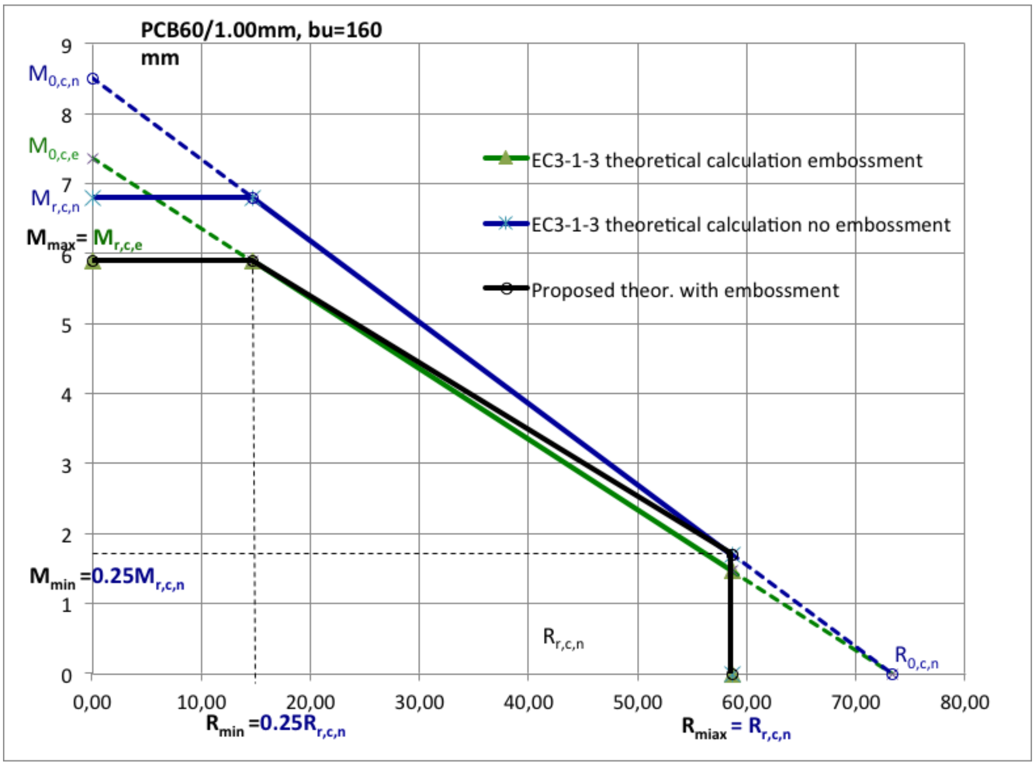


Fig. 3.3.10.a Determination of the parameters for calculation of the resistance to combined action Moment -Reaction of the profiles with embossments, full presentation

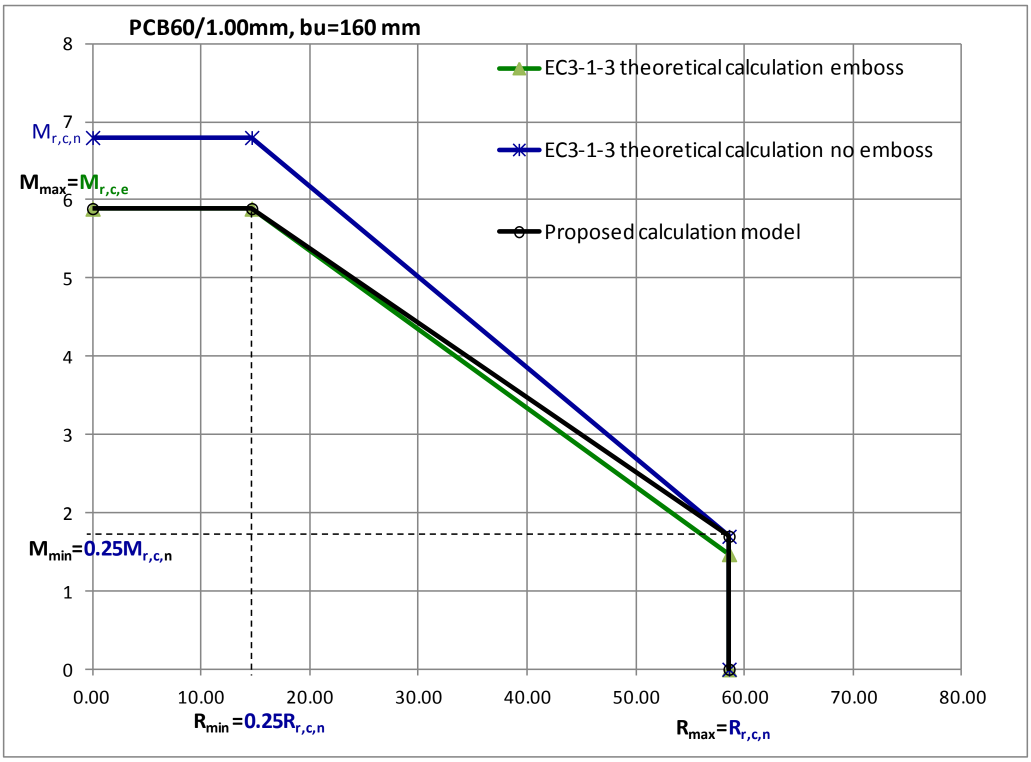


Fig. 3.3.10.b Determination of the parameters for calculation of the resistance to combined action Moment -Reaction of the profiles with the embossment, simplified presentation

In the Fig. 3.3.11 to 3.3.18 the results of the proposed calculation for profiles with embossments (green lines) are compared to the results of theoretical calculation without embossments (blue lines), and to the results of testing results (with embossments dotted green lines and without embossments dotted blue lines)

Proposed theoretical with embossment					
Rmin	Mmax	Rmax	Mmin	M0	R0
5,81	3,77	23,25	1,11	4,66	30,51

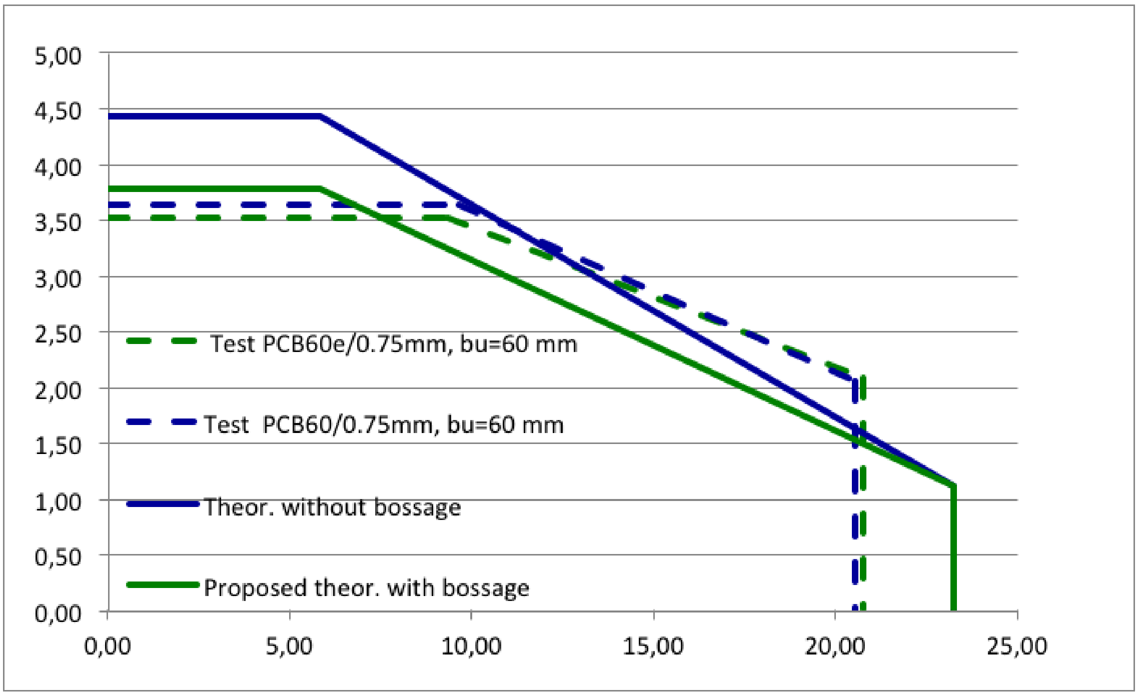


Fig. 3.3.11. Comparison between proposed calculation method and tests results for PCB60 0.75 mm at the support width bu=60 mm

Proposed theoretical with embossment					
Rmin	Mmax	Rmax	Mmin	M0	R0
8,48	3,77	33,90	1,11	4,66	44,49

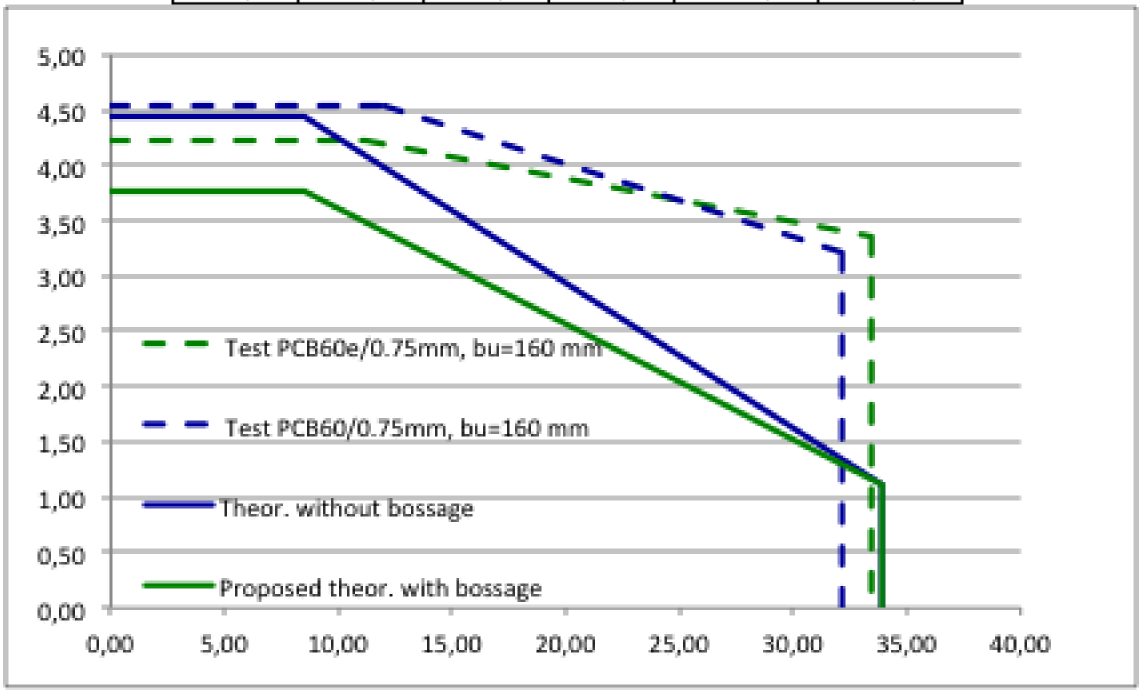


Fig. 3.3.12. Comparison between proposed calculation method and tests results for PCB60 0.75 mm at the support width bu=160 mm

Proposed theoretical with embossment					
Rmin	Mmax	Rmax	Mmin	M0	R0
10,17	5,95	40,69	1,70	7,37	52,89

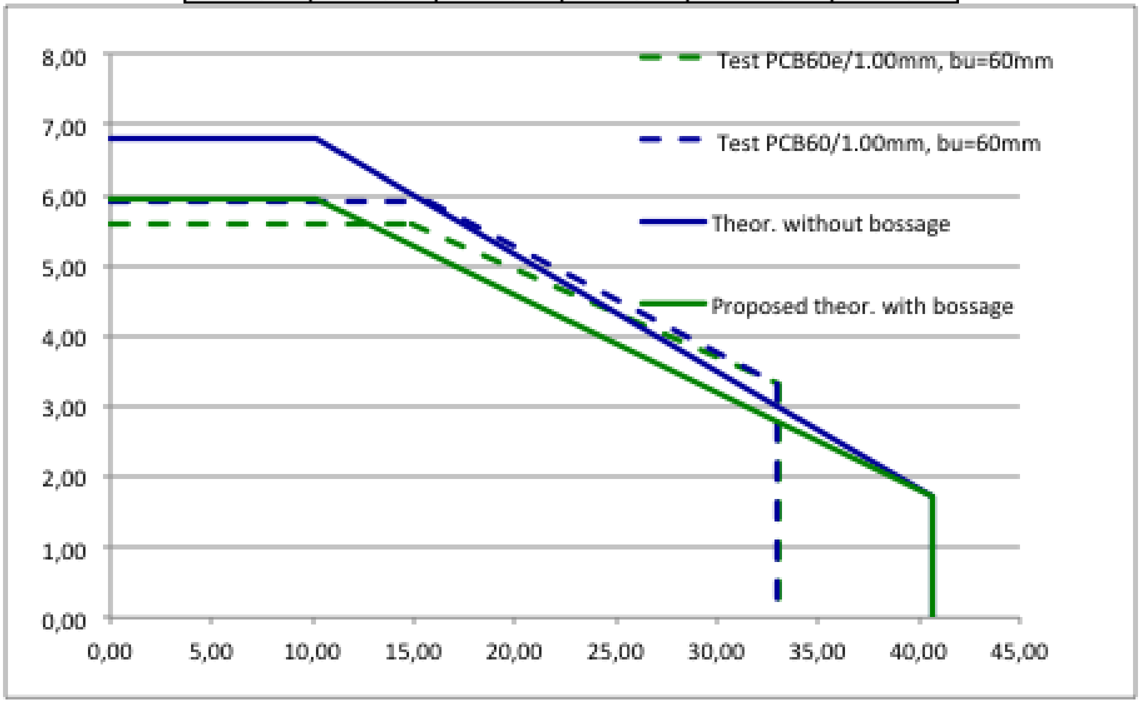


Fig. 3.3.13. Comparison between proposed calculation method and tests results for PCB60 1 mm at the support width bu=60 mm

Proposed theoretical with embossment					
Rmin	Mmax	Rmax	Mmin	M0	R0
14,64	5,95	58,57	1,70	7,37	76,13

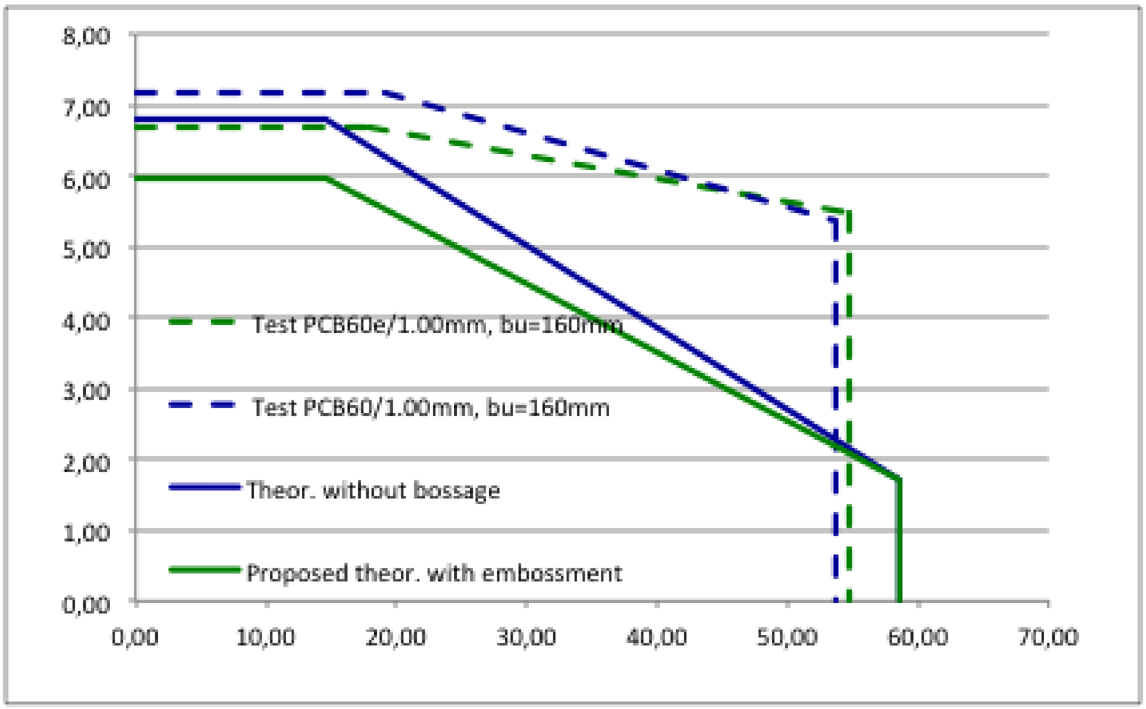


Fig. 3.3.14. Comparison between proposed calculation method and tests results for PCB60 1 mm at the support width bu=160 mm

Proposed theoretical with embossment					
Rmin	Mmax	Rmax	Mmin	M0	R0
7,33	4,95	29,34	1,46	6,11	38,58

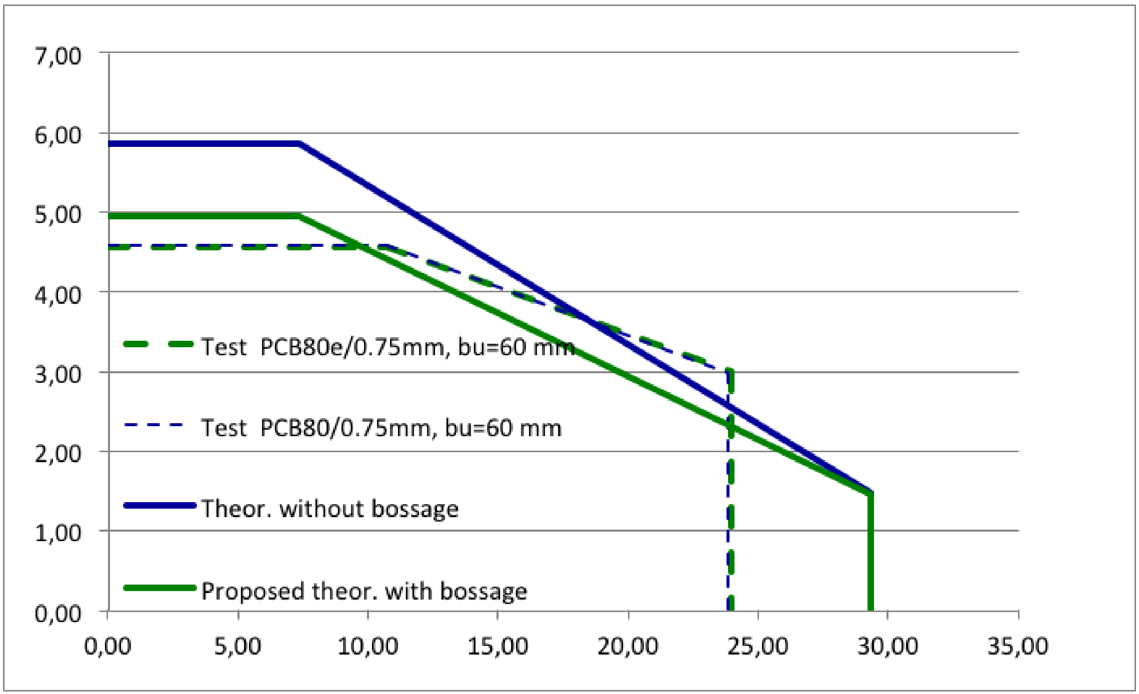


Fig. 3.3.15. Comparison between proposed calculation method and tests results for PCB80 0.75 mm at the support width bu=60 mm

Proposed theoretical with embossment					
Rmin	Mmax	Rmax	Mmin	M0	R0
10,69	4,95	42,77	1,46	6,11	56,24

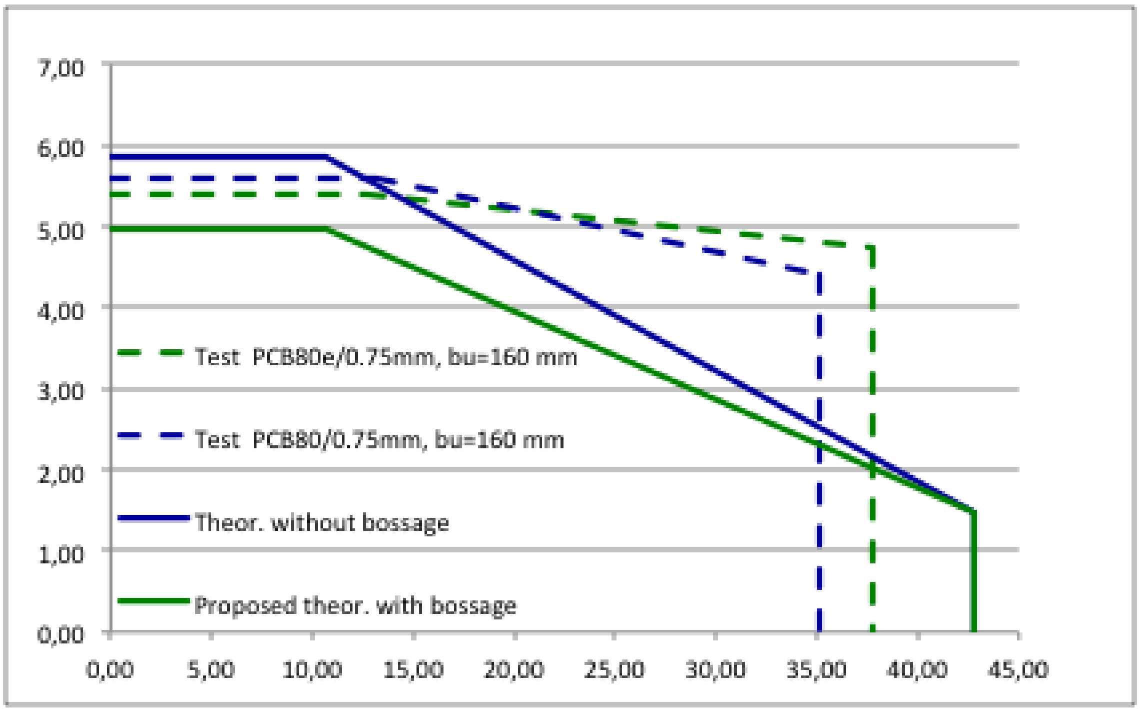


Fig. 3.3.16. Comparison between proposed calculation method and tests results for PCB80 0.75 mm at the support width bu=160 mm

Proposed theoretical with embossment					
Rmin	Mmax	Rmax	Mmin	M0	R0
13,45	8,98	53,80	2,50	11,14	69,36

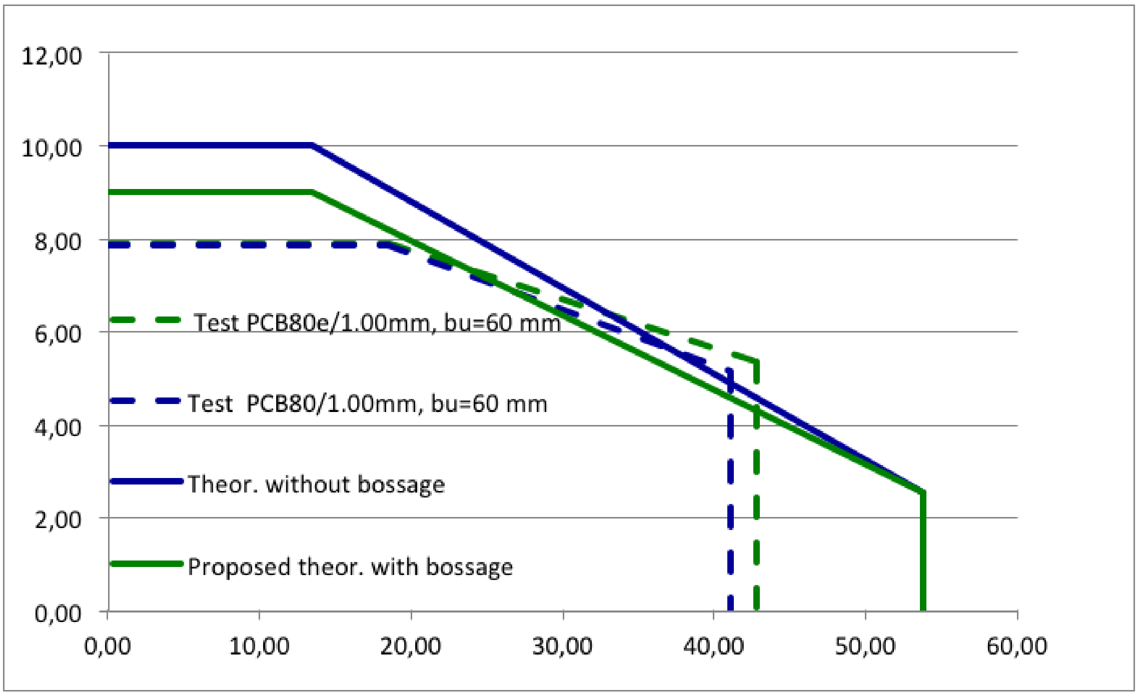


Fig. 3.3.17. Comparison between proposed calculation method and tests results for PCB80 1 mm at the support width bu=60 mm

Proposed theoretical with embossment					
Rmin	Mmax	Rmax	Mmin	M0	R0
19,31	8,98	77,23	2,50	11,14	99,57

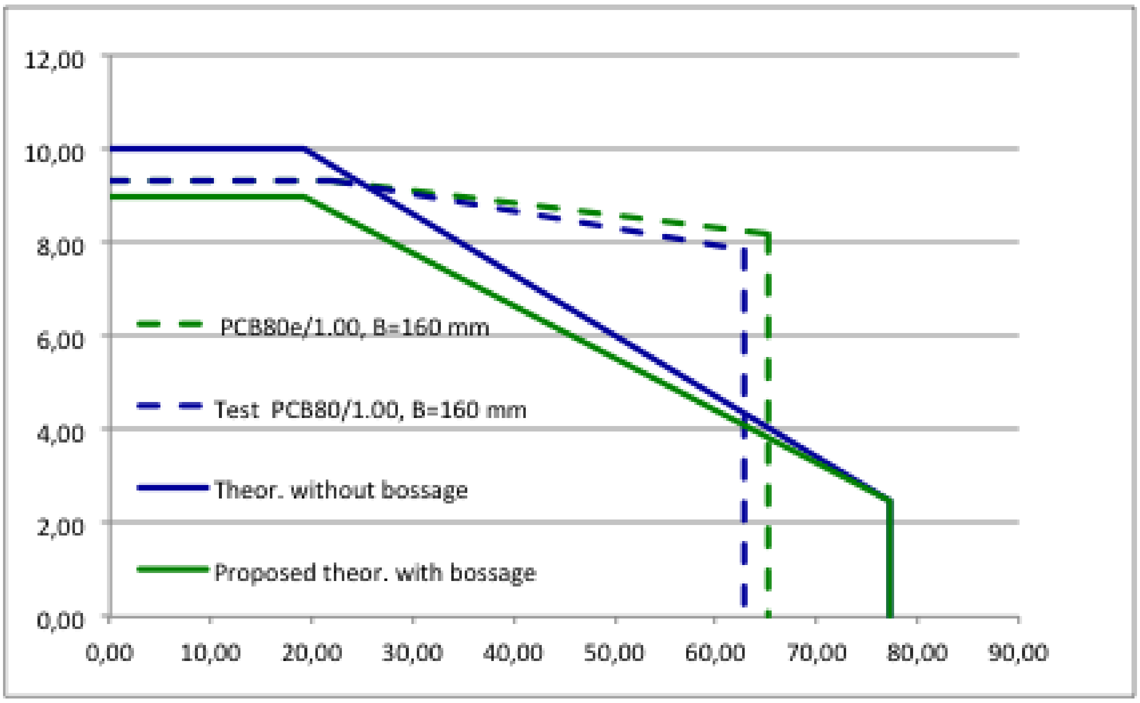


Fig. 3.3.18. Comparison between proposed calculation method and tests results for PCB80 1 mm at the support width bu=160 mm

3. CONCLUSION

The above presented study of tensile tests results on coupons with and without embossments provides a valuable basis to determine the influence of embossments on the resistance moment by modeling the plate element with an embossment as a plate element with reduced thickness instead of embossment $t_{red} = \rho * t$.

Based on this model and on the test results of the huge testing program on steel trapezoidal sheeting performed within the WP1, is proposed for steel decks with embossments / indentations

- To calculate span moment resistance according to EN 1993-1-3, considering the embossments / indentations as plate elements with a reduced thickness $t_{red} = \rho * t$
- To calculate web crippling resistance at support taking the usual formula (6.18) EN 1993-1-3
- To determine moment-reaction interaction at intermediate support
    - calculating the moment resistances M_{max} according to EN 1993-1-3 considering the embossments / indentations as plate elements with a reduced thickness $t_{red} = \rho * t$ and M_{min} according to EN 1993-1-3 without embossments
    - and calculating the web crippling resistances R_{max} and R_{min} without embossments taking the usual formula (6.18) EN 1993-1-3

REFERENCES

[1] A. PALISSON (Sokol Palisson Consultants) "GRISPE D1.1, WP1 BACKGROUND DOCUMENT" 2013

[2] P. REN, G. COUCHMAN, M. CRISINEL "COMPARISON BETWEEN THEORETICAL MODEL COMPCAL AND TEST RESULTS" 1993

[3] B. DANIELS, M. CRISINEL "ESSAIS DE DALLES MIXTES AVEC TOLES PROFILEE HIBOND 55" 1987

[4] B. J. DANIELS, A. ISLER, M. CRISINEL "MODELLING OF COMPOSITE SLABS WITH THIN-WALLED COLD-FORMED DECKING, 1990

[5] M. CRISINEL, 2004, "A NEW SIMPLIFIED METHOD FOR THE DESIGN OF COMPOSITE SLABS", JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH 60 481–491, 2004

[6] L.D. LUTTRELL, S. PRASANNAN," STRENGTH FORMULATIONS FOR COMPOSITE SLABS" SEVENTH INTERNATIONAL SPECIALTY CONFERENCE ON COLD·FORMED STEEL STRUCTURES ST. LOUIS, MISSOURI, U.S.A., NOVEMBER 13·14, 1984

[7] P; MÄKELÄINEN "THE LONGITUDINAL SHEAR BEHAVIOUR OF A NEW STEEL SHEETING PROFILE FOR COMPOSITE FLOOR SLABS, JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH" JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH 49, 117-128., 1999

[8] V.MARIMUTHU, "EXPERIMENTAL STUDIES ON COMPOSITE DECK SLABS TO DETERMINE THE SHEAR-BOND CHARACTERISTIC (M–K) VALUES OF THE EMBOSSED PROFILED SHEET", JOURNAL OF CONSTRUCTIONAL STEEL RESEARCH 63, 791-803, 2007

[9] P. LUURE AND M. CRISINEL "ESSAIS COMPARATIFS SUR TÔLES NERVUREES DE PLANCHERS MIXTES AVEC ET SANS BOSSAGES" 1993

[10] J. M. DAVIES, C. JIANG " DESIGN PROCEDURES FOR PROFILED METAL SHEETING AND DECKING", *THIN-WALLED STRUCTURES* VOL. 27, NO. I, PP. 43-53, 1997

[11] A. BIEGUS, D. CZEPIZAK " RESEARCH ON THE INTERACTIVE RESISTANCE OF CORRUGATED SHEETS UNDER COMBINED BENDING AND CONTACT PRESSURE", THIN-WALLED STRUCTURES 44, 825–831, 2006

[12] C. FAUT (KIT) "GRISPE D1.2, “WP1 Test report of steel trapezoidal sheeting with and without embossments and outward stiffeners " 2015

[13] A. PALISSON (Sokol Palisson Consultants) "GRISPE D1.4, “WP1 TEST ANALYSIS AND INTERPRETATION" 2015

[14] M. C.M. BAKKER “WEB CRIPPLING OF COLD-FORMED STEEL MEMBERS" 1992

Annex A : Calculation of span moment resistance value of PCB 60 0,75 mm profile with embossments

The moment resistance of the effective section is calculated according to EN 1993-1-3, considering the embossments / indentations (Fig. A1) as plate elements with a reduced thickness $t_{red} = \rho * t$ where the ratio ρ is defined according to § 2.2.2 .

1) Determination of the embossment height

The height of the embossments is called in Annex F of D1.3 Test Report "Depth of embossments v_{eb}".
The mean value of the measures performed on three ribs: 1,9; 2,0; 2,1 (Table A1) is considered.

Therefore the height = 2 mm

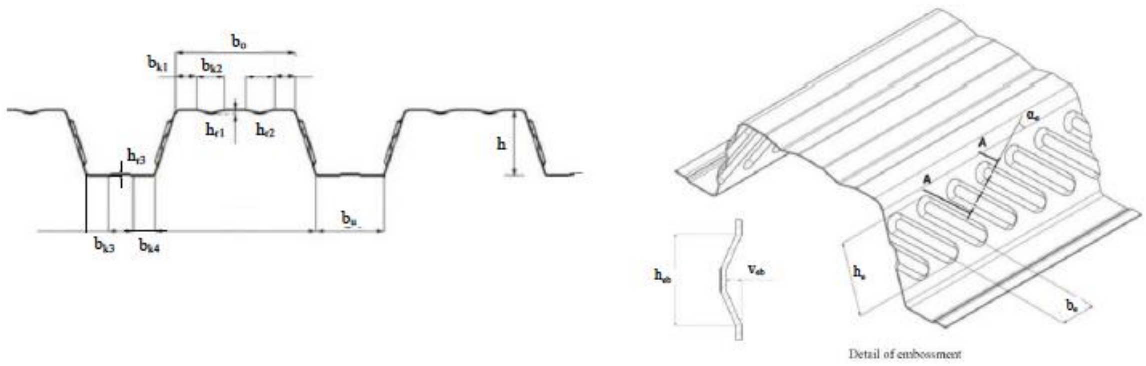


Fig. A1- Embossments / indentations

	PCB 60 t_N = 0.75											
	1st Rib		2nd Rib		3rd Rib		1st Rib		2nd Rib		3rd Rib	
Thickness t_N	0,72		0,73		0,73		0,76		0,74		0,74	
Depth of profile h	60,2		58,3		59,6		60,1		58,7		60,6	
Depth of stiff. valley hr_3/hr_4	1,1	-	1,3	-	0,7	-	0,6	-	1,4	-	1,4	-
Depth of stiff. crown h_{r1}/h_{r2}	1,7	2,8	2,0	2,5	2,3	2,3	2,5	2,3	2,6	2,1	-	-
Widths of crown b_o	107,0		107,0		107,0		106,0		106,0		-	
Position of stiff. crown b_{k1}/b_{k2}	21,5	26,0	20,0	25,0	20,0	25,0	21,0	25,5	20,0	25,5	-	-
Position of stiff. valley b_{k3}/b_{k4}	25,0	15,5	21,0	18,5	25,0	15,5	20,0		21,0		24,5	17,5
Widths of valley b_u	61,0		60,0		60,5		61,0		60,5		61,5	
Radius of bends r_o	5,5/6,0		5,0		Radius of bends r_u				6,0		5,5	
Ancle of embossment α_e	-		-		-		45,0		45,0		45,0	
Widths of embossment h_{eb}	-		-		-		12,8		12,9		13,1	
Depth of embossment v_{eb}	-		-		-		1,9		2,0		2,1	
height of embossment h_e	-		-		-		42,0		42,4		42,3	
distance of the embossments b_e	-		-		-		22,2		22,6		22,8	

Table A1

2) Determination of ratio ρ

The ratio ρ is defined according to the Table A2 (Table 2.2.2.5 in § 2.2.2) for thickness t = 0,75 mm, considering the height of embossments = 2mm

t = 0,75 mm	
h_e (mm)	$\rho_p = K_{pe}/K_p$
1,5	0,200
2	0,150
2,5	0,080
2,75	0,060
3	0,053
3,5	0,041
4	0,029

Table A2: Ratios ρ depending on the height dimensions for t = 0,75 mm

Therefore Ratio ρ = 0,150

3) Calculation of effective cross-section

The effective cross-section of the web is calculated according to EN 1993-1-3, considering the embossments / indentations as plate elements with a reduced thickness $t_{red} = \rho * t = 0,15 * t$ for the length $l_{embossment}$ (Fig A2)

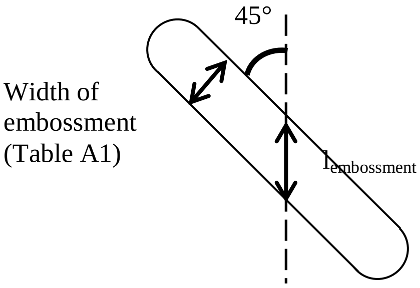


Fig. A2: Length of the reduced thickness

$l_{embossment}$ = Width / sin (45°)
and Width is the mean value of the measures performed on three ribs: (12,8; 12,9; 13,1) (Table A1)

Therefore $l_{embossment}$ = 18,29 mm

4) <u>Calculation of the moment resistance</u>

The calculation is made with the actual measured properties of the tested profile:
t= 0,698 mm and f_{yb} = 341 N/mm^2 (Table A3 issued from D1.3 Test Report))

Profile	Nominal thickness t_N [mm]	Core thickness t_K [mm]	Yield strength $R_{p0,2}$ [N/mm²]	Tensile strength R_m [N/mm²]	Elongation at fracture $A_{L=80mm}$ [%]
PCB 80 (profile 1)	0.75	0.688	362	493	23.5
		0.686	363	494	25.5
		0.682	363	495	24.9
		0.682	362	495	24.1
		0.684	364	496	24.1
	1.00	0.962	378	474	25.4
		0.954	363	470	26.7
		0.961	360	469	27.0
		0.964	382	481	24.3
		0.962	366	469	27.2
PCB 60 (profile 2)	0.75	0.697	342	460	23.9
		0.698	341	458	23.7
		0.699	339	456	23.2
		0.698	340	457	23.2
		0.696	342	459	23.1
	1.00	0.931	362	480	24.8
		0.932	360	480	24.9
		0.933	369	482	25.3
		0.931	365	479	25.5
		0.931	364	480	25.3

Table A3

Therefore the reduced thickness $t_{red} = \rho * t = 0{,}15 * t$ of the embossment is $t_{red} = 0{,}15 * 0{,}698 = 0{,}105$ mm for the length $l_{embossment} = 18{,}29$ mm

The calculation is performed in different cross sections in order to determine the section which induces the most important reduction of the resistance moment, and it is the section which cuts symmetrically 2 embossments as in Fig. A3

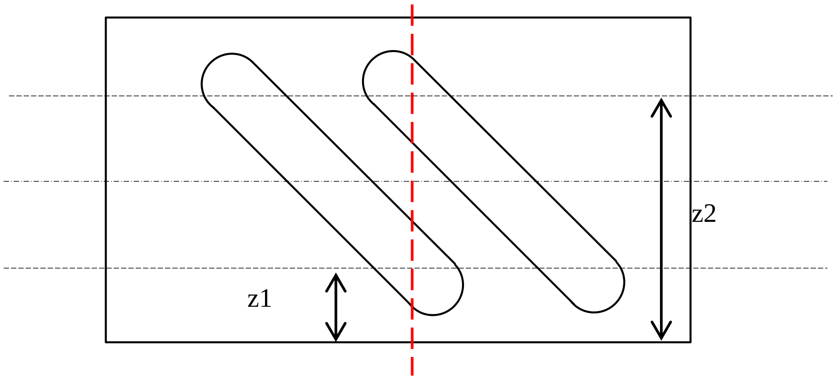


Fig. A3: Section of the calculation

The positions z1 and z2 of the embossments (z1=18,64 and z2=41,18) are calculated with values measured on the profile (Fig. 4 and Table A1)

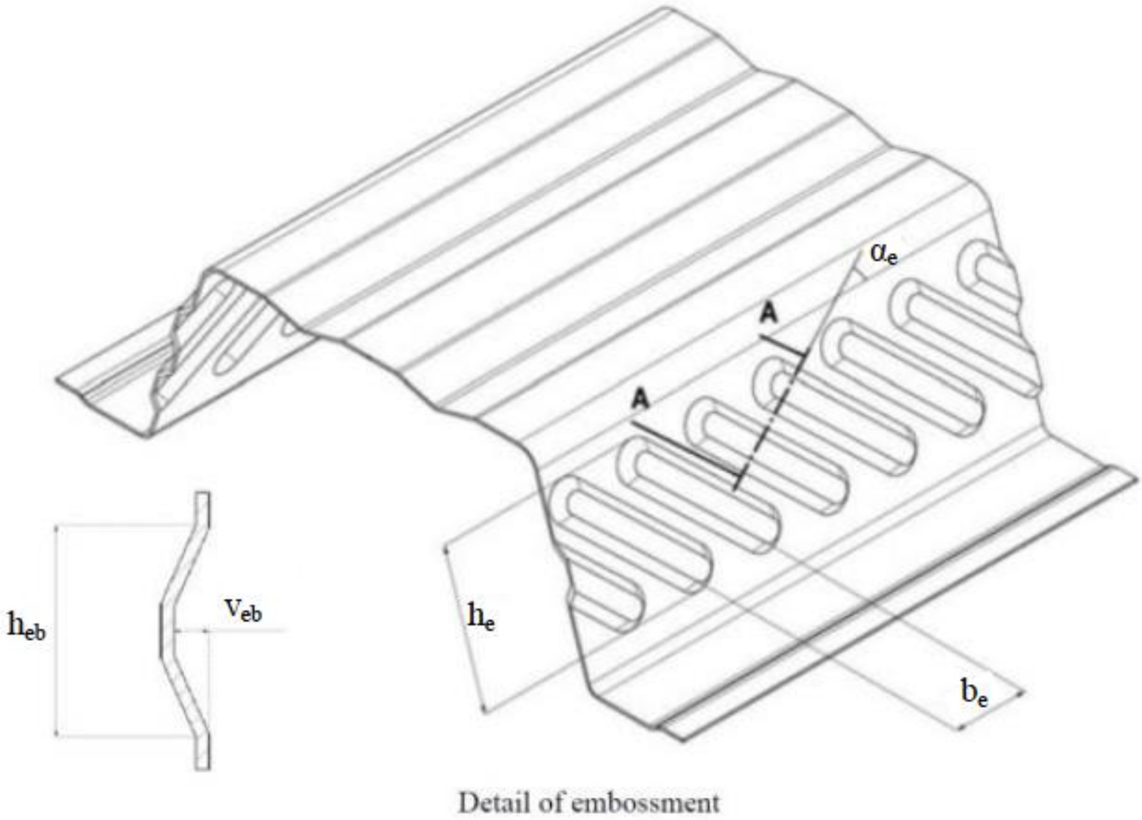


Fig. A4

The resistance moment calculated with two embossments (z1=18,64 and z2=41,18) in the cross-section is

$$\boxed{M = 4{,}42\ kN*m/m}$$