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, 2016.

**University of Belgrade
Faculty of Mechanical Engineering**

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**Exploring the impact of local load of trolley
wheels on stress states of monorail hoist
crane**

PhD dissertation

Belgrade, 2016

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I ,

IPE

(HEA, HEB)

IPE

IPB

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IPB

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EN 15011,

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EN

15011; ()

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EN 15011

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e IPE

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HE-A

EN 15011.

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UDK: 621.879.48(043.3)

Exploring the impact of local load of trolley wheels on stress states of monorail hoist crane

Abstract: The paper presents the research results of the local stress of open cross - section rolled girder exposed to the impact of movable carts' wheels. Experimental researches were carried out on the tensiometric table's original structure. Determination of stress state caused by the wheel local impact was performed using the original process supported by the software being developed during the implementation of the research. Numerical studies were performed using finite element method. On the basis of the research results we concluded the following: (a) stress state in the fictitious point of intersection of the flange lower contour and the ribs contour may not be regarded as the evidence of strength in the low flange / rib transition zone, as prescribed by standard EN 15011, but the stress state in the reference points of intersection at the beginning of the transition radius; (b) in the zone transition, there are pressing stresses in the lower contour of the low flange in the longitudinal direction which completely negates the process of identifying local stress state prescribed by the standard EN 15011; (c) the absolute value of the local stress on the upper and lower contour of the low flange are not equal in any reference point of the cross section, which negates the provision of standard EN 15011 according to which the absolute values of stress coefficients in the correspondent points of the upper and lower contours are equal; (d) the size of a profile of the same class significantly affects the value of the stress coefficients; (e) the impact of geometrical imperfections of cross - section profile on the stress value of the coefficient is highly expressed in the transition zone, while the impact in other reference points is relatively low. Based on the survey results, the original curves of stress coefficients are formed for mid - wide profiles (IPE) and wide flange profiles (HE-A) which eliminates the shortcomings of the current standard EN 15011.

Key words: monorail hoist crane, local bending, tensiometry, finite element method, stress coefficients

Academic Expertise: Mechanical Engineering

Field of Academic Expertise: Mechanization

UDC No: 621.879.48(043.3)

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1. |

1.1, 1.2 1.3.



1.1:



1.2:



1.3:

1.4.



1.4:

„Bomex 4M“

14%

DIN 1025 (Blatt 1), 12%

8239 - 56,

ASTM A6/A6M - 12

16,7%.

I

I

I

IPE

DIN 1025 (Blatt 5/1965),

EURONORM 19 - 57.

IPE

(IPE 600, 600 mm)

20

IPB (HEA, HEB)

: HEA - DIN 1025 (Blatt 3/1963),

, EURONORM 53 - 62; HEB - DIN 1025 (Blatt 2/1963),

EURONORM 53 - 62.

$h=1000$ mm.

300 (HEA 300, HEB 300)

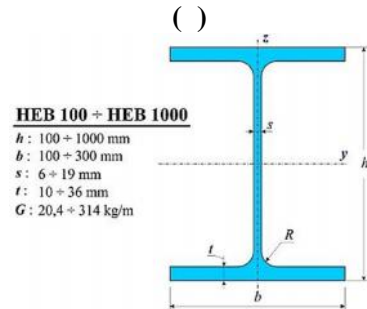
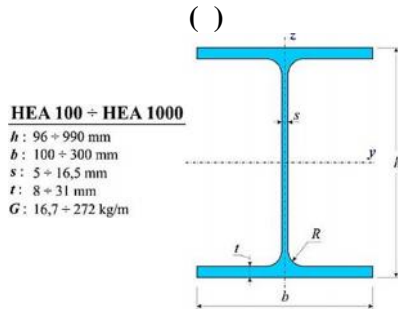
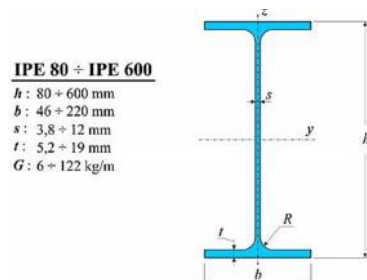
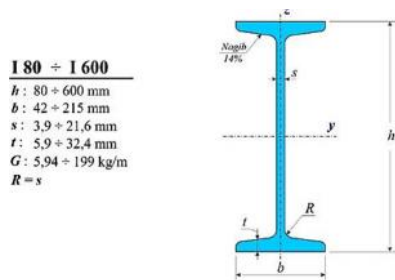
1000 (HEA 1000, HEB

1000)

IPB

$b=300$ mm.

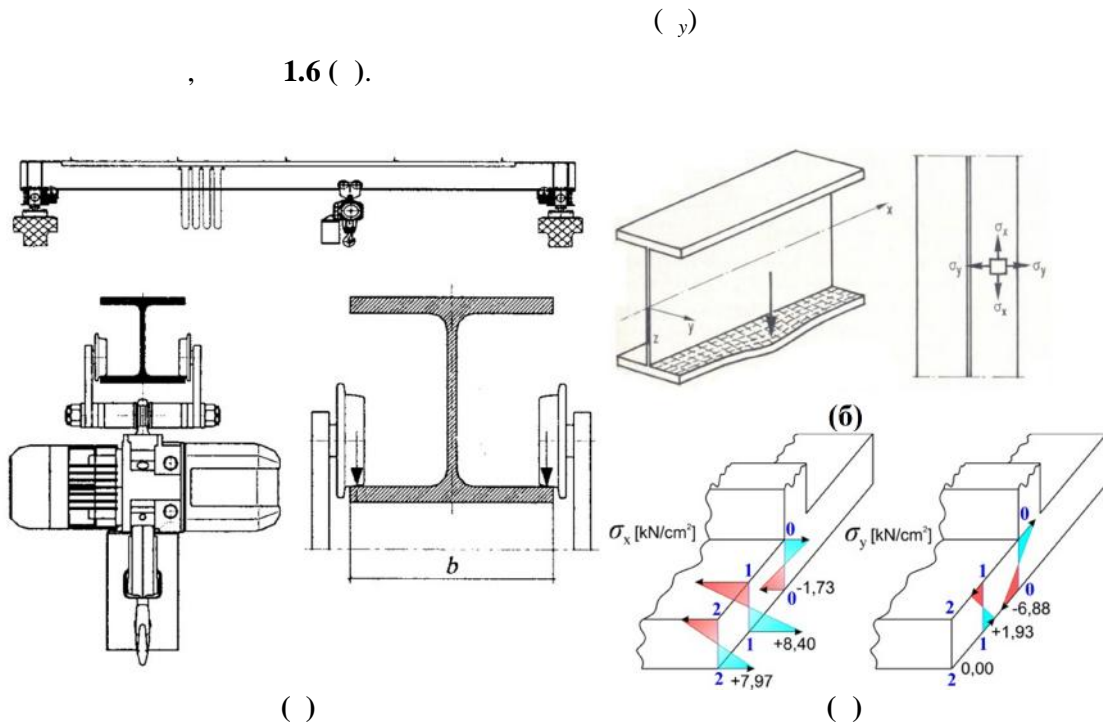
1.5.



1.5: I : ()
 () HEA ; () HEB

I ; () IPE ;

1.6. (x,l), 1.6(), (x,f), $\tau_{x,tot} = \tau_{x,f} + \tau_{x,l}$... (1.1)



1.6: () HEA [22]; () [22]; () [25]

() I IPE IPB (HEA, HEB)

[17]

[9,10],

FEM (*Fédération Européenne de la Manutention*),

[3, 14, 15, 24]

EN 15011 [5],

(SRPS EN 15011:2014).

IPE

IPB (HEA, HEB)

I

IPE

IPB

1.1

1.7,

0, **1.7,**

(1)

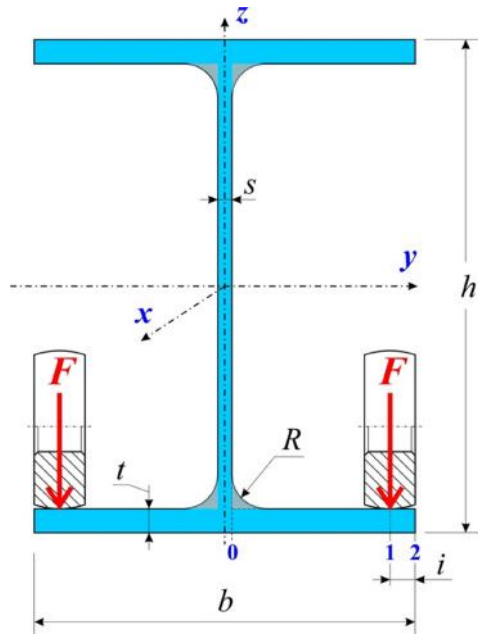
(2)

EN 15011.

HEA 360,

1.7,

1.1.



1.7:

(HEA 360)

1.1:

	H	350 mm
	b	300 mm
	t_f	17,5 mm
	s	10 mm
/	r	27 mm
	i	20 mm
	E	21000 kN/cm ²
		0,3
	F	10 kN

1.1.1

(Gokhberg)

[17]

I

(Rozensteyn) [23],

[7]

(Kirchhoff) 1850. [26],

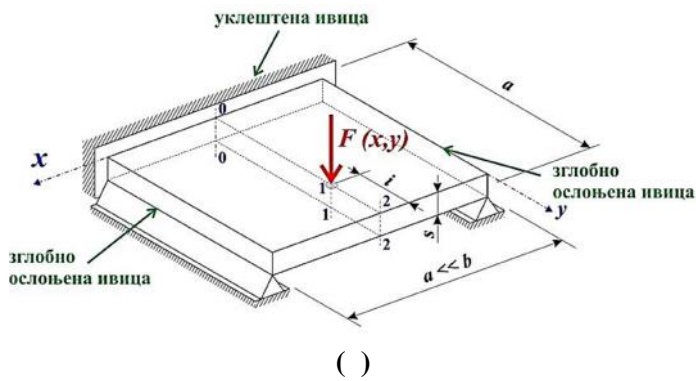
1.8. , 1.8(),

1.8().

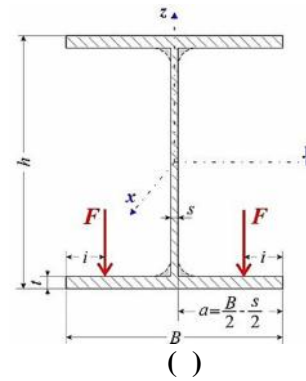
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- ;

1.8().

1.8().



1.8:



()
()

[21]

$$\frac{\partial^4 w}{\partial x^4} + 2 \frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{F(x, y)}{D}, \quad \dots(1.2)$$

: w -

z, F(x,y) -

$$D = \frac{Et^3}{12(1-\epsilon^2)}$$

, t -

(Poisson)

(1.2)

[21])

$$w = \sum_{m=1}^{\infty} f_m(y) \sin \frac{mf}{b} x. \quad \dots(1.3)$$

$$(1.3) \quad (1.2),$$

$$\sum_{m=1}^{\infty} (f_m^{IV} - 2f_m'' + f_m^4) \sin \frac{mf}{b} x = \frac{F(x, y)}{D}, \quad \dots(1.4)$$

1.8(),

- , $x = 0: w = 0, \frac{\partial^2 w}{\partial x^2} = 0 (M_x = 0);$
- , $x = b: w = 0, \frac{\partial^2 w}{\partial x^2} = 0 (M_x = 0);$
- , $y = 0: w = 0, \frac{\partial w}{\partial y} = 0 ($);
- , $y = a: \frac{\partial^2 w}{\partial y^2} + \epsilon \frac{\partial^2 w}{\partial x^2} = 0 (M_y = 0);$
 $\frac{\partial^3 w}{\partial y^3} + (2 - \epsilon) \frac{\partial^3 w}{\partial x^2 \partial y} = 0 (V_y = 0);$

w(x,y).

[21]

$$M_x = -D \left(\frac{\partial^2 w}{\partial x^2} + \epsilon \frac{\partial^2 w}{\partial y^2} \right), \quad \dots(1.5)$$

$$M_y = -D \left(\frac{\partial^2 w}{\partial y^2} + \epsilon \frac{\partial^2 w}{\partial x^2} \right). \quad \dots(1.6)$$

$$\dagger_x = \pm \frac{6M_x}{t^2} \quad \dots(a), \quad \dagger_y = \pm \frac{6M_y}{t^2} \quad \dots(), \quad \dots(1.7)$$

$$\tau_x = \pm \frac{6M_x F}{F t^2} = c_x \frac{F}{t^2} = c_x \tau_0, \quad \dots(1.8)$$

$$\tau_y = \pm \frac{6M_y F}{F t^2} = c_y \frac{F}{t^2} = c_y \tau_0, \quad \dots(1.9)$$

(c_x) (c_y)

$$c_x = \pm \frac{6M_x}{F} \quad \dots(), c_y = \pm \frac{6M_y}{F} \quad \dots(), \quad \dots(1.10)$$

$$\tau_0 = \frac{F}{t^2}. \quad \dots(1.11)$$

(x=0,5b), **1.8**()

(0)

$$\tau_y = \pm 3,06 \frac{F}{t^2}, \quad \dots(1.12)$$

$$c_y = \pm 3,06. \quad \dots(1.13)$$

(+)

(-)

0 :

$$\sigma_x = \pm 0,85 \frac{F}{t^2}, \quad \dots(1.14)$$

$$C_x = \pm 0,85 \quad \dots(1.15)$$

$$C_x \approx \gamma C_y = 0,3 \cdot 3,06 = 0,918 \quad \dots(1.16)$$

1.9.

(Gokhberg)

$$\xi < \frac{c}{a}, \quad \dots(1.17)$$

a -

c -

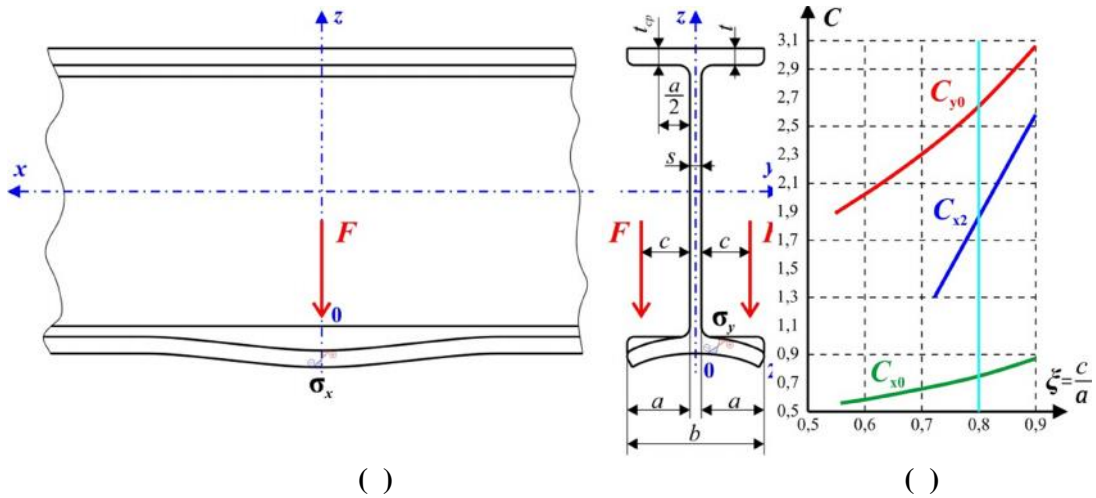
1.9().

(Gokhberg)

1.9().

1 (

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1.9:

()

()

()

() [9]

/

(Gokhberg)

(2).

=0,9, 1.9(),

I , $i=0$.

HEA 360, 1.7, 1.1,

$$c_{\max} = 0,5(b-s) - r = 0,5(300-10) - 27 = 118 \text{ mm} \quad \dots(1.18)$$

$$=0,5(b-s)=0,5(300-10)=145 \text{ mm}, \quad \dots(1.19)$$

($i=0$)

$$\zeta_{\max} = \frac{c_{\max}}{a} = \frac{118}{145} = 0,81. \quad \dots(1.20)$$

$i=20 \text{ mm}$

$$c_0 = c_{\max} - i = 0,5(b-s) - r - i = 0,5(300-10) - 27 - 20 = 98 \text{ mm}. \quad \dots(1.21)$$

2,

2

$$c_2 = 0,5(b-s) - i = 0,5(300-10) - 20 = 125 \text{ mm}. \quad \dots(1.22)$$

0 2

$$\zeta_0 = \frac{c_0}{a} = \frac{98}{145} = 0,68, \quad \dots(1.23)$$

$$\zeta_2 = \frac{c_2}{a} = \frac{125}{145} = 0,86. \quad \dots(1.24)$$

, **1.9** (),

0 2

$$c_{y0} = \pm 2,25, \quad c_{x0} = \pm 0,6, \quad c_{x2} = \mp 2,3, \quad \dots(1.25)$$

$$F=10 \text{ kN}, \quad \mathbf{1.1},$$

(1.11)

$$\tau_0 = \frac{F}{t_f^2} = \frac{10}{1,75} = 3,265 \text{ kN/cm}^2, \quad \dots(1.26)$$

$$\tau_{x_0} = c_{x_0} \tau_0 = \pm 0,6 \times 3,265 = \pm 1,96 \text{ kN/cm}^2; \quad \dots(1.27)$$

$$\tau_{y_0} = c_{y_0} \tau_0 = \pm 2,25 \times 3,265 = \pm 7,35 \text{ kN/cm}^2; \quad \dots(1.28)$$

$$\tau_{x_2} = c_{x_2} \tau_0 = \mp 2,3 \times 3,265 = \mp 7,51 \text{ kN/cm}^2; \quad \dots(1.29)$$

$$\tau_{y_2} = 0. \quad \dots(1.30)$$

1.1.2 (Klöppel, Lie)

(Klöppel, Lie) [18],

1.10,

$$c/a=0,85, \quad \dots(1.31)$$

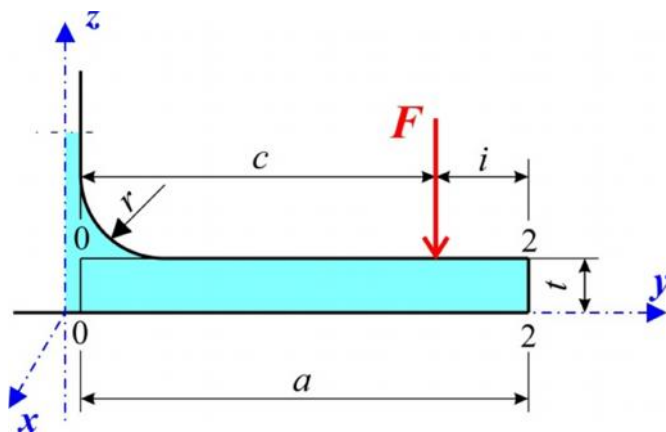
) 2,

$$\tau_{y_0} = \pm 2,8 \frac{F}{t_f^2} = \pm 2,8 \tau_0, \quad \dots(1.31)$$

$$\tau_{x_0} = \pm \epsilon \tau_{y_0} = \pm 0,3 \times 2,8 \frac{F}{t_f^2} = \pm 0,84 \tau_0, \quad \dots(1.32)$$

$$\tau_{x_2} = \mp (1,6 \div 1,8) \frac{F}{t_f^2} = \mp (1,6 \div 1,8) \tau_0, \quad \dots(1.33)$$

$$\tau_{y_2} = 0. \quad \dots(1.34)$$



1.10:

(Klöppel, Lie) [18]

$$c/a=0,85$$

$$c_{x0} = \pm 0,84 \text{ ..()}, \quad c_{y0} = \pm 2,8 \text{ ..()}, \quad c_{x2} = \mp 1,6 \div 1,8 \text{ ..()}, \quad c_{y2} = 0 \text{ ..()}. \quad \dots(1.35)$$

HEA 360, **1.7,** **1.1,**

(Klöppel, Lie)

$$\dagger_{x0} = \pm c_{x0} \dagger_0 = \pm 0,84 \times 3,265 = 2,74 \text{ kN/cm}^2; \quad \dots(1.36)$$

$$\dagger_{y0} = \pm c_{y0} \dagger_0 = \pm 2,8 \times 3,265 = 9,14 \text{ kN/cm}^2; \quad \dots(1.37)$$

$$\dagger_{x2} = \mp c_{x2} \dagger_0 = \mp (1,6 \div 1,8) \times 3,265 = 5,22 \dots (5,55) \dots 5,88 \text{ kN/cm}^2; \quad \dots(1.38)$$

$$\dagger_{y2} = \pm c_{y2} \dagger_0 = 0. \quad \dots(1.39)$$

(Klöppel, Lie) (c/a=0,85)

HEA 360

$$i = a \left(1 - \frac{c}{a} \right) = 145(1 - 0,85) = 21,8 \text{ mm}, \quad \dots(1.40)$$

1.1.3 (Sahmel)

(Sahmel) [24]

$$(l) \quad \dots, \quad \mathbf{1.11.}$$

$$(\quad 0)$$

$$M_y = Fc, \quad \dots(1.41)$$

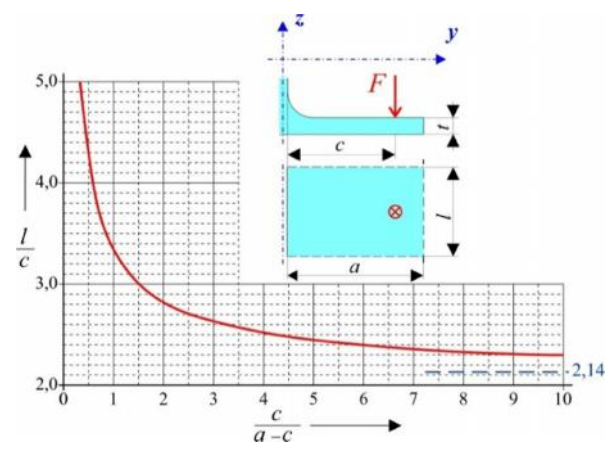
$$W_y = \frac{lt_f^2}{6}. \quad \dots(1.42)$$

0,

$$\tau_{y0} = \pm \frac{M_y}{W_y}, \quad \dots(1.43)$$

$$\tau_{x0} = \pm \epsilon \tau_{y0}. \quad \dots(1.44)$$

(1.43) (1.44), + , -



1.11: (Sahmel) [24]

1.1, (Sahmel)

$$a = 0,5(b - s) = 0,5(300 - 10) = 145 \text{ mm}; \quad \dots(1.45)$$

$$c = a - i = 145 - 20 = 125 \text{ mm}; \quad \dots(1.46)$$

$$\frac{c}{a - c} = \frac{125}{145 - 125} = 6,25 \rightarrow 1.11 \rightarrow \frac{l}{c} = 2,37; \quad \dots(1.47)$$

$$l = 2,37c = 2,37 \times 125 = 296 \text{ mm}; \quad \dots(1.48)$$

$$M_y = Fc = 10 \times 12,5 = 125 \text{ kNcm}; \quad \dots(1.49)$$

$$W_y = \frac{lt_f^2}{6} = \frac{29,6 \times 1,75^2}{6} = 15,1 \text{ cm}^3; \quad \dots(1.50)$$

$$\tau_{y0} = \pm \frac{M_y}{W_y} = \pm \frac{125}{15,1} = 8,278 \text{ kN/cm}^2; \quad \dots(1.51)$$

$$\tau_{x0} = \pm \epsilon \tau_{y0} = \pm 0,3 \times 8,278 = 2,483 \text{ kN/cm}^2. \quad \dots(1.52)$$

$$, \quad (1.26),$$

$$c_{x0} = \pm \frac{\tau_{x0}}{\tau_0} = \pm \frac{2,483}{3,265} = \pm 0,76; \quad \dots(1.53)$$

$$c_{y0} = \pm \frac{\tau_{y0}}{\tau_0} = \pm \frac{8,278}{3,265} = \pm 2,54. \quad \dots(1.54)$$

(Sahmel)

(0), ,

(1 2).

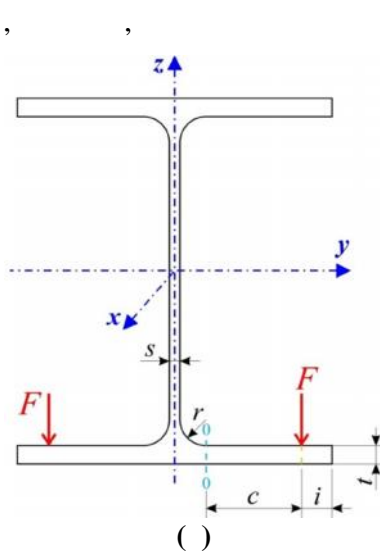
1.1.4

B1

1979. ,

„Berechnungsgrundlagen für Kranbahnen“ [27],

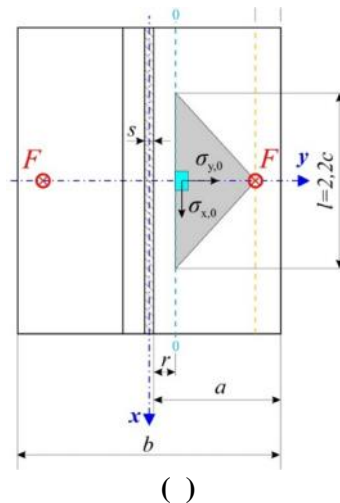
(Sahmel)



1.12:

()

1.12.



B1:

; ()
[27]

$$l = 2,2c, \quad \dots(1.55)$$

$$c = a - r - i, \quad \dots(1.56)$$

$$a = 0,5(b - s), \quad \dots(1.57)$$

1.12.

$$(\quad 0),$$

$$(Sahmel) \quad , \quad (1.42),$$

(1.43) (1.44),

$$M_0 = Fc, \quad \dots(1.58)$$

$$W_0 = \frac{lt_f^2}{6} = \frac{2,2ct_f^2}{6}, \quad \dots(1.59)$$

$$\dagger_{y0} = \pm \frac{M_0}{W_0} = \pm \frac{Fc}{\frac{2,2ct_f^2}{6}} = \pm 2,73 \frac{F}{t_f^2} = \pm c_{y0} \dagger_0, \quad c_{y0} = 2,73. \quad \dots(1.60)$$

,

,

$$\dagger_{x0} = \dagger_{y0}, \quad \dots(1.61)$$

· ,

$$(\quad (Poisson) \quad),$$

0

$$\dagger_{x0} = \epsilon \dagger_{y0}, \quad \dots(1.62)$$

(Sahmel) (1.44).

HEA 360,

1.7, **1.1,** :

$$t_{y0} = cx_0 = c_{y0} t_0 = \pm 2,73 \times 3,265 = 8,91 \text{ kN/cm}^2 = t_{x0}. \quad \dots(1.63)$$

$$, \quad , \quad (1.62),$$

$$t_{x0} = \epsilon t_{y0} = \pm 0,3 \times 8,91 = \pm 2,67, \quad \dots(1.63)$$

1.1.5 (Becker)

(Becker) [3]

I , , IPE
(IPE 200, IPE 300 IPE 360).

$l=4920 \text{ mm},$, **1.13,**

(

) , **1.13.**

$d=100 \text{ mm}$ $d=160 \text{ mm},$ $14 \text{ mm},$

$15 \text{ mm}.$,

: $P=2R=2, 4, 8 \text{ kN}.$

,

.

, IPE 300 $4, 14, 24, 34, 44$

54 mm , IPE 360

64 mm .

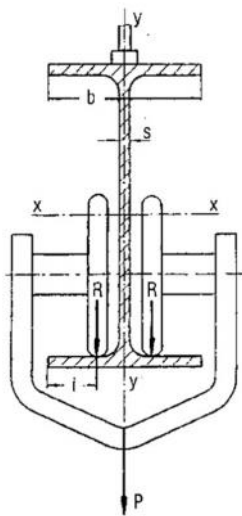
() (z)

(x), **1.13.** 54 mm

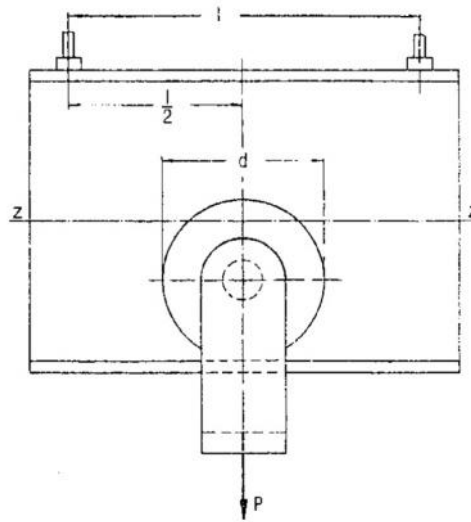
(54) IPE 300, , 64 mm

(64) IPE 360, (2,45

IPE 300; 1 mm IPE 360)



1.13:



[3]

(z)

1.14.

$R=100 \text{ kp,}$

, $9,81 \text{ kN.}$

$(P = 2R = 2 \times 100 = 200 \text{ kp}),$

IPE 300 (

$W_{x,IPE 300}=557 \text{ cm}^3)$

IPE 360 (

$W_{x,IPE 360}=904 \text{ cm}^3)$

e

$$\tau_{p,IPE 300} = \frac{Pl}{4W_{x,IPE 300}} = \frac{200 \times 4920}{4 \times 557 \times 10^3} = 0,44 \text{ kp/mm}^2; \quad \dots(1.64)$$

$$\tau_{p,IPE 360} = \frac{Pl}{4W_{x,IPE 360}} = \frac{200 \times 4920}{4 \times 904 \times 10^3} = 0,27 \text{ kp/mm}^2, \quad \dots(1.65)$$

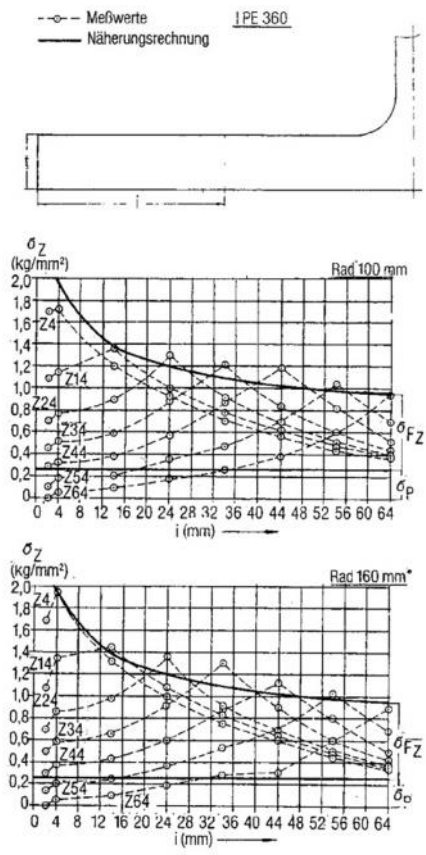
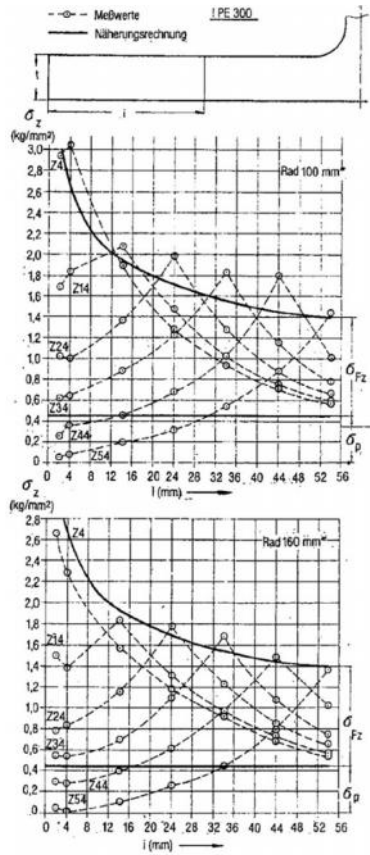
1.14.

(z)

(x),

$$\tau_z = \frac{E}{1-\epsilon^2} (v_z + \epsilon v_x), \quad \dots(1.66)$$

$$\tau_x = \frac{E}{1-\epsilon^2} (v_x + \epsilon v_z). \quad \dots(1.67)$$



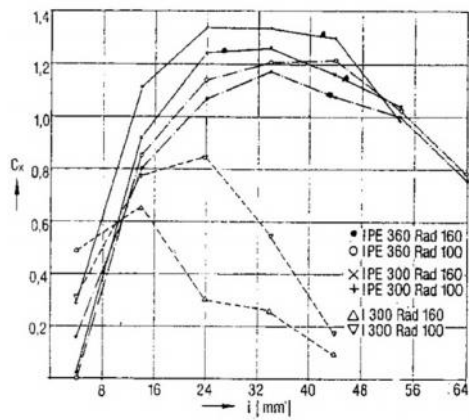
1.14:

: () IPE 300; () IPE 360 [3]

1.15,

$$c_x = \dagger_x \frac{t^2}{R}$$

...(1.68)



1.15:

(c_x) [3]

(z), **1.14,** g (p)

(Fz),

$$\tau_z = \tau_p + \tau_{Fz} \quad \dots(1.69)$$

(

, ,) ,

,

$$\tau_{Fz} = \tau_z - \tau_p \quad \dots(1.70)$$

, , , ,

z > p, , z < p,

54 IPE 300, , 64 IPE 360,

2 mm < i < 34 mm. ,

64 IPE 360

d=100 mm i=4 mm, **1.14()**,

$$\tau_z = 0,05 \text{ kp/mm}^2, \quad \dots(1.71)$$

p, (1.65),

$$\tau_{Fz} = \tau_z - \tau_p = 0,05 - 0,27 = -0,22 \text{ kp/cm}^2. \quad \dots(1.72)$$

IPE 360 t=12,7 mm,

$$\tau_0 = \frac{R}{t^2} = \frac{100}{12,7^2} = 0,62 \text{ kp/mm}^2, \quad \dots(1.73)$$

/ (64 1 mm), ,

0,

$$c_{z0} = \frac{\tau_{Fz}}{\tau_0} = \frac{-0,22}{0,62} = -0,36. \quad \dots(1.74)$$

1.2

c_{z0}

1.16.

[3]

$$\} = \frac{2i}{b-s}. \quad \dots(1.75)$$

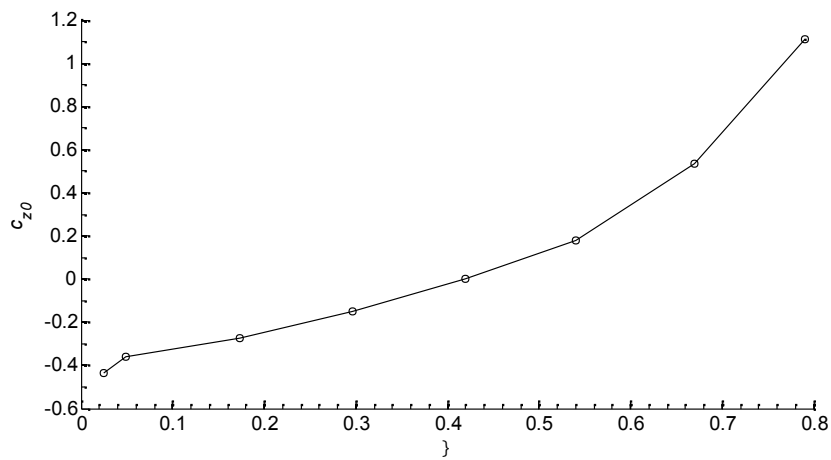
1.2:

$d=100$ mm,
(Becker)

c_{z0}

IPE 360

i (mm)	2	4	14	24	34	44	54	64
	0,025	0,049	0,173	0,296	0,42	0,540	0,670	0,790
c_{z0}	-0,436	-0,360	-0,274	-0,150	0,00	0,180	0,532	1,110



1.16:

(Becker)

c_{z0}

IPE 360

$d=100$ mm

(Becker),

1.14,

1)

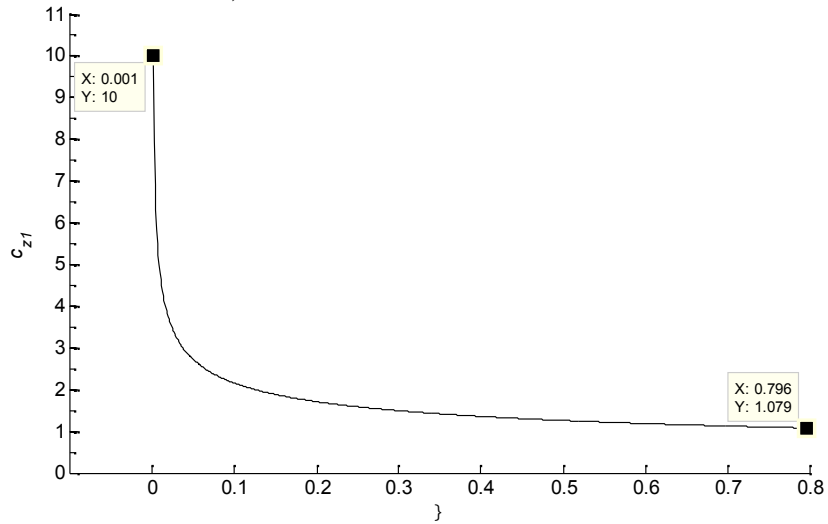
[3]

$$c_{z1} = \sqrt[3]{\frac{b-s}{2i}} = \sqrt[3]{\frac{1}{\}}, \quad \dots(1.76)$$

1.17. (1.76)

, 1.17,

$$\lim_{\beta \rightarrow 0} c_{z1} = \infty, \quad \dots(1.77)$$



1.17: c_{z1} (Becker)

(Becker)

(1.76),

$b/4$

$$\tau_{z,u} = \tau_p + c_{z0} \tau_0 \leq \tau_{dop}. \quad \dots(1.78)$$

(1.76)

HEA 360, 1.7,

1.1,

$$c_{z1} = \sqrt[3]{\frac{b-s}{2i}} = \sqrt[3]{\frac{300-10}{2 \times 20}} = 1,395; \quad \dots(1.79)$$

$$\tau_{FZ} = c_{z0} \tau_0 = 1,395 \times 3,265 = 4,56 \text{ kN/cm}^2. \quad \dots(1.80)$$

(Becker)

/ (0),

, (2)

2

” “

1: c_{x1} , **1.15** c_{z1} ,

(1.76), **1.17.** , (*Becker*)

0 2. c_{z0}

54 IPE 300, 64

IPE 360.

IPE 360, 1.2, **1.6.**

c_{z2} 4

(4 mm),

c_{z2} .

c_{x0} .

1.1.6 (*Mendel*)

(*Mendel*) [14,15]

, ,

(*Becker*) .

(*Mendel*)

I , .

, ()

/ (0),

(1).

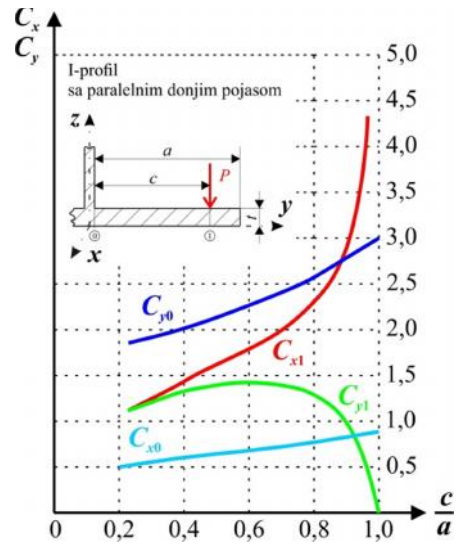
(*Mendel*) (2).

I , (*Mendel*)

IPE

(x) (y)
(c/a),

1.18.



1.18:

I

[15]

(Mendel),

$$\sigma_{x0} = \pm C_{x0} \sigma_0 \quad \dots(1.81)$$

$$\sigma_{y0} = \pm C_{y0} \sigma_0 \quad \dots(1.82)$$

$$\sigma_{x1} = \pm C_{x1} \sigma_0 \quad \dots(1.83)$$

$$\sigma_{y1} = \pm C_{y1} \sigma_0 \quad \dots(1.84)$$

0, (1.26),

(1.81) - (1.84),

HEA 360, 1.7, 1.1, :

$$c_{x0} = 0,8; \quad \dots(1.85)$$

$$c_{y0} = 2,7; \quad \dots(1.86)$$

$$c_{x1} = 2,5; \quad \dots(1.87)$$

$$c_{y1} = 1,2; \quad \dots(1.88)$$

$$\tau_{x0} = \pm 2,61 \text{ kN/cm}^2; \quad \dots(1.89)$$

$$\tau_{y0} = \pm 8,82 \text{ kN/cm}^2; \quad \dots(1.90)$$

$$\tau_{x1} = \mp 8,16 \text{ kN/cm}^2; \quad \dots(1.91)$$

$$\tau_{y1} = \mp 3,92 \text{ kN/cm}^2. \quad \dots(1.92)$$

(1.83) (1.84),
 1, (1.87) (1.88),
 1, (1.91) (1.92), (Mendel)

32 mm.

(Mendel)

1.19,

600 kp,

1.20.

1.20.

($\tau_{y,d} = 12,5 \text{ kp/mm}^2$)

$\tau_{y,g} = 14,5 \text{ kp/mm}^2$, **1.20**(),

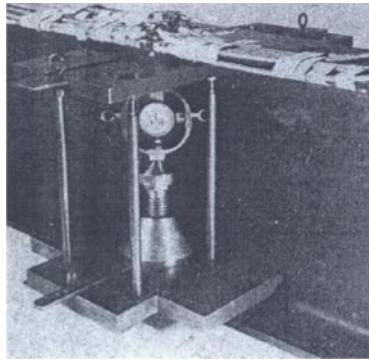
IPE 300,

$$\frac{14,5 - 12,5}{12,5} \times 100 = 16\%.$$

...(1.93)

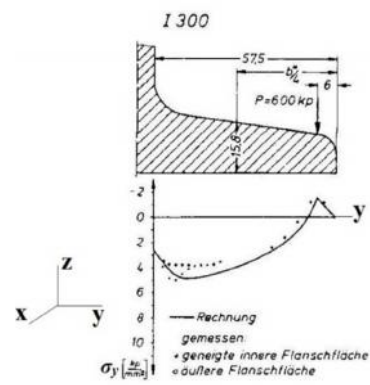
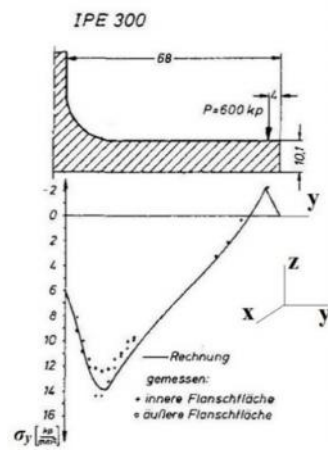
I

1.20().



1.19:

[15]



()

1.20:

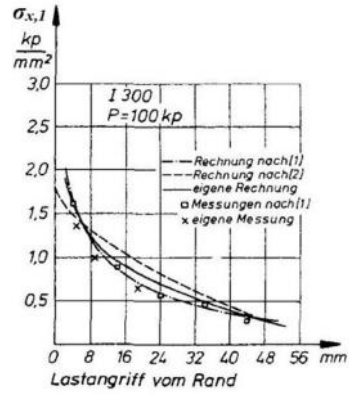
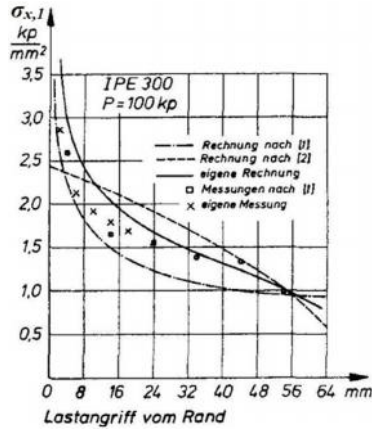
IPE 300 ()

()

I 300 () [15]

(Mendel)

(Becker) [3], 1.21.



1.21:

() IPE 300; () I 300 [15]

(Mendel)

(Poisson)

($E=21000 \text{ kN/cm}^2$, $\nu=0,3$),

: / $\pm 0,05$; / $\pm 0,1$;

(Mendel)

1.1.7

(Hannover, Reichwald) -

EN 15011

(Becker) [3]

(Mendel) [14,15],

(Hannover, Reichwald) [9,10] :

- 0, 1 2, 1.22,

;

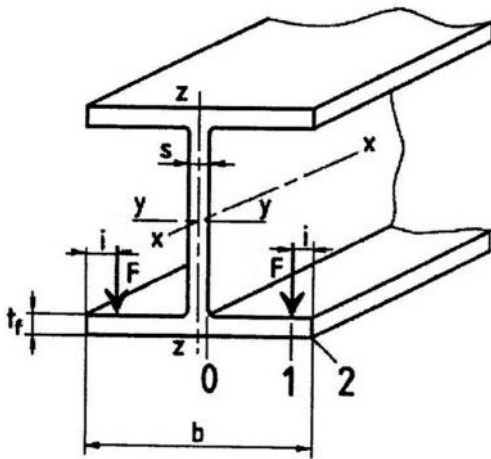
- (x) (y) ,

$$\tau_{Fx} = c_x(\zeta) \frac{F}{t_f^2}; \quad \dots(1.94)$$

$$\tau_{Fy} = c_y(\zeta) \frac{F}{t_f^2}; \quad \dots(1.95)$$

- (1.75), $c_x(\zeta)$ -
 $c_y(\zeta)$ - , F -

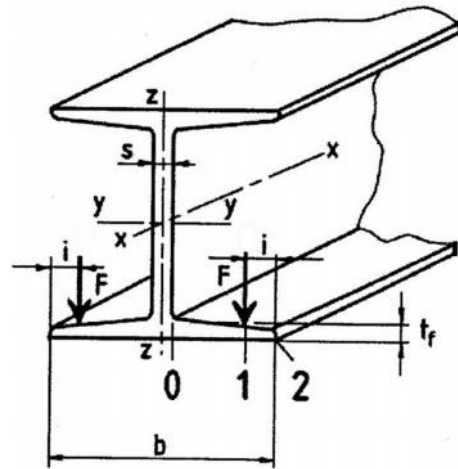
, t_f -



()

1.22:

() I



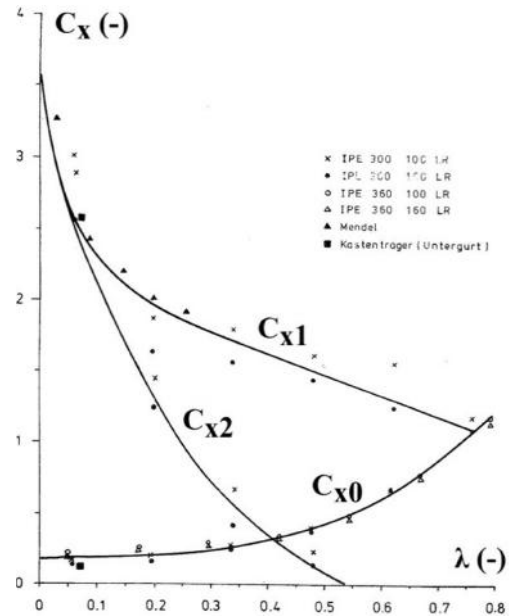
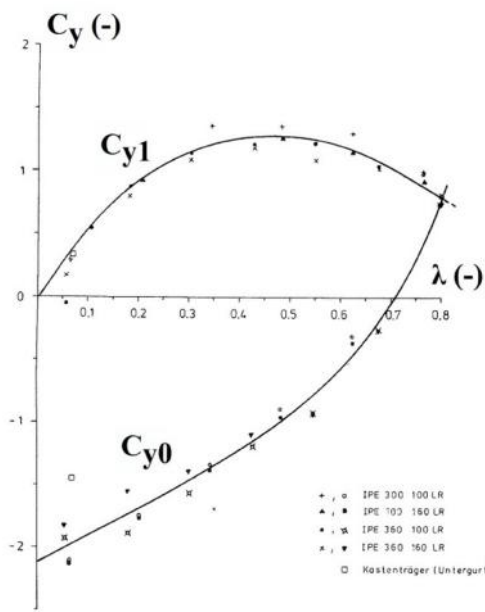
()

; () I
 [9]

(1.26).

1.23,

$$c = c(\lambda) = a + b\lambda + ce^{d\lambda}. \quad \dots(1.96)$$



1.23: ()
I

()
: () c_x ; () c_y [9]

, 1.22,

- 0 -
- 1 -
- 2 -

[9]:

$$C_{x0} = 0,050 - 0,580\lambda + 0,148e^{3,015\lambda}; \quad \dots(1.97)$$

$$C_{x1} = 2,230 - 1,490\lambda + 1,390e^{-18,33\lambda}; \quad \dots(1.98)$$

$$C_{x2} = 0,730 - 1,580\lambda + 2,910e^{-6,00\lambda}; \quad \dots(1.98)$$

$$C_{y0} = -2,110 + 1,977\lambda + 0,0076e^{6,53\lambda}; \quad \dots(1.100)$$

$$C_{y1} = 10,108 - 7,408\lambda - 10,108e^{-1,364\lambda}; \quad \dots(1.101)$$

$$C_{y2} = 0.$$

[9],

CETIM

FEM (IX, Nr 9.341, 1978)

(Hannover,

Reichwald)

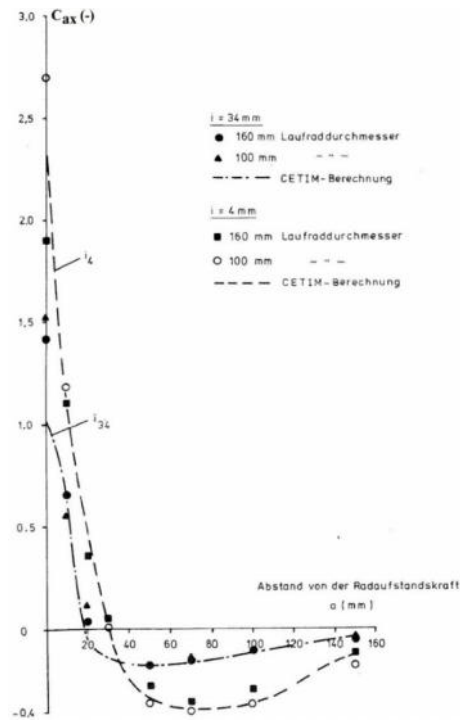
SAP IV - B,

(IPE).

(Hannover, Reichwald)

0

1.24.



1.24:

[10]

HEA 360, 1.7, 1.1, :

$$\tau_{x0} = 0,63 \text{ kN/cm}^2; \quad \dots(1.102)$$

$$\sigma_{x0} = 6,97 \text{ kN/cm}^2; \quad \dots(1.103)$$

$$\tau_{x2} = 5,82 \text{ kN/cm}^2; \quad \dots(1.104)$$

$$\tau_{y0} = -5,94 \text{ kN/cm}^2; \quad \dots(1.105)$$

$$\tau_{y1} = 2,32 \text{ kN/cm}^2; \quad \dots(1.106)$$

$$\tau_{y2} = 0. \quad \dots(1.107)$$

:

•

, ,

(10 mm ,

, 1.24);

•

,

,

(f_y)

(u), = f_y / u ;

(=1,5),

(x,g),

$$\tau_x = \tau_{x,g} + v\tau_{x(0,1,2)}; \quad \dots(1.108)$$

$$\tau_y = v\tau_{y(0,1)}; \quad \dots(1.109)$$

=0,75.

(, ,),

$$t_u = \sqrt{t_x^2 + t_y^2 - t_x t_y + 3t^2} \leq t_{dop} = \frac{f_y}{\epsilon} \quad \dots(1.110)$$

(Hannover, Reichwald),

N 15011,

0

1.1.8

1.1.1 ÷ 1.1.7

HEA 360,

1.7,

1.1.

1.3.

-
-

, 0,

(Hannover, Reichwald),

N 15011;

-

N 15011

0,

1.20.

1)

1.1.1 ÷ 1.1.7.

1.1,

125 mm,

- 186,7 kN/cm²,

1.3.

1.3:

						(kN/cm ²)	
		^x		^y			
		0	1	2	0	1	
		± 1,96*		∓ 7,51	± 7,35		
		± 0,84		∓ 5,55	± 9,14		
		± 2,48			± 8,28		
B1		± 8,91			± 8,91		
		± 2,67**					
			+ 4,56***				
		± 2,61	∓ 8,16		± 8,82	∓ 3,92	
(N 15011)		∓ 0,63	∓ 6,97	∓ 5,82	± 5,94	∓ 2,32	

*

**

(1.62)
b/4

1.1.9

I

[19].

:

(1994)

•

•

,
 [1,7 - 10, 14, 15, 18].
 I
 (14%),
 / .
 [19]

(Mendel) [14, 15].
 [4],
 I ,
 INP 240, INP 300 INP 400,

(Mendel) [14, 15]

(Gokhberg)

$c/a=0,7\div 0,9$ (c -
 , a -).

[22]

[19],

HEA HEB

(),

(Mendel) [14, 15].

(Mendel) , , [29]

2÷30 mm),

I (I 160, I 200, I 240, I 300, I 340 I 400), 2÷8 m.
[29, 30] ,

[6]

I (I HEA
) (160, 200, 240, 260, 300, 340).
HEA I

1.2

:

•

;

•

;

•

,

;

•

;

•

N 15011

,

,

:

1.

;

2.

;

3.

-

;

4.

,

;

5.

;

6.

,

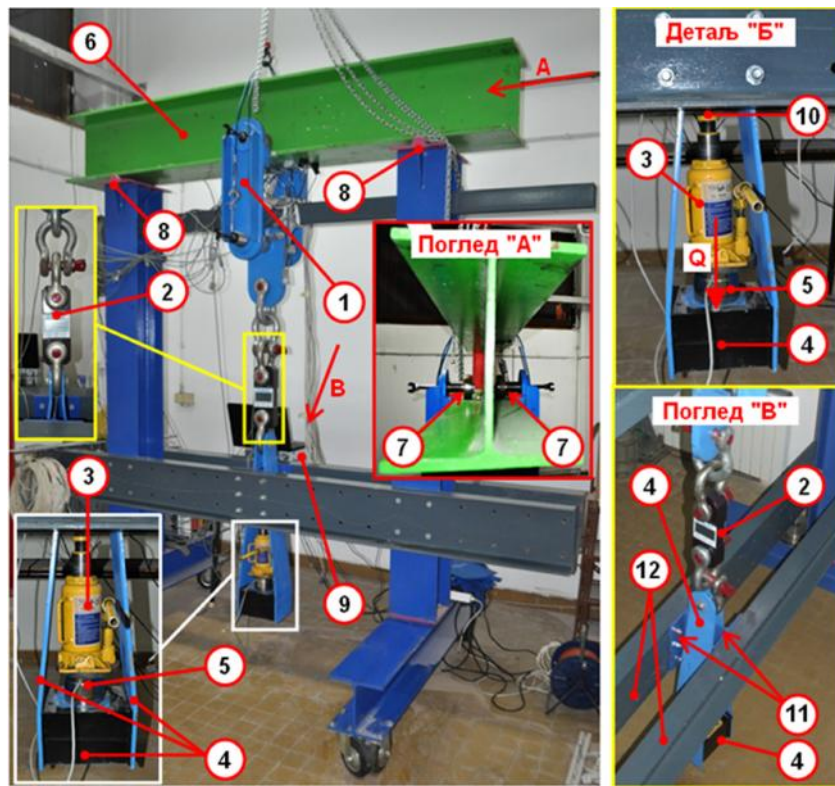
N 15011.

2.

IPB HEA 360 [DIN

1025 (Blatt 3/1963)]

2.1.



2.1: : 1 - Dynafor (LLx12,5 t); 3 - (12 t); 4 - ; 2 - HBM U3; 6 - (HEA 360); 7 - ; 8 - ; 9 - - HBM (3 x SPIDER 8 and Quantum X); 10 - ; 11 - ; 12 -

2370 mm

(8) 1640 mm. (6)

(1) (7),

(„ “).

125 mm, 40 mm) : ()

(1),

(2), (3), (4),

(5) (, 1 - 5

); (b)

(

a „ a “).

G=1,45 kN. (Q)

(5) (2).

(Q)

(3) (4), „ “,

(10) (11)

(12). (4)

(2) (1).

DIN 1025 (Blatt 3/1963), **2.1.**

2.1:

			(mm)
			HEA 360*
<i>H</i>	354		350
<i>b</i>	297		300
<i>t_{BF}</i>	17.3		17.5
<i>t_{UF}</i>	17.6		17.5
<i>s</i>	10.7		10
/	<i>r</i>	23	27

* DIN 1025 (Blatt 3/1963)

2.1.

31 (), 2.2, 2.2.

$Q=20$ kN,

$$F = \frac{Q + G}{2} = \frac{20.0 + 1.45}{2} = 10.73 \text{ kN}, \quad \dots(2.1)$$

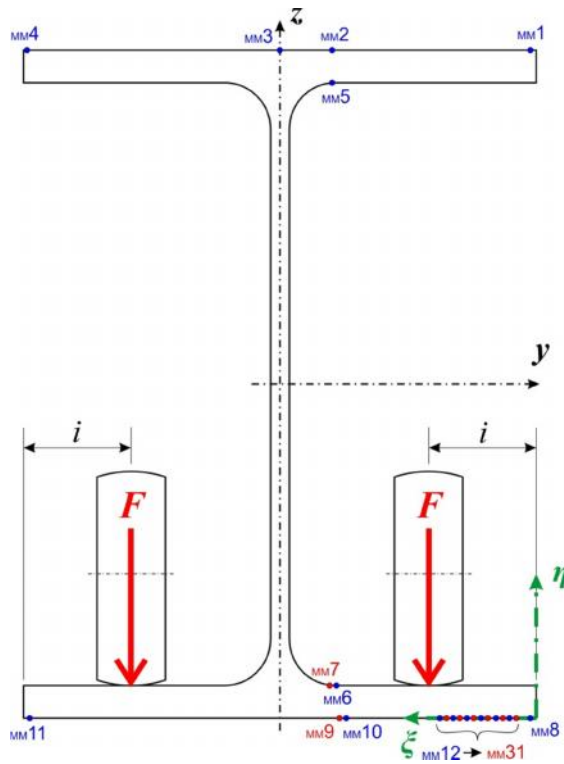
(i 1.22) $i=5, 10, 15, 20, 25, 30, 35, 45, 50,$

60 70 mm, 2.3 2.4, 2.3.

2.3 2.4

$F=10$ kN.

2.4.



()



()



()



()

2.2:

(,)

; (,)

: ()

;

2.2: (2.2())

() 1, 2, ..., 10

M	1	2	3	4	5	6	7	8	9	10
(mm)	1,100	116,1	144,6	287,1	118,6	118,0	120,2	5,000	116,0	115,0
(mm)	354,0	354,0	354,0	354,0	336,3	17,30	17,50	0,000	0,000	0,000

() 11, 12, ..., 20

M	11	12	13	14	15	16	17	18	19	20
(mm)	293	52,0	50,0	48,0	46,0	44,0	42,0	40,0	38,0	36,0
(mm)	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

() 21, 22, ..., 31

M	21	22	23	24	25	26	27	28	29	30	31
(mm)	34	26	24	22	20	18	16	14	12	10	8,0
(mm)	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

M 6 - 7 M 9 - 10, 2.5(),
 , 2.3 2.4,
 () [21]

$$\dagger_{x,tot}^{MM\ 6-7} = \frac{E}{1-\epsilon^2} (v_{x6} + \epsilon v_{y7}), \quad \dots(2.2)$$

$$\dagger_{y,tot}^{MM\ 6-7} = \frac{E}{1-\epsilon^2} (v_{y7} + \epsilon v_{x6}), \quad \dots(2.3)$$

$$\dagger_{x,tot}^{MM\ 9-10} = \frac{E}{1-\epsilon^2} (v_{x10} + \epsilon v_{y9}), \quad \dots(2.4)$$

$$\dagger_{y,tot}^{MM\ 9-10} = \frac{E}{1-\epsilon^2} (v_{y9} + \epsilon v_{x10}), \quad \dots(2.5)$$

$$E=21000 \text{ kN/cm}^2, \quad \epsilon=0.3$$

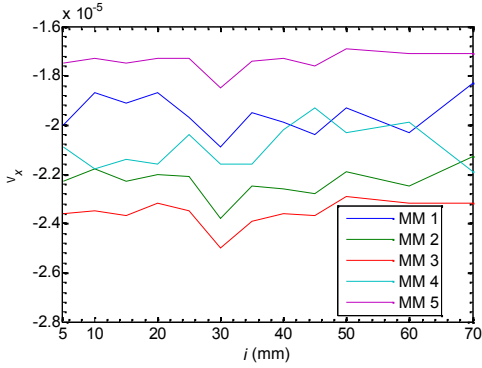
2.3:

 $i=5, 10, 15, 20, 25, 30$ mm.

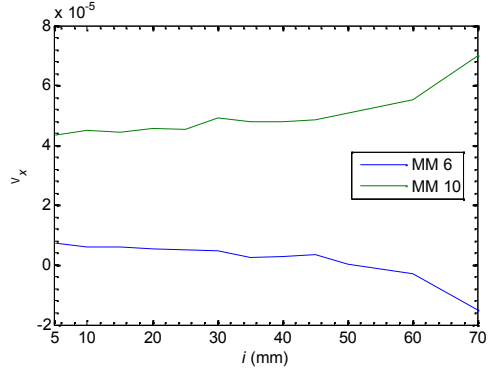
M	i (mm)	i (mm)					
		5 ($\mu\text{m/m}$)	10	15	20	25	30
1	x	-20,0	-18,7	-19,1	-18,7	-19,7	-20,9
2	x	-22,3	-21,8	-22,3	-22,0	-22,1	-23,8
3	x	-23,6	-23,5	-23,7	-23,2	-23,5	-25,0
4	x	-20,9	-21,8	-21,4	-21,6	-20,4	-21,6
5	x	-17,5	-17,3	-17,5	-17,3	-17,3	-18,5
6	x	7,2	6,1	6,1	5,4	5,2	4,7
7	y	386,4	378,3	363,3	353,7	339,9	344,6
8	x	611,2	531,1	461,5	405,0	350,7	316,3
9	y	-366,5	-357,8	-343,4	-333,1	-319,1	-322,3
10	x	43,5	44,9	44,5	45,6	45,3	49,2
11	x	578,1	513,1	427,8	374,4	340,5	309,1
12	y	-181,9	-161,4	-140,6	-121,0	-100,4	-70,6
13	x	161,2	164,9	163,6	166,5	163,9	173,0
14	y	-180,5	-156,8	-134,4	-112,7	-89,7	-53,8
15	x	179,1	183,2	181,1	185,0	184,6	194,3
16	y	-176,8	-149,3	-125,1	-101,8	-75,3	-31,2
17	x	197,1	201,5	198,7	203,6	205,3	215,6
18	y	-172,7	-142,4	-115,3	-89,0	-49,8	0,7
19	x	215,0	219,8	216,3	222,1	226,0	236,9
20	y	-167,5	-134,0	-104,6	-72,3	-33,9	38,9
21	x	238,9	244,1	242,1	249,0	253,7	262,9
22	y	-164,4	-114,6	-69,3	-7,9	52,5	92,6
23	x	299,0	303,8	305,3	308,1	304,8	284,0
24	y	-161,2	-96,0	-36,9	34,3	77,7	60,7
25	x	333,5	339,0	333,8	334,8	317,1	280,9
26	y	-153,4	-68,2	4,9	61,2	59,5	19,9
27	x	374,8	377,1	365,0	349,6	318,5	273,5
28	y	-161,3	-36,1	34,4	45,6	16,4	-16,4
29	x	490,1	479,5	448,1	412,9	365,0	329,1
30	y	-136,2	-21,5	15,7	-3,3	-30,5	-46,2
31	x	548,7	511,3	460,7	412,4	359,3	322,9

2.4: $i=35, 40, 45, 50, 60, 70$ mm

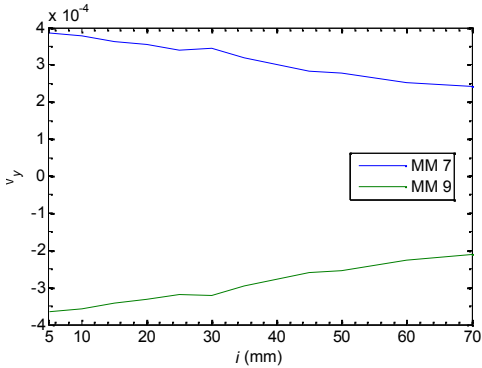
M	i (mm)	i (mm)					
		35 ($\mu\text{m/m}$)	40	45	50	60	70
1	x	-19,5	-19,9	-20,4	-19,3	-20,3	-18,3
2	x	-22,5	-22,6	-22,8	-21,9	-22,5	-21,3
3	x	-23,9	-23,6	-23,7	-22,9	-23,2	-23,2
4	x	-21,6	-20,2	-19,3	-20,3	-19,9	-21,9
5	x	-17,4	-17,3	-17,6	-16,9	-17,1	-17,1
6	x	2,5	2,7	3,4	0,3	-2,9	-15,1
7	y	319,2	300,3	283,5	278,1	251,5	241,2
8	x	278,2	234,6	201,8	189,6	146,8	136,6
9	y	-297,0	-278,5	-261,0	-253,8	-225,1	-210,5
10	x	47,8	47,8	48,4	50,9	55,3	69,8
11	x	263,6	235,0	219,6	188,1	156,5	106,6
12	y	-48,9	-10,0	45,4	97,5	82,7	33,9
13	x	190,3	207,7	217,2	237,2	184,2	161,5
14	y	-25,9	27,9	84,6	110,8	53,4	20,0
15	x	214,0	219,4	218,8	217,8	174,1	153,9
16	y	8,2	76,3	105,5	102,2	29,1	9,9
17	x	237,8	231,1	220,5	218,4	164,0	146,2
18	y	57,0	112,5	96,6	67,7	13,5	2,6
19	x	261,5	242,8	222,1	209,0	153,9	138,6
20	y	96,8	103,1	61,7	34,5	2,8	-3,7
21	x	281,2	249,3	215,7	198,8	147,8	135,2
22	y	78,1	31,0	7,7	-1,7	-10,2	-13,8
23	x	275,9	227,6	195,9	180,3	137,4	127,3
24	y	31,6	2,1	-8,8	-12,3	-16,3	-18,3
25	x	266,3	220,0	189,7	175,4	134,2	124,9
26	y	-2,7	-14,4	-19,6	-20,5	-20,5	-21,5
27	x	256,2	227,9	190,7	172,3	131,6	120,7
28	y	-31,1	-32,6	-35,3	-36,8	-24,6	-42,5
29	x	290,0	243,1	208,6	196,0	152,1	141,7
30	y	-47,9	-43,9	-40,3	-38,6	-32,5	-31,1
31	x	285,5	240,8	207,8	193,2	150,4	139,9



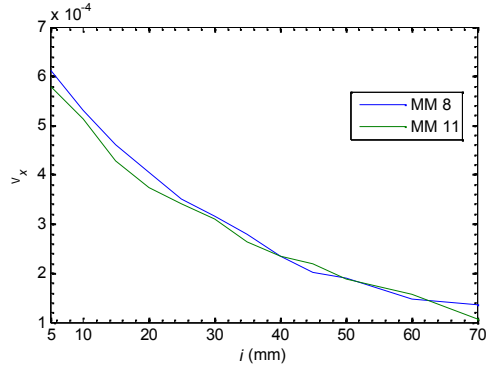
()



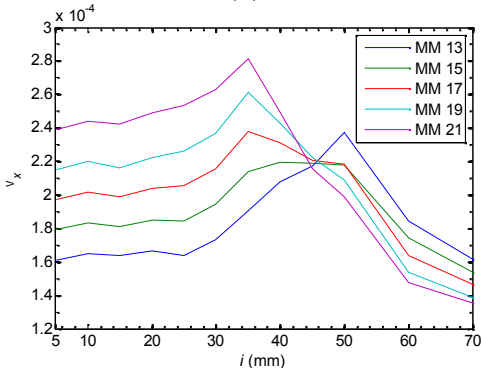
()



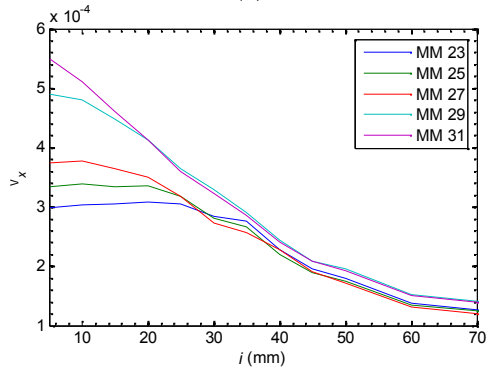
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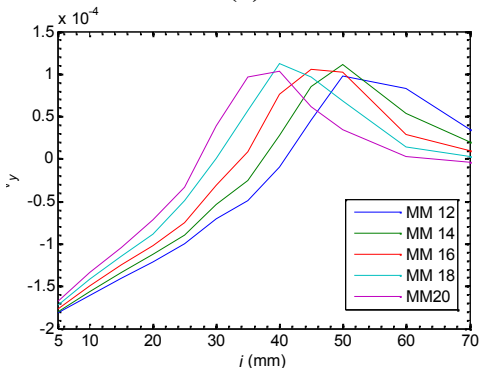
()



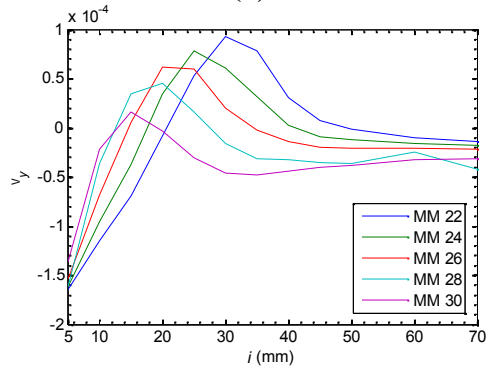
()



()

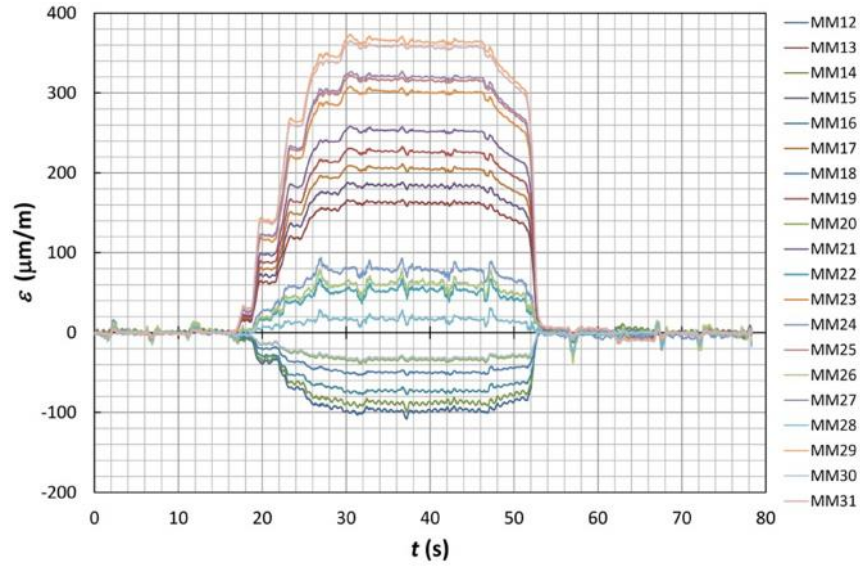


()

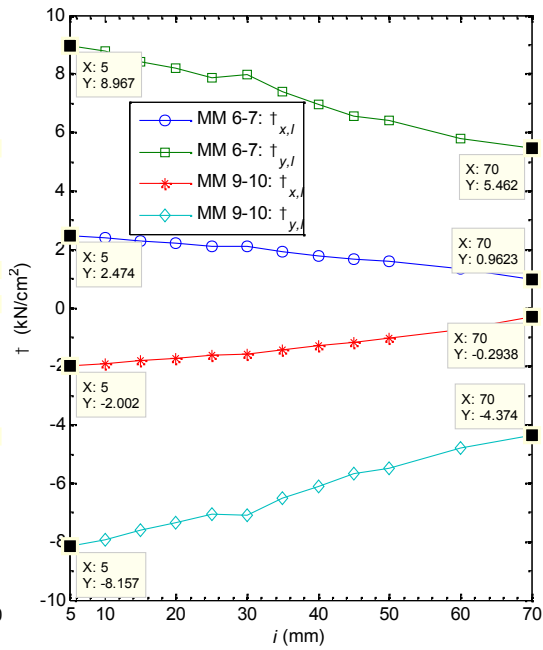
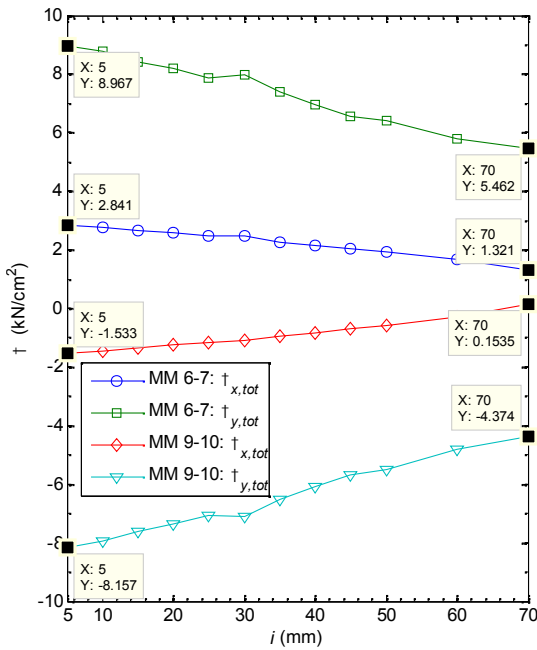


()

2.3:



2.4:



()

()

2.5:

M 6 - 7 M 9 - 10:

()

; ()

M 6 - 7 M 9 - 10

M - M 5 M 2,

(x) M 6 - 7 M 9 -

(y) $M_2 M_5$ $M_5 M_2$ (,).

$$v_{y2} = -\epsilon v_{x2}, \quad \dots(2.6)$$

$$v_{y5} = -\epsilon v_{x5}, \quad \dots(2.7)$$

10 (2.2), (2.3), (2.4) (2.5) $M_{6-7} M_{9-}$ $M_5 M_2$, (x)

(y) ,

$$\begin{aligned} \dagger_{x,l}^{MM\ 6-7} &= \frac{E}{1-\epsilon^2} \left\{ v_{x6} - (-v_{x5}) + \epsilon [v_{y7} - (-v_{y5})] \right\} = \\ &= \frac{E}{1-\epsilon^2} [v_{x6} + v_{x5} + \epsilon (v_{y7} + v_{y5})], \quad \dots(2.8) \end{aligned}$$

$$\begin{aligned} \dagger_{y,l}^{MM\ 6-7} &= \frac{E}{1-\epsilon^2} \left\{ v_{y7} - (-v_{y5}) + \epsilon [v_{x6} - (-v_{x5})] \right\} = \\ &= \frac{E}{1-\epsilon^2} [v_{y7} + v_{y5} + \epsilon (v_{x6} + v_{x5})], \quad \dots(2.9) \end{aligned}$$

$$\begin{aligned} \dagger_{x,l}^{MP\ 9-10} &= \frac{E}{1-\epsilon^2} \left\{ v_{x10} - (-v_{x2}) + \epsilon [v_{y9} - (-v_{y2})] \right\} = \\ &= \frac{E}{1-\epsilon^2} [v_{x10} + v_{x2} + \epsilon (v_{y9} + v_{y2})], \quad \dots(2.10) \end{aligned}$$

$$\begin{aligned} \dagger_{y,l}^{MM\ 9-10} &= \frac{E}{1-\epsilon^2} \left\{ v_{y9} - (-v_{y2}) + \epsilon [v_{x10} - (-v_{x2})] \right\} = \\ &= \frac{E}{1-\epsilon^2} [v_{y9} + v_{y2} + \epsilon (v_{x10} + v_{x2})]. \quad \dots(2.11) \end{aligned}$$

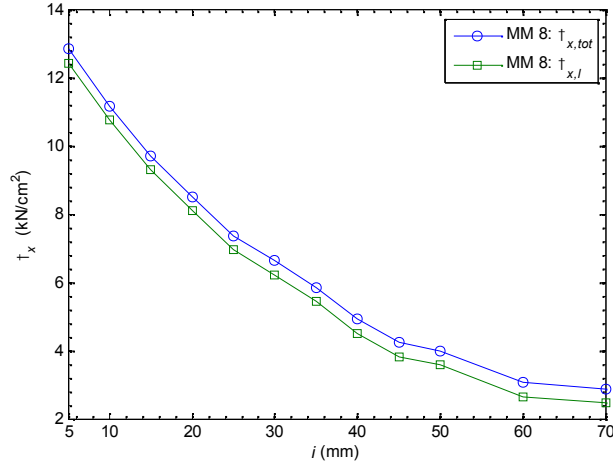
M_8 M_1

2.6,

M_8 , [21],

$$\dagger_{x,tot}^{MM8} = E v_{x8}, \quad \dots(2.12)$$

$$\dagger_{x,l}^{MM8} = E (v_{x8} + v_{x1}). \quad \dots(2.13)$$



2.6:

MM 8

12(),
 (y) MM 13, 15, ..., 29,
 (x),
 MM 14, 16, ..., 30, 2.2(a,).
 MM 31 ()
 y M 30 M 8

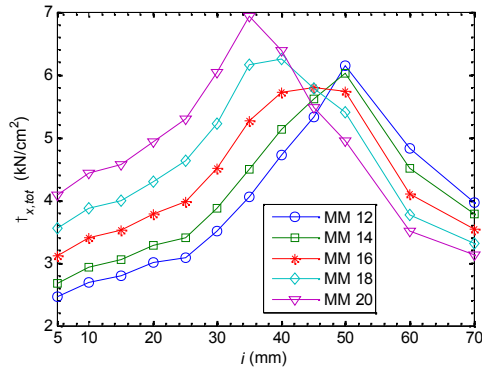
$$v_{y8} = \epsilon v_{x8}. \quad \dots(2.14)$$

M 14, 16, ..., 30 (x)
 (y).
 x M 12 ()
 M 13. M 12, 13, ..., 31,

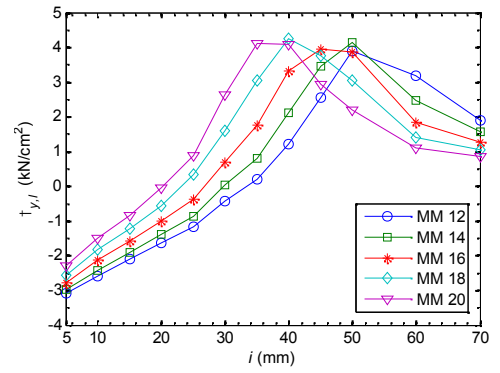
2.7,

$$\dagger_{x,tot}^{MMi} = \frac{E}{1-\epsilon^2} (v_{x,MMi} + \epsilon v_{y,MMi}), \quad \dots(2.15)$$

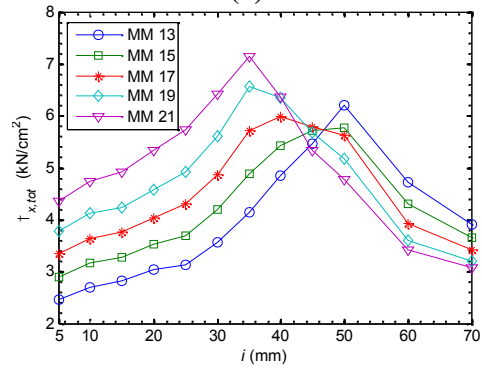
$$\dagger_{y,tot}^{MMi} = \frac{E}{1-\epsilon^2} (v_{y,MMi} + \epsilon v_{x,MMi}), \quad i=12,13, \dots, 31. \quad \dots(2.16)$$



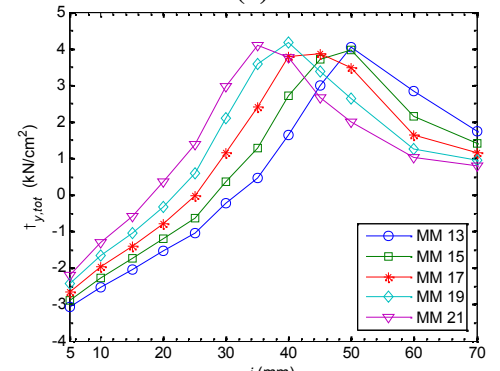
()



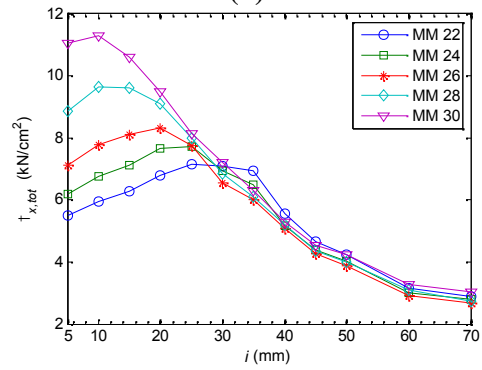
()



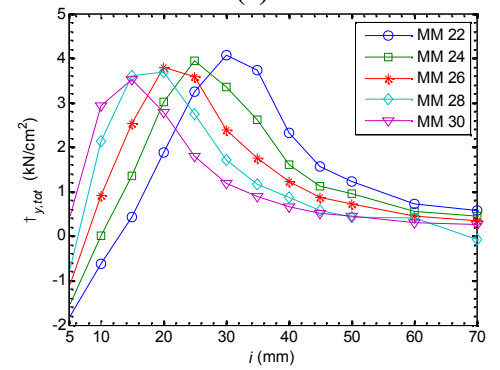
()



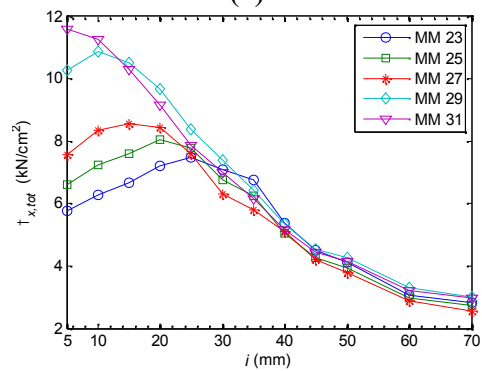
()



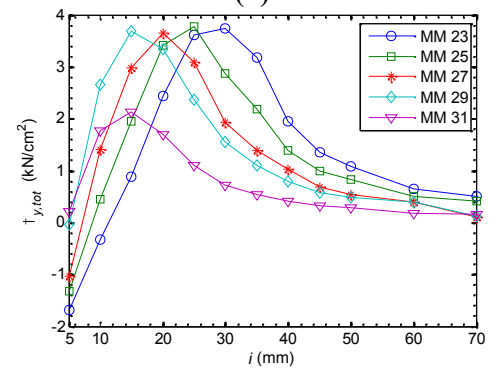
()



()



()



()

2.7:

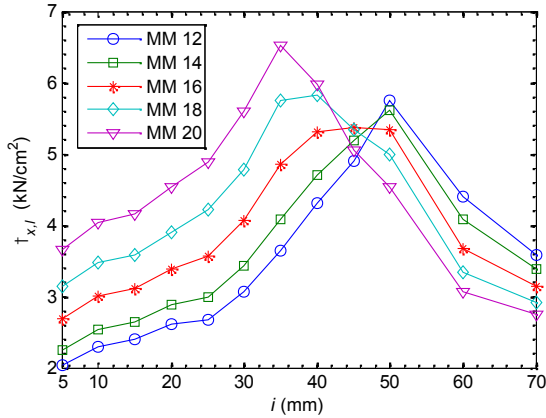
M 12, 13, 14, ..., 30, 31

9 - 10,

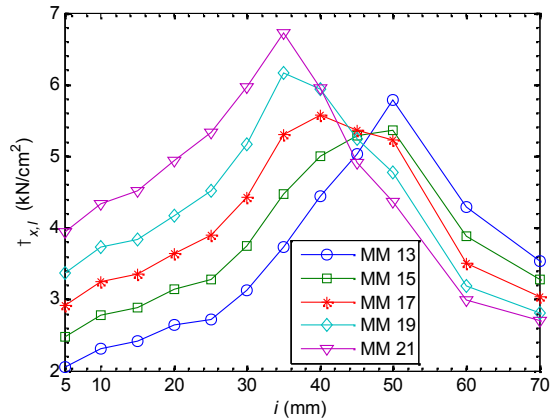
$$\begin{aligned} \dagger_{x,l}^{MMi} &= \frac{E}{1-\epsilon^2} \left\{ v_{x,MMi} - (-v_{x1}) + \epsilon \left[v_{y,MMi} - (-v_{y1}) \right] \right\} = \\ &= \frac{E}{1-\epsilon^2} \left[v_{x,MMi} + v_{x1} + \epsilon (v_{y,MMi} + v_{y1}) \right], \end{aligned} \quad \dots(2.17)$$

$$\begin{aligned} \dagger_{y,l}^{MMi} &= \frac{E}{1-\epsilon^2} \left\{ v_{y,MMi} - (-v_{y1}) + \epsilon \left[v_{x,MMi} - (-v_{x1}) \right] \right\} = \\ &= \frac{E}{1-\epsilon^2} \left[v_{y,MMi} + v_{y1} + \epsilon (v_{x,MMi} + v_{x1}) \right], \quad i=12,13, \dots, 31. \end{aligned} \quad \dots(2.18)$$

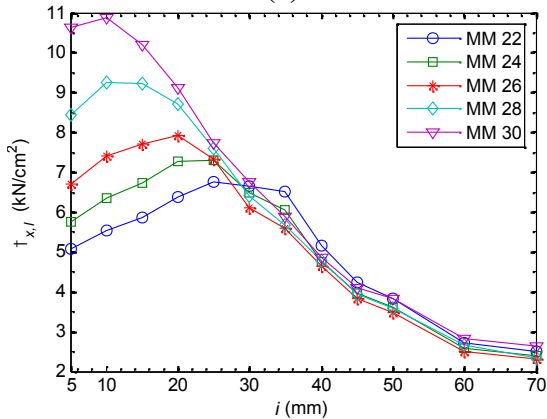
2.8 2.9.



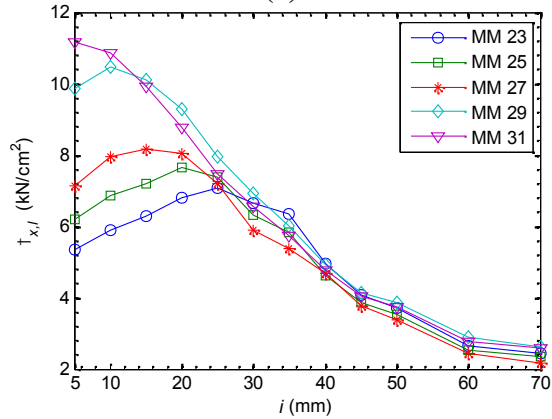
()



()



()

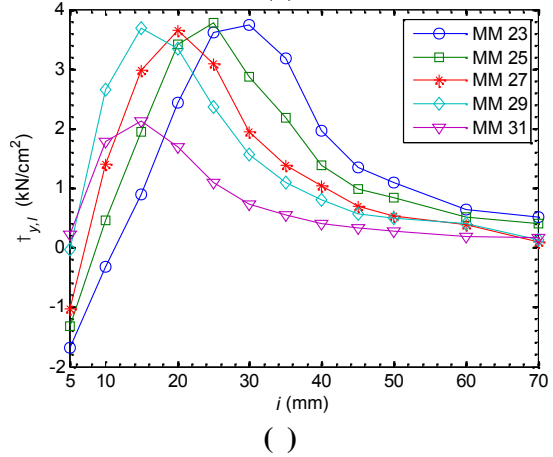
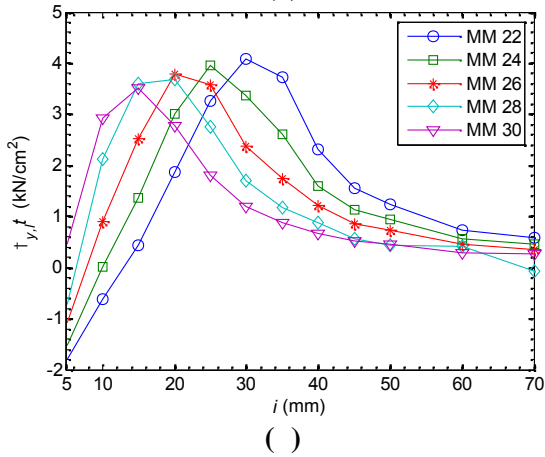
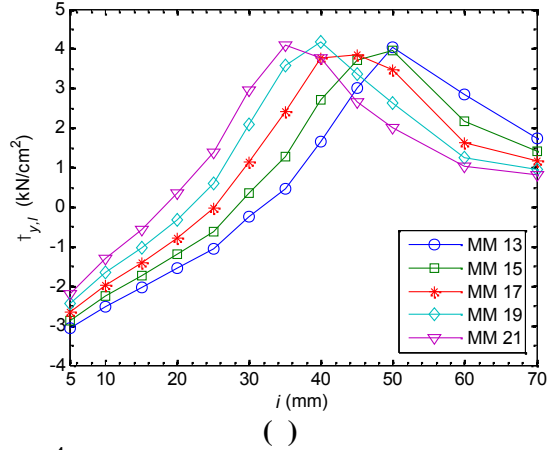
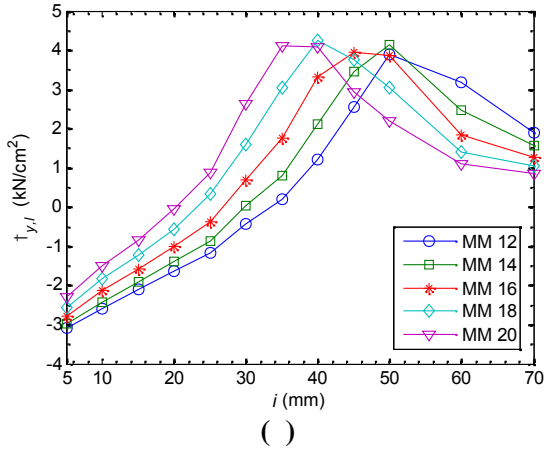


()

2.8:

12, 13, 14, ..., 30, 31

(x)



2.9:

12, 13, 14, ..., 30, 31

(y)

(i)

(M 8, 31, 30, ..., 12, 9, 10)

(i=10, 20, 30, 40, 50 mm)

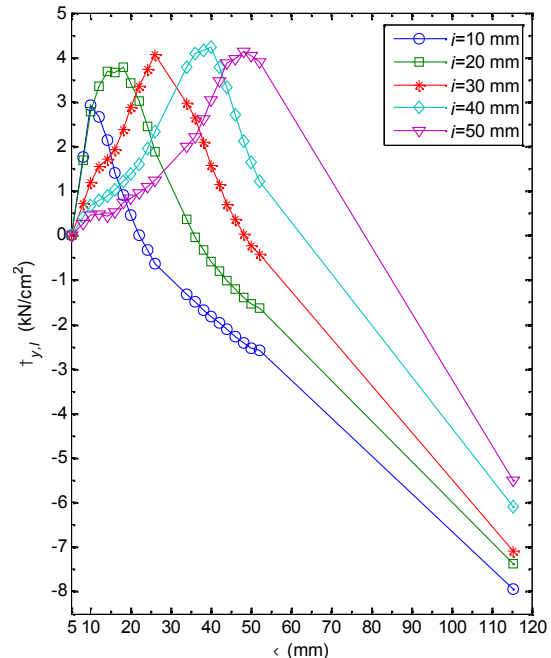
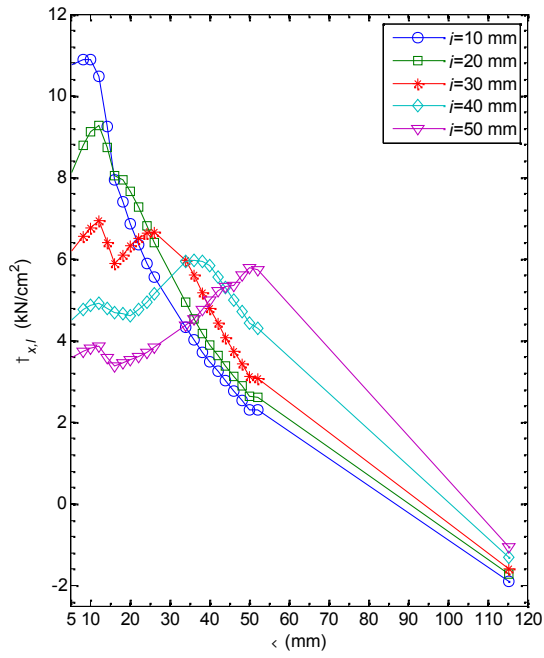
2.10.

2.5(), 2.6, 2.8, 2.9

2.10,

$$\tau_0 = \frac{F}{t_{jBF}^2} = \frac{Q}{2t_{jBF}^2} = \frac{20.0}{2 \times 1.73^2} = 3.34 \text{ kN/cm}^2, \quad \dots(2.19)$$

:



2.10:

()

()

• ,
M 6 - 7, M 9 - 10 ,
2.11 2.12;

• , 2.13 2.14;

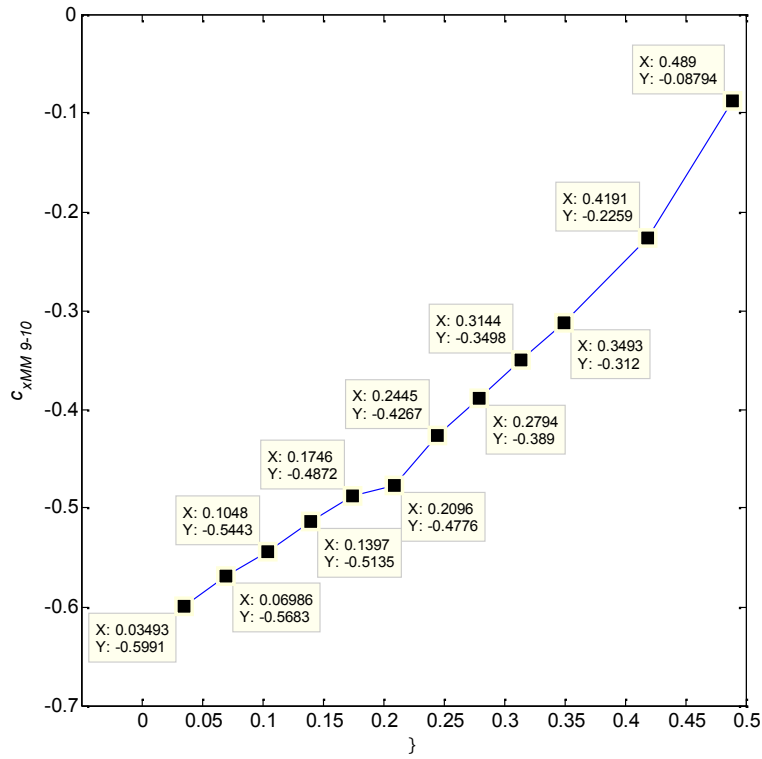
• ($i=10$ mm: M 30; $i=20$ mm: M 25;
 $i=30$ mm, 21 22;
 $i=40$ mm: M 18; $i=50$ mm: M 13), 2.15;

• , M 8, 2.16;

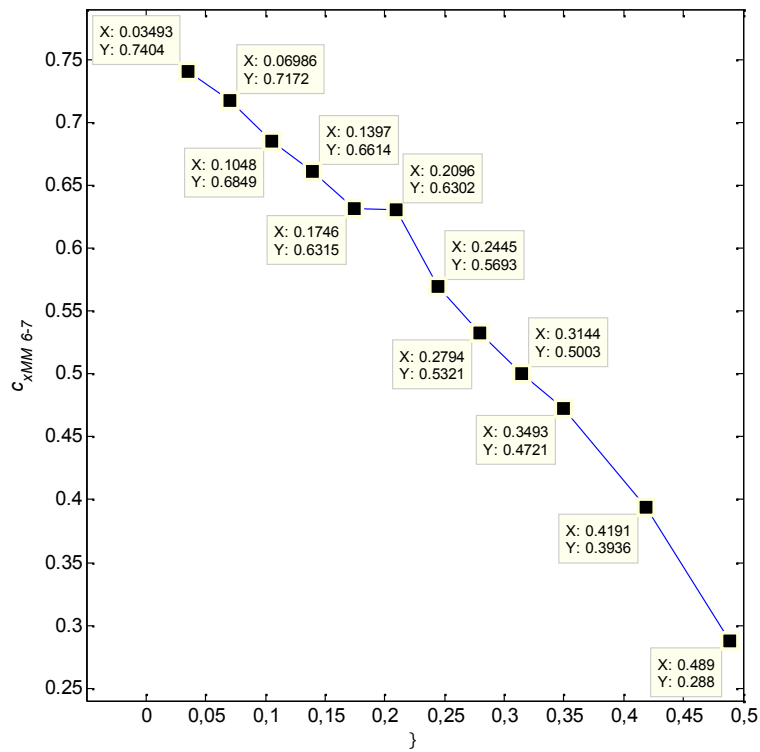
[5], i , a

2.11, 2.12, 2.15 2.16,

(1.75).

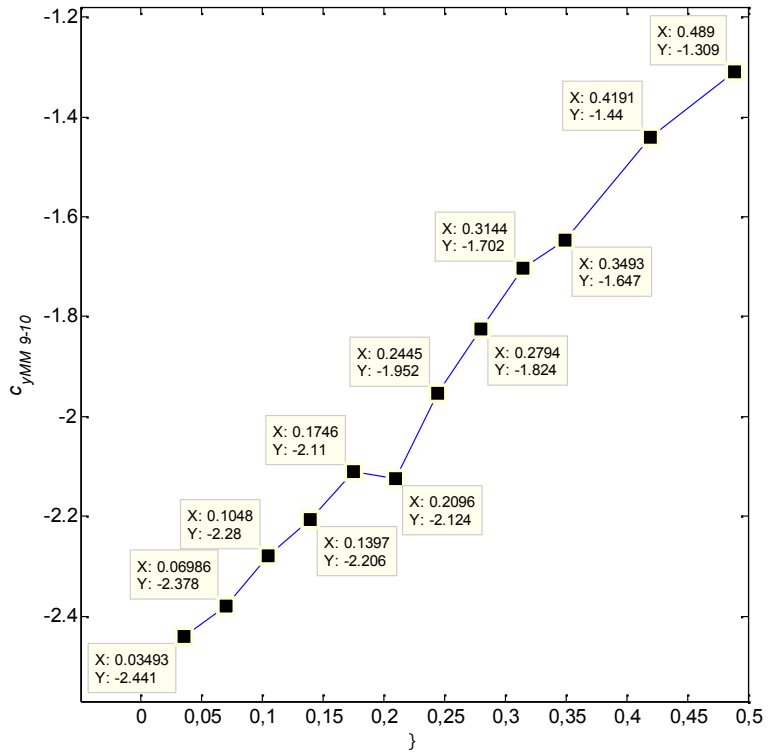


()

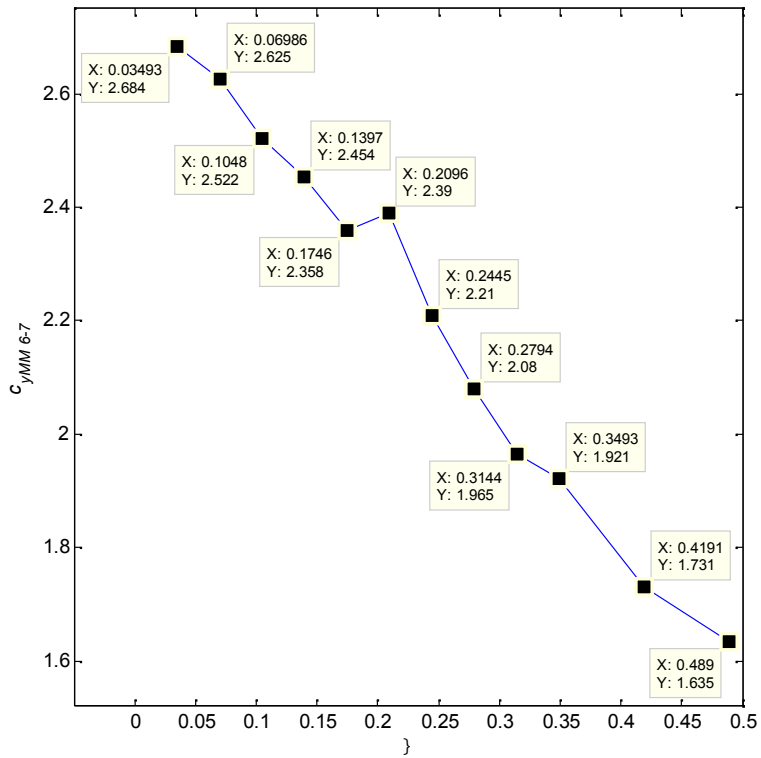


()

2.11: c_x : (a) M 9 - 10; () M 6 - 7

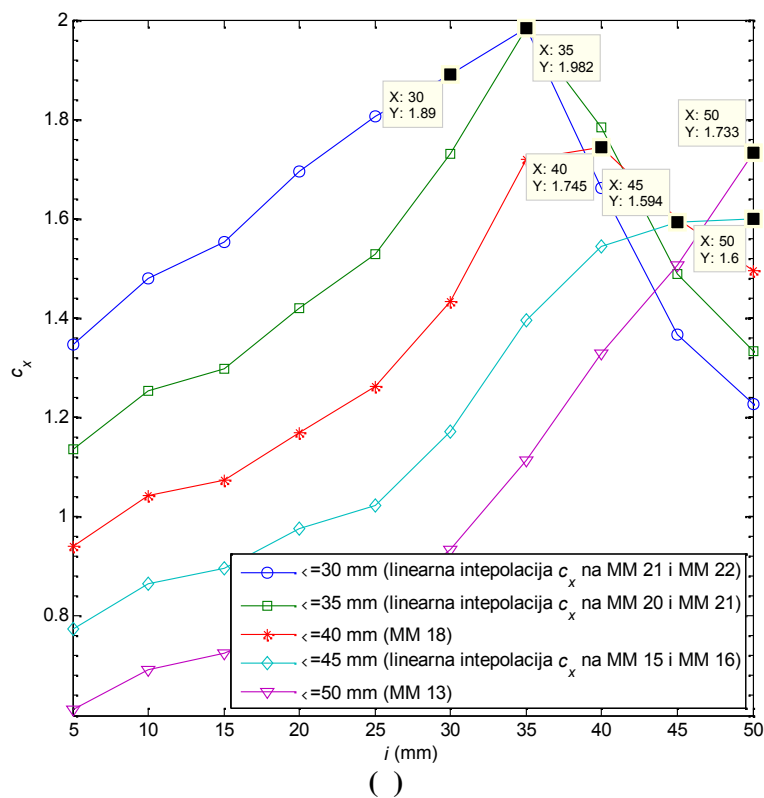
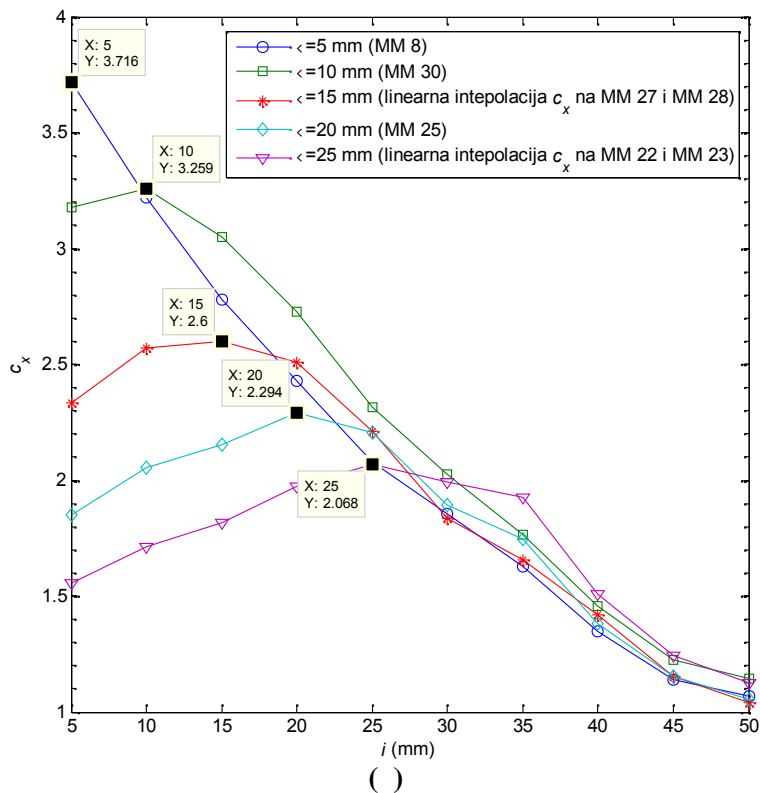


()

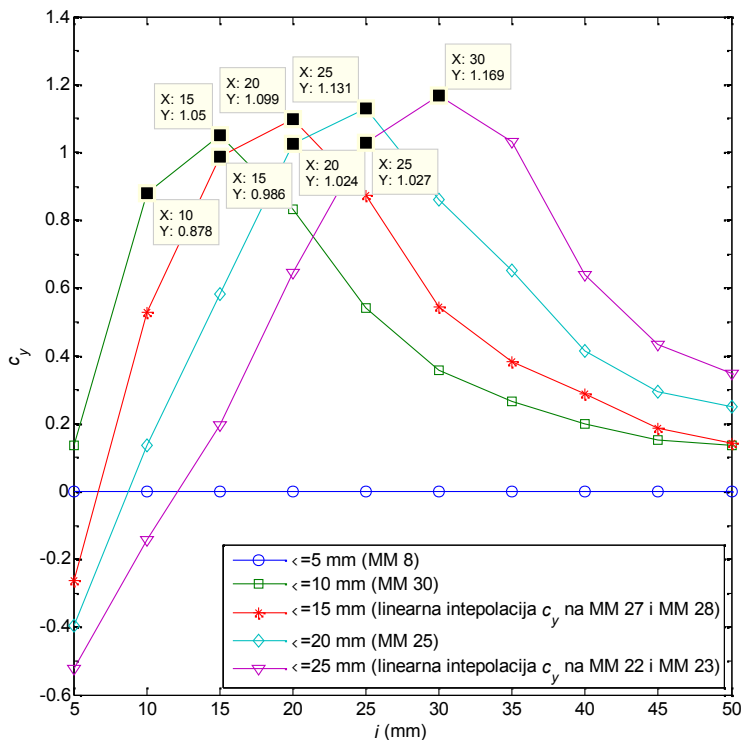


()

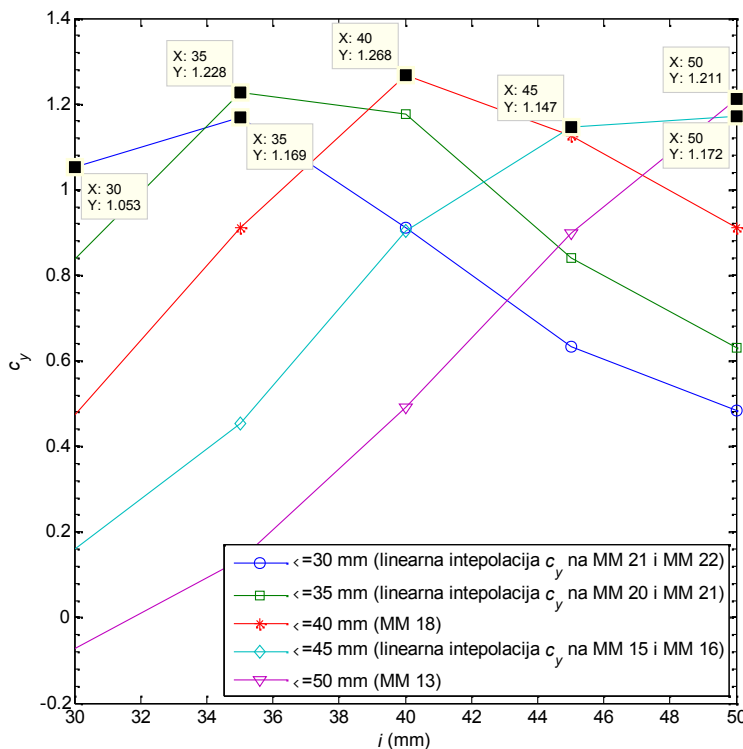
2.12: c_y : (a) 9 - 10; () M 6 - 7



2.13: c_x : (a) $= 5, 10, 15, 20, 25$ mm;
 () $= 30, 35, 40, 45, 50$ mm

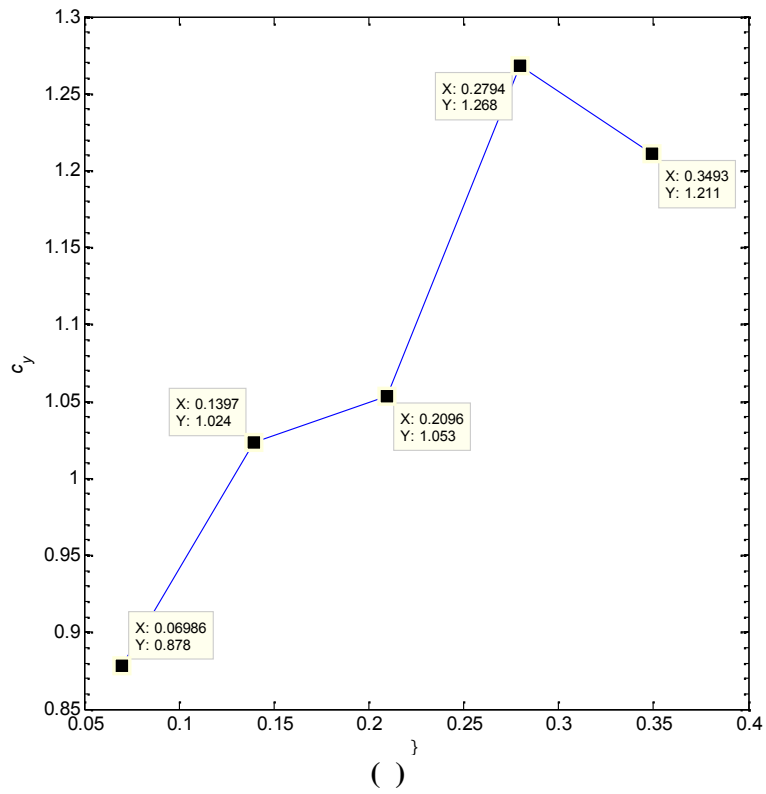
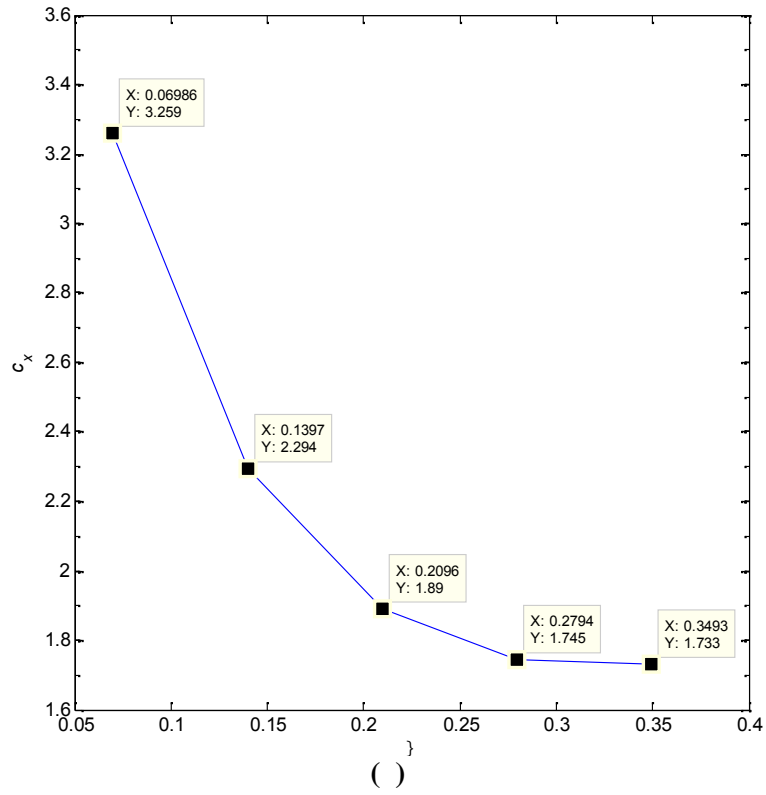


()



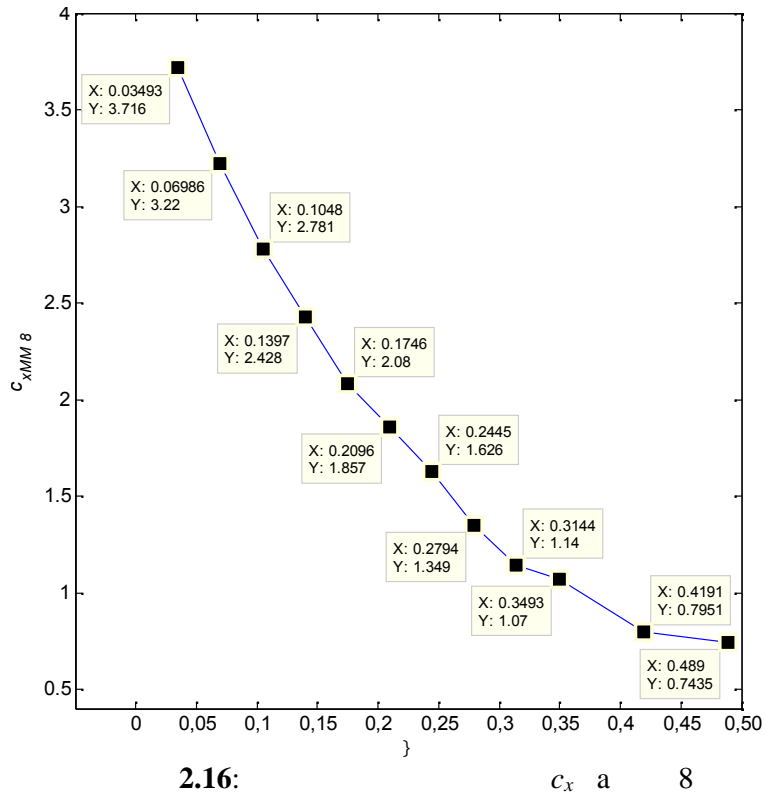
()

2.14: c_y : (a) $\leq 5, 10, 15, 20, 25$ mm;
 () $\leq 30, 35, 40, 45, 50$ mm



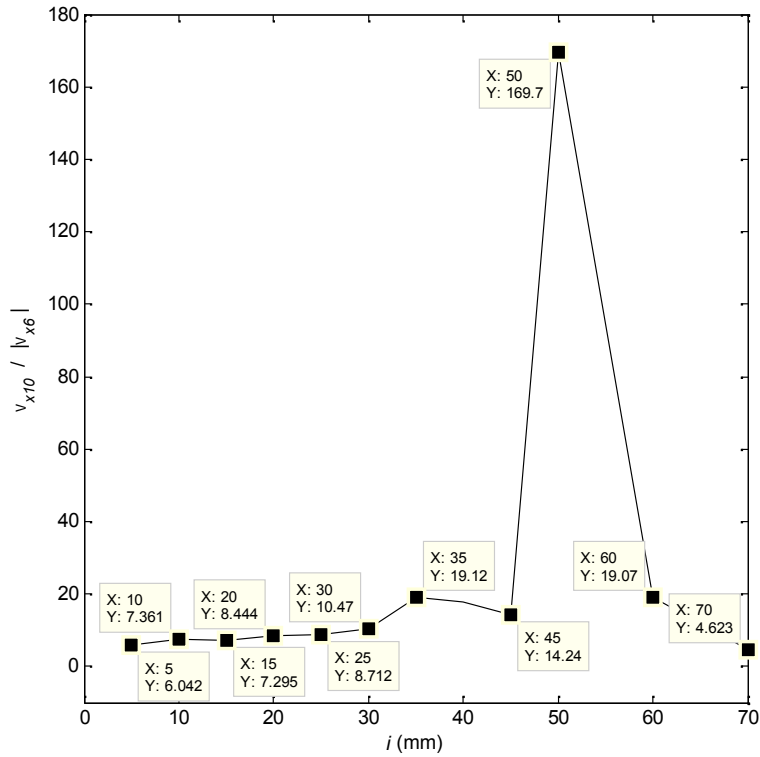
2.15:

: (a) c_x ; () c_y



2.1

4,63 , (l=1640 mm) je
 (H=354 mm,
 2.1). , (x) 1 - 5,
 2.3(), ,
 8 - 31, 2.3(-).
 6 10,
 , 2.3(). „shear - leg” :
 3, 2.3().
 10 ,
 6, ,
 2.3(). , 6
 $i > 50$ mm. $v_{x10} / |v_{x6}|$ 2.17.
 (170) 6.



2.17:

10 6

7

9

2.3(),

9,

7 9

2.18.

(5,4%)

$i=5$ mm,

(14,6%)

$i=70$ mm.

8

11

2.3().

11

8,

2.19,

: 8,8% $i=45$ mm,

-22% $i=70$ mm.

(x) 13, 15, ..., 21

, 2.3(). $i=45$ mm

13,

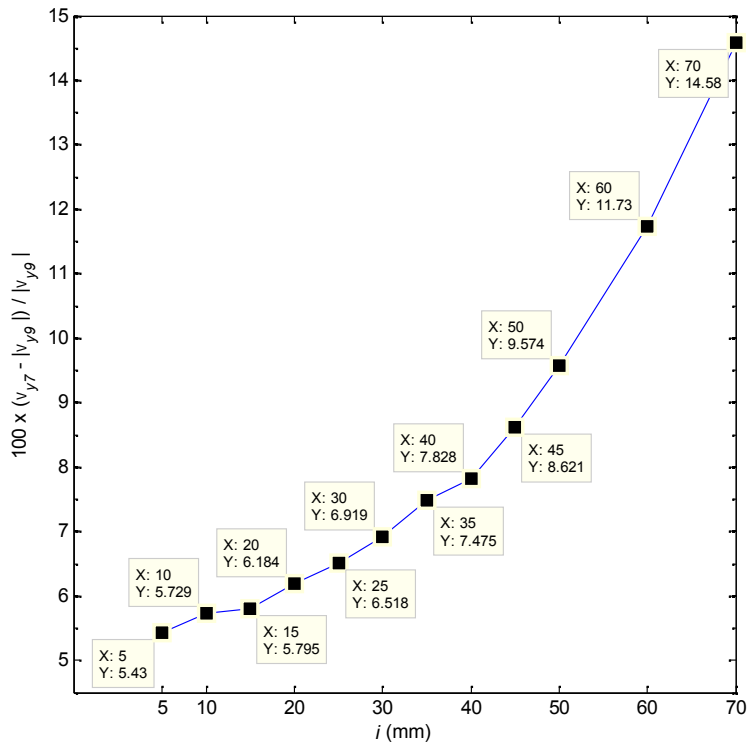
21,

. $i=45$ mm

x

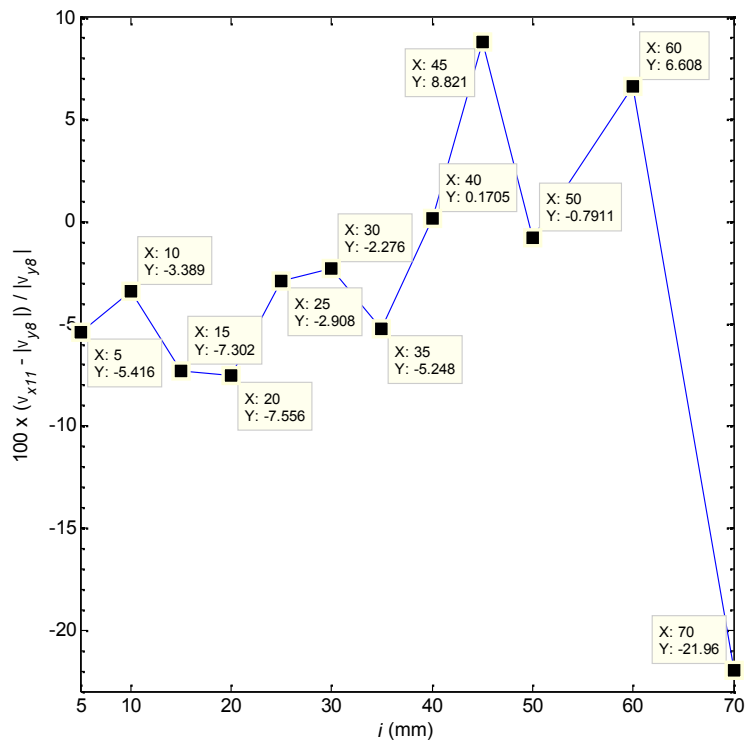
6,4 $\mu\text{m}/\text{m}$,

2.4.



2.18:

7 9



2.19:

8 11

$i=45$ mm.

: 13, 21,

13

$i=25$ mm, (237,2 $\mu\text{m/m}$)
 $i=50$ mm, 161,5 $\mu\text{m/m}$ $i=70$ mm, **2.3** **2.4.**

$i=50$ mm,
13 ($i=50$ mm, **2.2** (), **2.2** ()).

15,

(219,4 $\mu\text{m/m}$, **2.4**) $i=40$ mm.
153,9 $\mu\text{m/m}$, **2.4**, $i=70$ mm. 17, 19 21

(237,8 $\mu\text{m/m}$, 261,5 $\mu\text{m/m}$, 281,2 $\mu\text{m/m}$, **2.4**)
 $i=35$ mm. $i=70$ mm

146,2 $\mu\text{m/m}$, 138,6 $\mu\text{m/m}$, 135,2 $\mu\text{m/m}$, **2.4.**
() 23, 25, ..., 31

, **2.3** (). 31 29 ()

($i=5$ mm)

, 548,7 $\mu\text{m/m}$ 490,1 $\mu\text{m/m}$, **2.3.**

$i=70$ mm : 139,9 $\mu\text{m/m}$ 31 141,7 $\mu\text{m/m}$ 27, **2.4.**
27, 374,8 $\mu\text{m/m}$ $i=5$ mm 377,1 $\mu\text{m/m}$

$i=10$ mm, 120,7 $\mu\text{m/m}$ $i=70$ mm, **2.3** **2.4.**
25 334,8 $\mu\text{m/m}$

$i=20$ mm (, =20 mm,
2.2 ()), 124,9 $\mu\text{m/m}$ $i=70$ mm, **2.3** **2.4.**

23 299,0 $\mu\text{m/m}$ $i=5$ mm

308,1 $\mu\text{m/m}$ $i=20$ mm, 127,3 $\mu\text{m/m}$

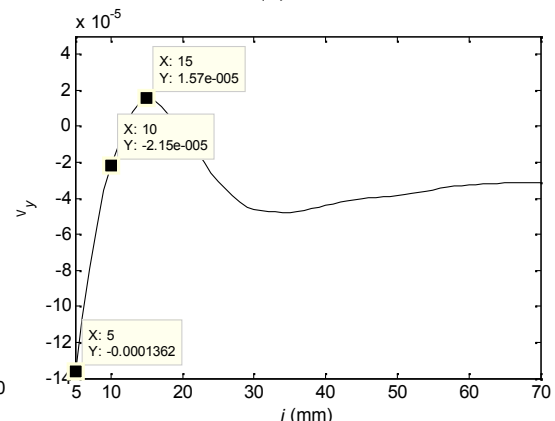
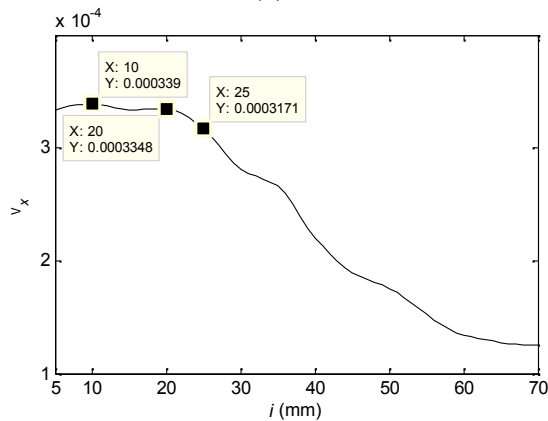
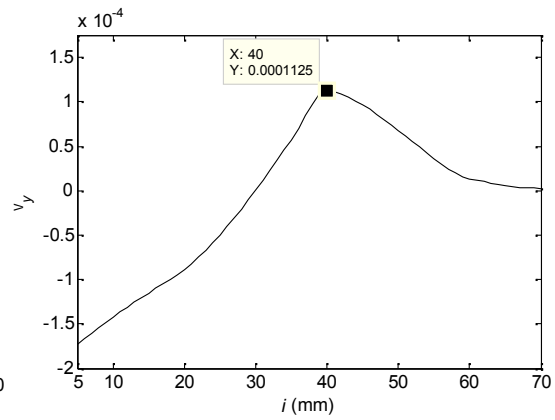
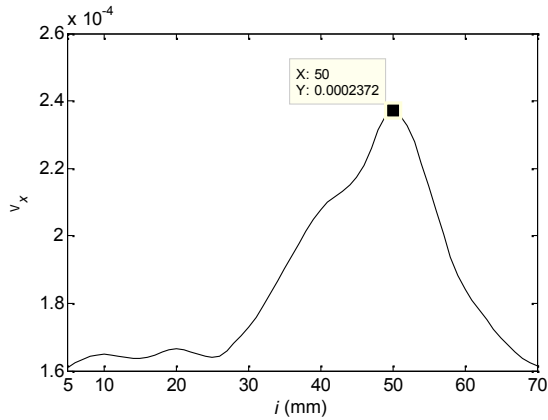
$i=70$ mm, **2.3** **2.4.** $i=35$ mm

23, 25, ..., 31 . $i=35$ mm

(290,0 $\mu\text{m/m}$) 29,
 27 (256,2 $\mu\text{m/m}$), 2.4,
 33,8 $\mu\text{m/m}$. , $i=70$ mm,
 (141,7 $\mu\text{m/m}$) 29,
 (120,7 $\mu\text{m/m}$) 27, 2.4.
 23, 25,..., 31 21,0 $\mu\text{m/m}$.
 23, 25,..., 31
 ($MM_{31}=8$ mm,
 $MM_{23}=24$ mm, 2.2()), 2.2()), i 35 mm
 (y) 12, 14,..., 30, 2.3(,),
 2.3 2.4,
 .
 .
 $i=5$ mm.
 ,
 .
 y 12, 14,...,20, 2.3()
 ,
 .
 12
 $i>40$ mm 97,5 $\mu\text{m/m}$
 $i=50$ mm, 33,9 $\mu\text{m/m}$ $i=70$ mm. 14
 $i>35$ mm, 110,8 $\mu\text{m/m}$ $i=50$ mm,
 20,0 $\mu\text{m/m}$ $i=70$ mm. y 16, 18 20
 , (105,5 $\mu\text{m/m}$, 112,5 $\mu\text{m/m}$,
 103,1 $\mu\text{m/m}$,) i ($i=50$ mm, $i=40$ mm,
 $i=40$ mm,), 2.4.
 y 22, 24,..., 30, 13().
 13 ($MM_{13}=50$ mm), 18 ($MM_{18}=40$ mm), 25 ($MM_{25}=20$ mm), 30
 ($MM_{30}=10$ mm) ,
 $i=50$ mm, $i=40$ mm, $i=20$ mm $i=10$ mm, . 13 (x)
 18 (y)
 , 2.20(,).

25 (x), 2.20(),
i=10 mm

1,3%
25 (i=20 mm).
30 (y), 2.20(),
(i=5 mm) 8,7
i=15 mm.



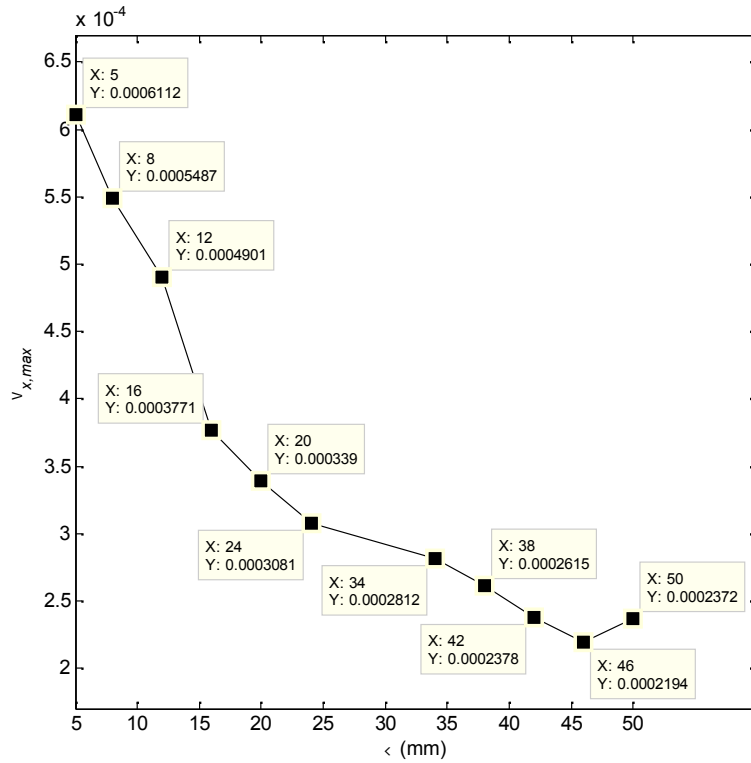
2.20: () 13; () 18; () 25; () 30

(x), 2.21.

2.21,

13,

(i=50 mm).



2.21:

(y)

2.22.

= MM28=14 mm

28

i=15 mm.

2.11 - 2.16,

2.5 (), 2.6, 2.8, 2.9 2.10,

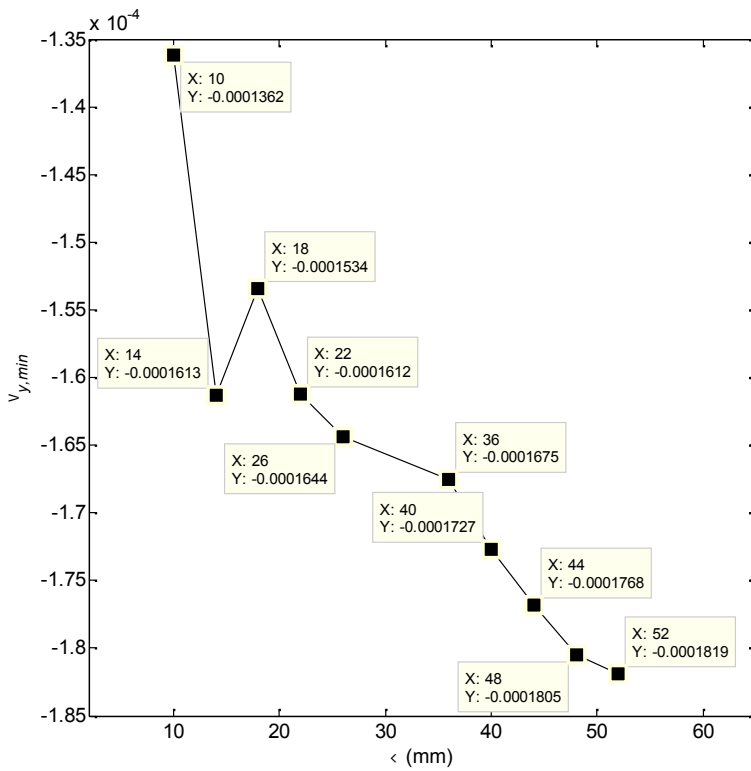
(2.19).

9 - 10 6 - 7, 2.11

=0,2096,

2.12,

i=30 mm.



2.22:

$C_{xMM9-10}$

, 2.11().

(i)

=0,0349 (i=5 mm) 0,60,

(0,09) =0,489 (i=70 mm).

C_{xMM6-7}

, 2.11().

(0,74)

=0,0349

(i=5 mm), (0,29) =0,489 (i=70 mm).

(c_x) 6 - 7 9 - 10, 2.23, 23,6% =0,0349 (i=5 mm)

227,5% =0,489 (i=70 mm).

$C_{xMM9-10}$ C_{xMM6-7}

$$c_{yMM\ 9-10} \quad c_{yMM\ 6-7}, \quad \mathbf{2.12.}$$

$$c_{yMM\ 9-10} (2,44) \quad =0,0349 (i=5 \text{ mm}),$$

$$(1,31) \quad =0,489 (i=70 \text{ mm}),$$

2.12().

$$=0,0349 (i=5 \text{ mm}), \quad (1,64) \quad =0,489 (i=70 \text{ mm}).$$

$$c_{yMM6-7} (2,68)$$

$$(c_y) \quad 6 - 7$$

9 - 10

9,9%

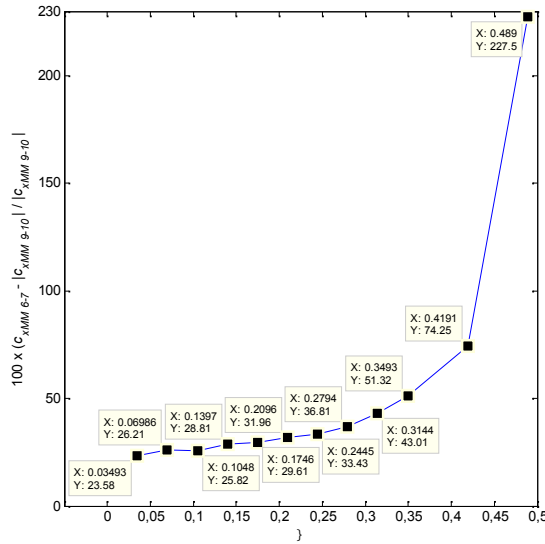
$$=0,0349 (i=5 \text{ mm})$$

24,9%

$$=0,489$$

($i=70 \text{ mm}$),

2.24.

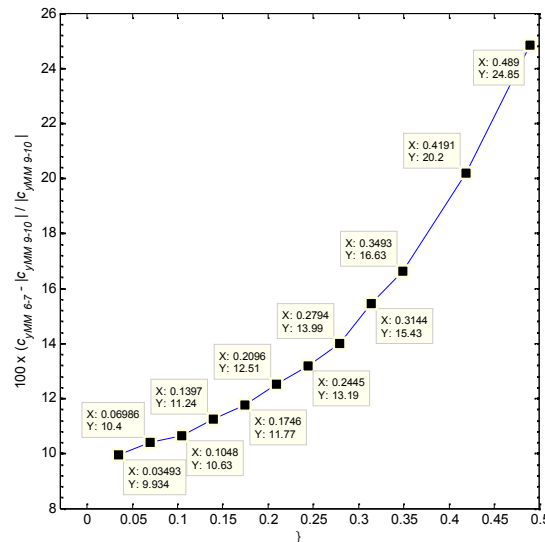


2.23:

6 - 7

9 - 10

c_x



2.24:

c_y

6 - 7

9 - 10

c_x

/
12, 13,..., 30 31, 2.2(,),

2(,),

2.2(),

$i=15$

mm 27 28; $i=25$ mm 22 23;
 $i=30$ mm 21 22; $i=35$ mm 20 21; $i=45$
mm 15 16.

()

(c_x)

2.13.

=30 mm =45 mm.

30 mm

$i=35$ mm, 2.13().

c_x

4 mm

(21

22).

c_x

1,89 $i=30$ mm 1,98 $i=35$ mm.

45 mm,

c_x

1,6

$i=50$ mm, $i=45$ mm

1,594,

2.13().

1 mm (15 16).

(c_y) , **2.14**, c_y

5 mm. (8)

()

(30 mm) c_y

$i = +5$ mm, 5 mm

(>30 mm),

c_y (

=45 mm,

), **2.14** ().

c_x

) 40 mm 1, **2.25**.

45 mm

1 $i > 6$ mm, 13 ($i_3 = 50$ mm) $i > 11,5$ mm, **2.26**.

, **2.27**.

c_x

c_y 1.

3,71 $= i = 10$ mm

1,38 $= i = 40$ mm, 1,43 $= i = 50$ mm,

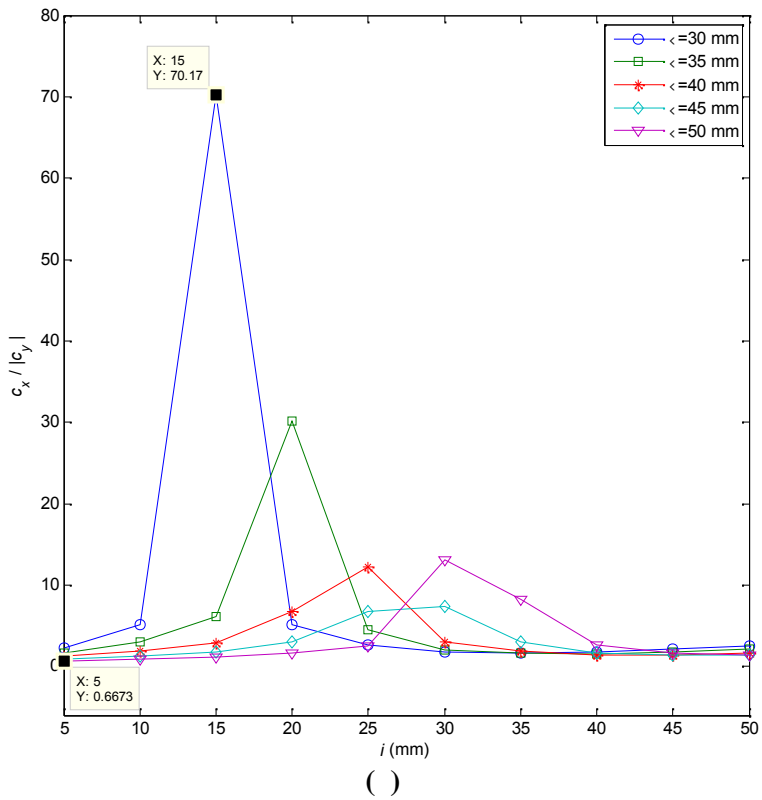
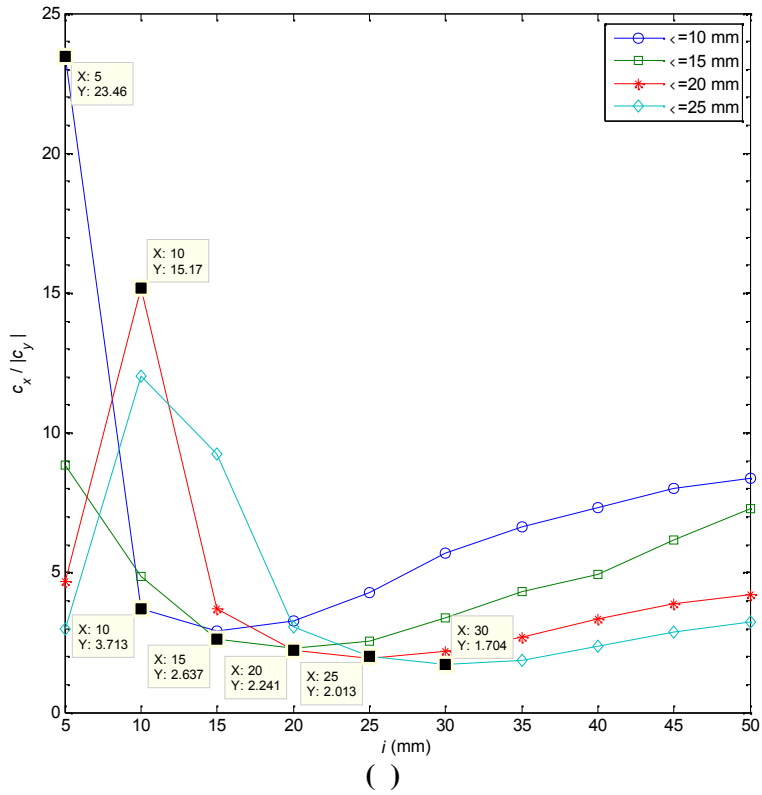
2.27.

, **2.15**.

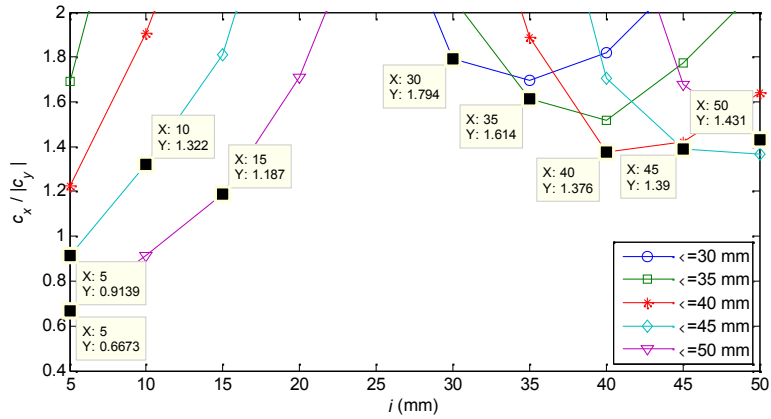
c_x

2.15 (). (3,26)

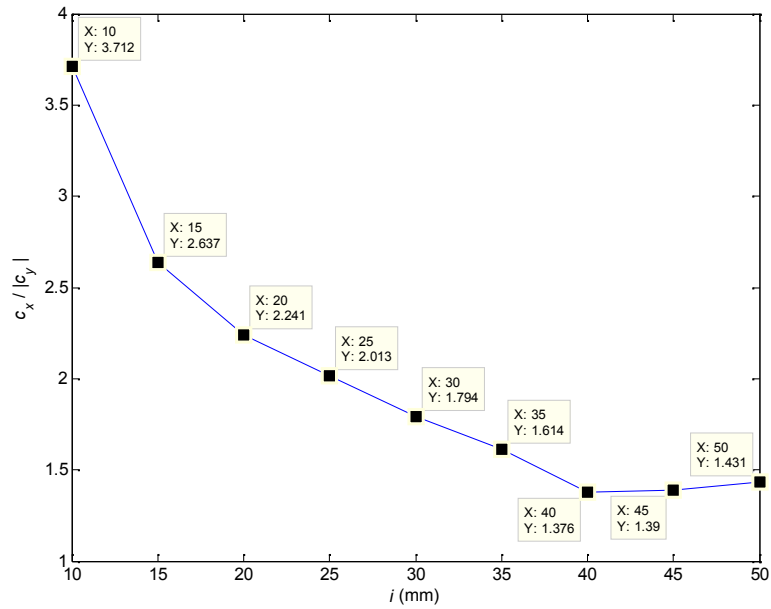
=0,0349 ($i = 5$ mm), (1,73) =0,3493 ($i = 50$ mm).



2.25: $c_x/|c_y|$: (a) $=5, 10, 15, 20, 25$ mm;
 () $=30, 35, 40, 45, 50$ mm



2.26: $c_x/|c_y| = 30, 35, 40, 45, 50$ mm



2.27: $c_x/|c_y| \quad i =$

c_y

0,88 = 0,0349 ($i=5$ mm)

1,27 = 0,2794 ($i=40$ mm), 1,21 = 0,3493

($i=50$ mm), 2.15 ().

c_x

(8) , 2.16.

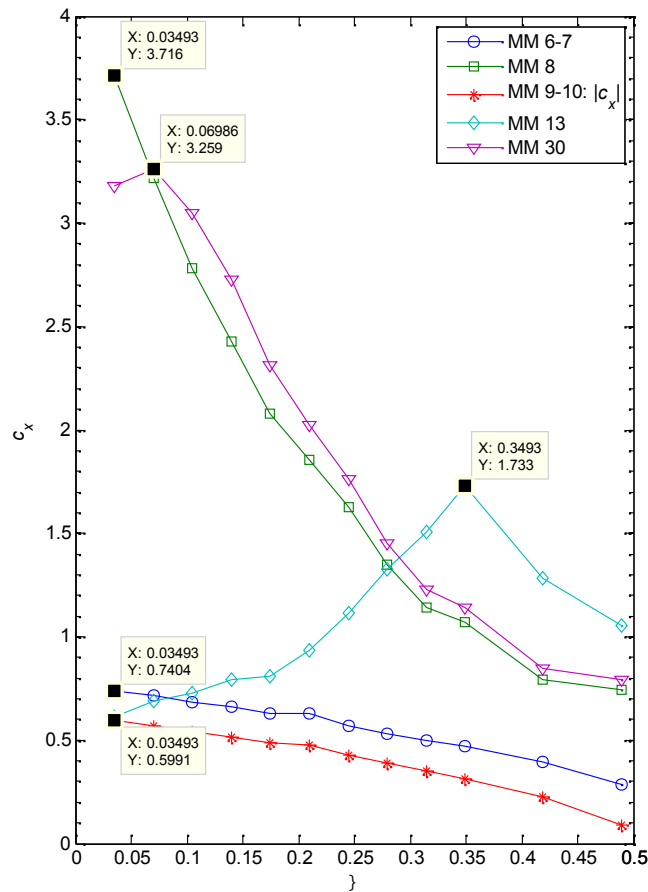
(3,72)

$=0,0349$ ($i=5$ mm), (0,74)
 $=0,489$ ($i=70$ mm).

(/ -
 6 - 7 9 - 10;
 - 30 , $_{30}=10$ mm,
 13 ,
 $_{30}=10$ mm; - 8)

2.28 2.29.

• (x),
 2.28, 8 (
 c_{xMM8} 3,72) , , 30, 13, 6 - 7
 9 - 10;

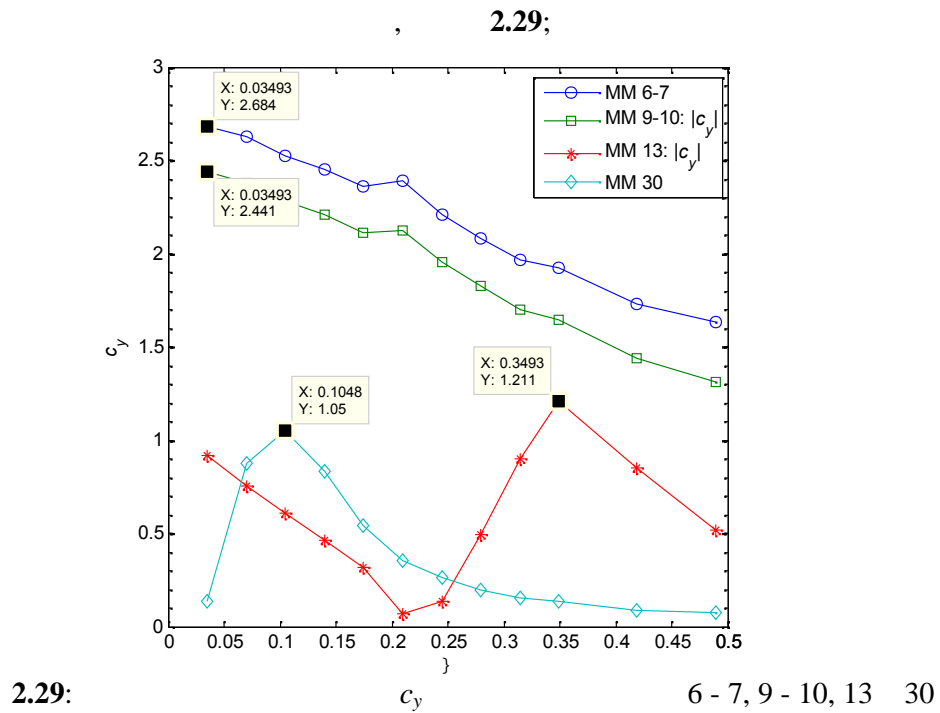


2.28:

c_x

6 - 7, 8, 9 - 10, 13 30

- c_y (6 - 7)
- 9 - 10),
(8),
- c_y 2.28;
- 13 30
- $i =_{MM30} = 10 \text{ mm} (=0,06986) \quad i =_{MM13} = 50 \text{ mm}$
(=0,3493), 2.28;
- c_y (y),
- 2.29, 6 - 7 (/ ,
- $c_{yMM6-7} = 2,68$, 9 - 10, 13 30;
- / (6 - 7
- 9 - 10)



- 13

, $i = i_{MM13} = 50 \text{ mm}$ ($= 0,3493$), **2.29**,
 30 ($i_{MM30} = 10 \text{ mm}$), $i = 15 \text{ mm}$
($= 0,1048$), **2.29**;

•

(8), (x) .

2.2

() .

, :

• - „shear - leg” ,

, ;

• / , ,

N 15011 [5];

• / c_x

;

, $i = 20 \text{ mm}$,

c_x

30%

c_x

;

• / c_y

; $i=20$ mm,

c_y 11%

c_y ;

• ,

(c_x)

(c_y) .

/ . [5]

3. |

2370 mm (. 1 2.1) (. 7 2.1),
3.1.

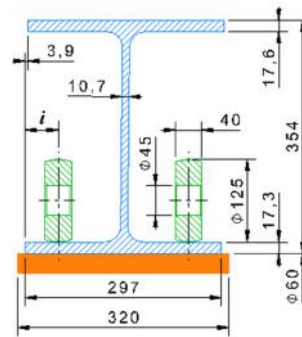
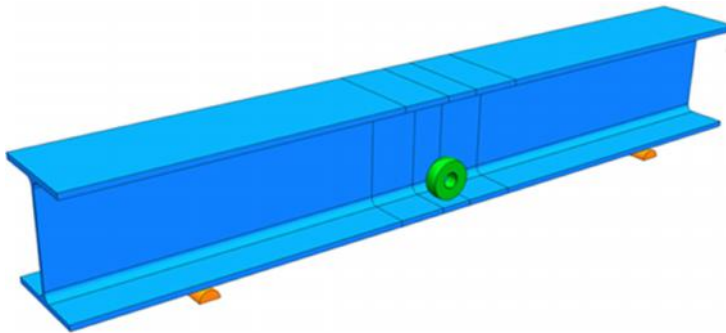
DIN 1025 (Blatt 3/1963), 2.1.

. 3

1640 mm. , 3 ,

3.1,

2.1.

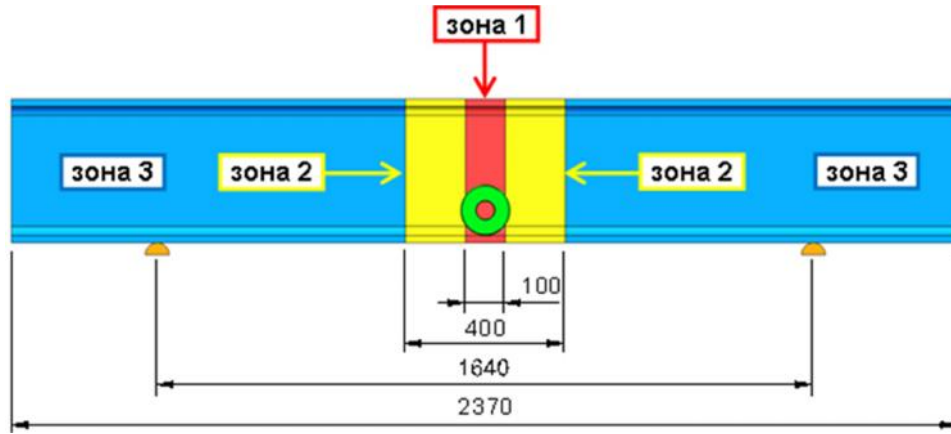


()
3.1: 3
()

()
:
; ()

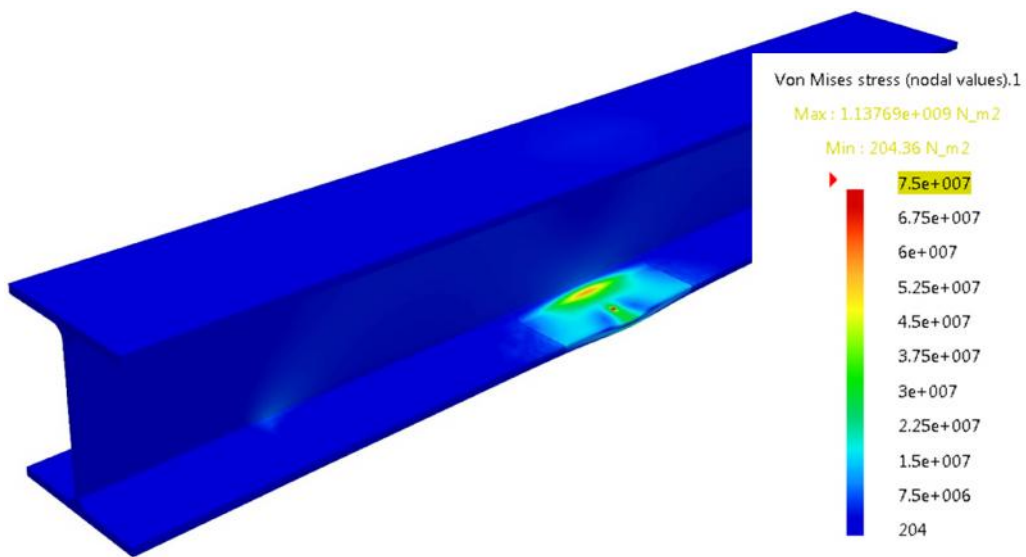
3.2.

(1, 100 mm)
 2,5 mm
 , 2 5 mm,
 (3) 10 mm.
 2,5 mm,
 5 mm.



3.2:

50 mm , 10 kN 3.3.



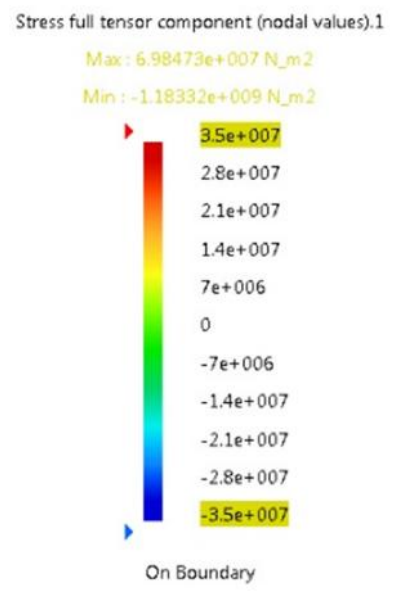
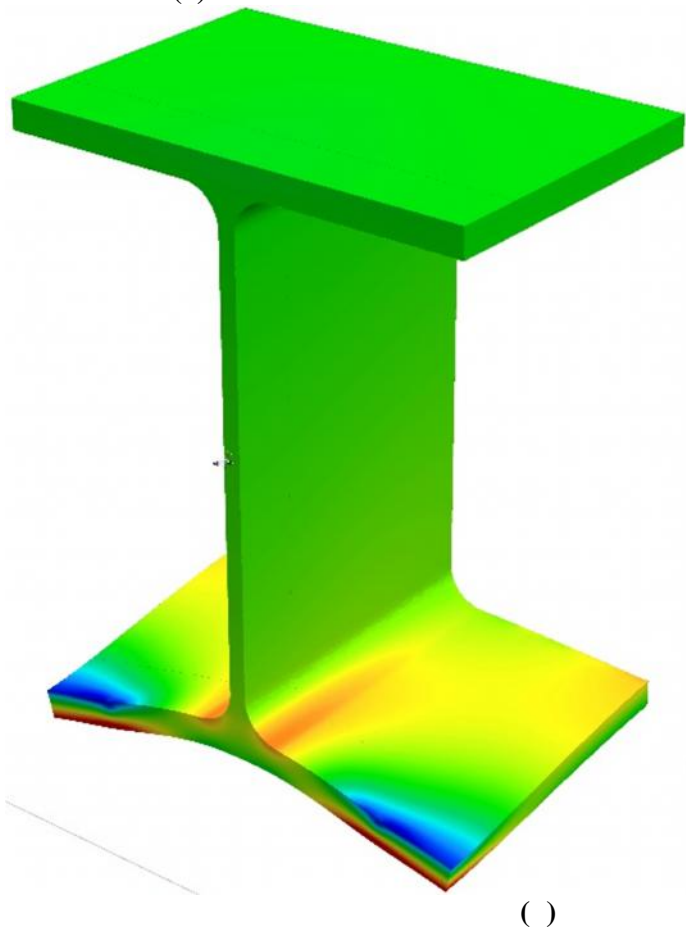
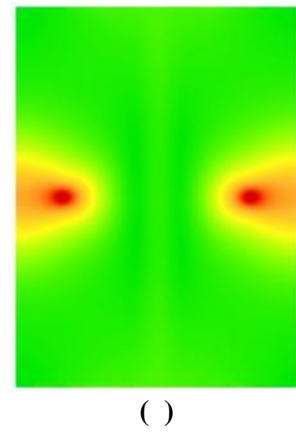
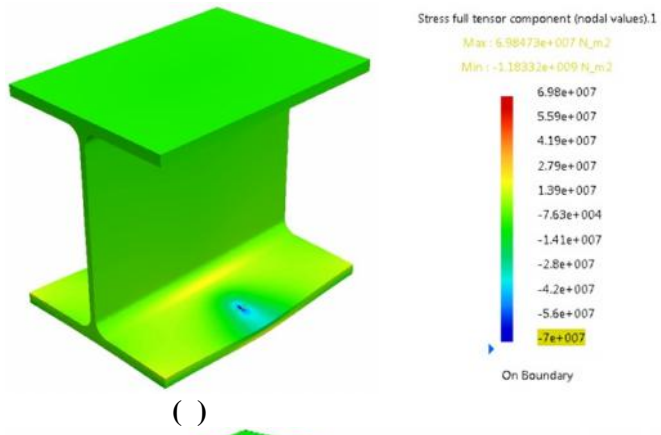
3.3:

3.3,
(y_{tot})

(x_{tot})
3.4

3.5,

3.6 3.7.

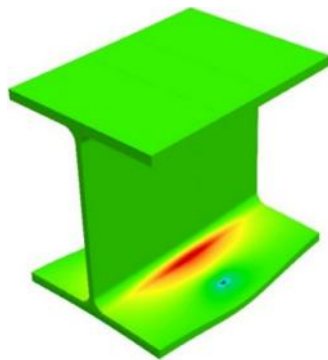


3.4:
()

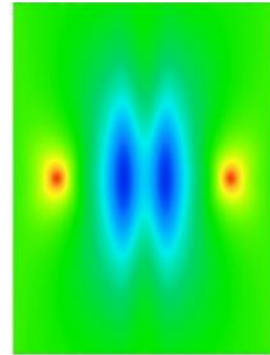
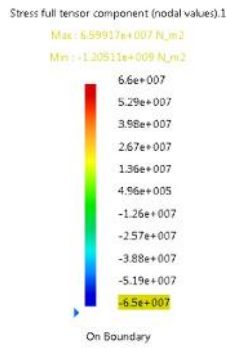
()
; ()

x_{tot}
; ()

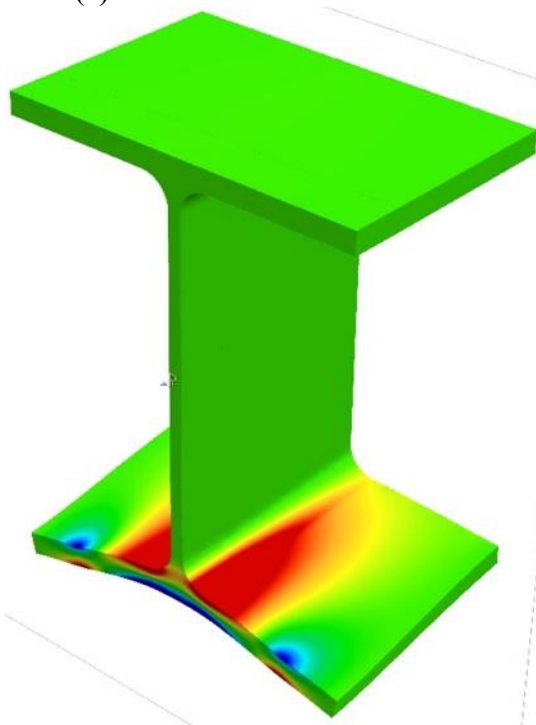
:



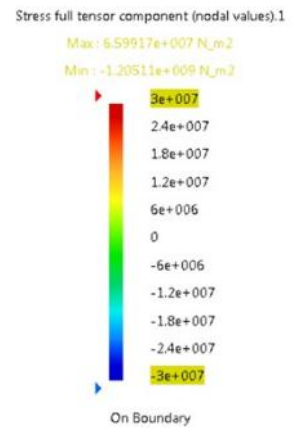
()



()



()



3.5:

()

;

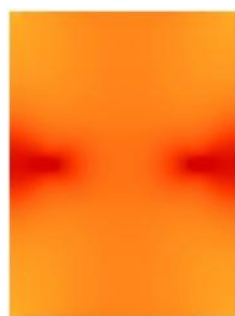
y,tot

;

:



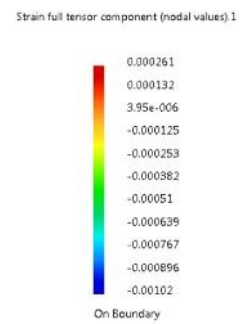
()



()



()



3.6:

;

x ;

;

3.1 3.2,

3.3 3.4,

3.8.

3.1:

(x)

(a) $i=5,10,\dots,30$ mm

	i (mm)					
	5	10	15	20	25	30
	x (kN/cm ²)*					
1	-0,41	-0,41	-0,4119	-0,41	-0,41	-0,41
2	-0,48	-0,48	-0,48	-0,48	-0,47	-0,47
3	-0,49	-0,49	-0,49	-0,49	-0,49	-0,49
4	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41
5	-0,36	-0,36	-0,36	-0,36	-0,36	-0,36
6	2,40	2,31	2,22	2,13	2,04	1,95
7	2,93	2,83	2,73	2,63	2,54	2,44
8	12,66	11,00	9,33	7,92	6,84	6,01
9	-1,28	-1,20	-1,11	-1,03	-0,94	-0,85
10	-1,16	-1,07	-0,98	-0,89	-0,80	-0,70
13	2,99	3,13	3,31	3,55	3,84	4,24
30	11,21	10,84	9,77	8,35	7,12	6,17
0	-0,65	-0,61	-0,57	-0,53	-0,48	-0,44
0'	-0,49	-0,49	-0,49	-0,49	-0,49	-0,49

*

3.1:

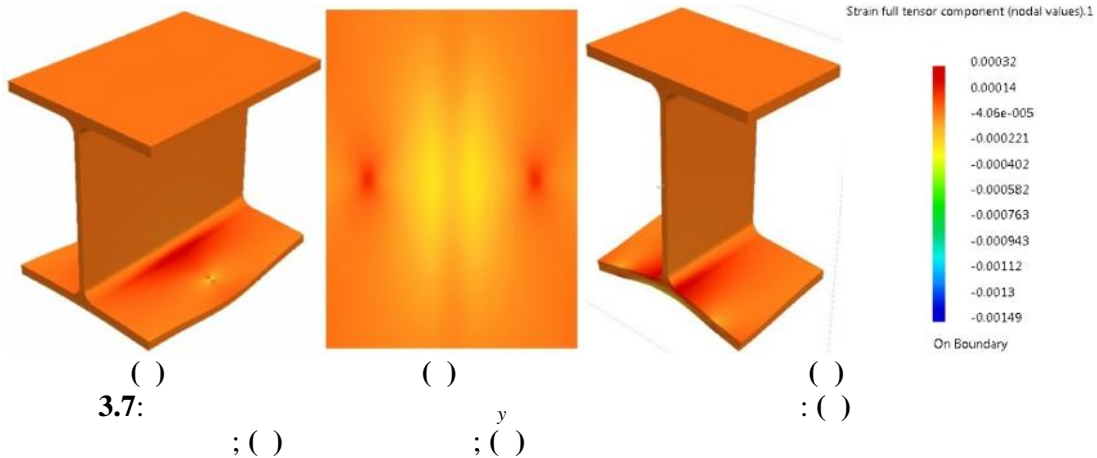
(x)

() $i=35, 40, \dots, 70$ mm

	i (mm)					
	35	40	45	50	60	70
	σ_x (kN/cm ²)*					
1	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41
2	-0,47	-0,47	-0,47	-0,47	-0,47	-0,47
3	-0,49	-0,49	-0,49	-0,49	-0,49	-0,49
4	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41
5	-0,36	-0,36	-0,36	-0,36	-0,36	-0,36
6	1,85	1,75	1,65	1,54	1,30	1,01
7	2,34	2,25	2,14	2,04	1,81	1,55
8	5,31	4,72	4,22	3,77	3,02	2,42
9	-0,75	-0,65	-0,55	-0,44	-0,19	0,10
10	-0,60	-0,50	-0,38	-0,26	0,01	0,33
13	4,81	5,60	6,50	6,91	5,32	3,71
30	5,42	4,80	4,28	3,82	3,06	2,45
0	-0,39	-0,35	-0,31	-0,26	-0,16	-0,04
0'	-0,49	-0,49	-0,49	-0,49	-0,49	-0,49

*

o , 0 (0) [5] 0
 0' , **5.1** , **3.1 3.2.**



3.2:

() $i=5, 10, \dots, 30$ mm

	i (mm)					
	5	10	15	20	25	30
	σ_y (kN/cm ²)*					
1	-0,00	-0,00	-0,00	-0,00	-0,00	-0,00
2	0,01	0,01	0,01	0,01	0,01	0,01
3	0,02	0,02	0,02	0,02	0,02	0,02
4	-0,00	-0,00	-0,00	-0,00	-0,00	-0,00
5	0,04	0,04	0,04	0,04	0,04	0,04
6	7,82	7,53	7,23	6,96	6,70	6,43
7	9,07	8,75	8,47	8,18	7,87	7,61
9	-7,40	-7,13	-6,87	-6,60	-6,35	-6,09
10	-7,18	-6,90	-6,63	-6,35	-6,08	-5,82
13	-3,00	-2,44	-1,88	-1,30	-0,69	0,02
30	0,35	2,22	2,25	1,39	0,76	0,46
0	-4,76	-4,63	-4,52	-4,41	-4,29	-4,19
0'	0,02	0,02	0,02	0,02	0,02	0,02

*

() $i=35, 40, \dots, 70$ mm

	i (mm)					
	35	40	45	50	60	70
	σ_y (kN/cm ²)*					
1	-0,00	-0,00	-0,00	-0,00	-0,00	-0,00
2	0,01	0,01	0,01	0,01	0,01	0,01
3	0,02	0,02	0,02	0,02	0,02	0,02
4	-0,00	-0,00	-0,00	-0,00	-0,00	-0,00
5	0,04	0,04	0,04	0,04	0,04	0,04
6	6,15	5,89	5,62	5,33	4,76	4,16
7	7,32	7,05	6,77	6,49	5,92	5,31
9	-5,84	-5,59	-5,33	-5,07	-4,54	-3,97
10	-5,55	-5,28	-5,01	-4,73	-4,16	-3,54
13	0,94	2,27	3,97	4,94	2,93	1,38
30	0,32	0,24	0,19	0,15	0,10	0,06
0	-4,08	-3,99	-3,89	-3,80	-3,61	-3,43
0'	0,02	0,02	0,02	0,02	0,02	0,02

*

3.3:

(x)

(a) $i=5, 10, \dots, 30$ mm

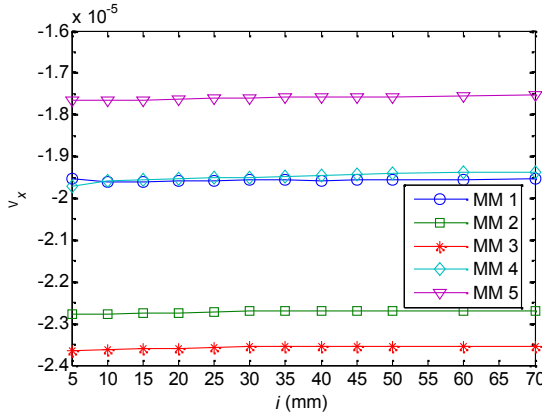
	<i>i</i> (mm)					
	5	10	15	20	25	30
	x ($\mu\text{m/m}$)*					
1	-19,54	-19,62	-19,62	-19,60	-19,59	-19,57
2	-22,78	-22,77	-22,76	-22,74	-22,73	-22,71
3	-23,65	-23,63	-23,61	-23,59	-23,57	-23,56
4	-19,71	-19,60	-19,56	-19,54	-19,51	-19,50
5	-17,67	-17,67	-17,65	-17,63	-17,62	-17,61
6	3,20	2,99	2,76	2,44	1,88	1,37
8	592,20	508,90	435,00	373,10	324,00	284,80
10	47,30	47,50	47,82	48,29	48,92	49,71
11	597,50	510,50	433,90	371,80	323,10	283,90
13	185,50	184,20	184,70	187,50	192,80	201,80
30	528,40	483,60	432,80	377,80	328,20	287,50

*

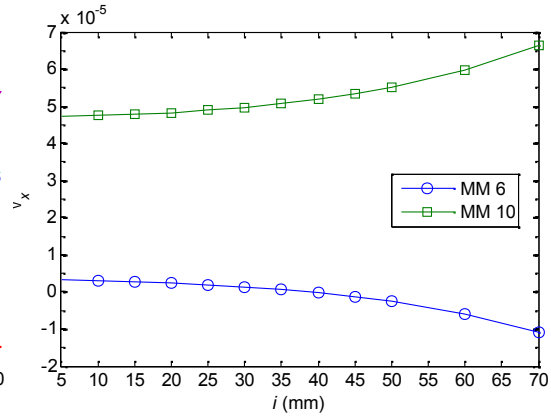
() $i=35,40, \dots, 70$ mm

	<i>i</i> (mm)					
	35	40	45	50	60	70
	x ($\mu\text{m/m}$)*					
1	-19,56	-19,58	-19,57	-19,57	-19,56	-19,54
2	-22,70	-22,70	-22,69	-22,69	-22,69	-22,69
3	-23,55	-23,54	-23,54	-23,54	-23,54	-23,54
4	-19,49	-19,45	-19,44	-19,41	-19,39	-19,38
5	-17,59	-17,59	-17,58	-17,57	-17,77	-17,54
6	0,67	-0,17	-1,23	-2,53	-5,91	-10,83
8	252,00	224,20	200,20	179,00	143,70	115,00
10	50,69	51,88	53,35	55,11	59,75	66,45
11	251,10	223,80	199,70	178,70	143,30	114,40
13	215,60	234,20	252,40	257,50	211,30	156,80
30	253,70	225,40	201,10	179,70	144,30	115,60

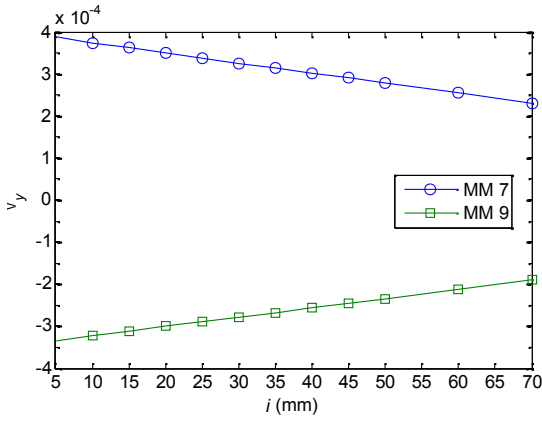
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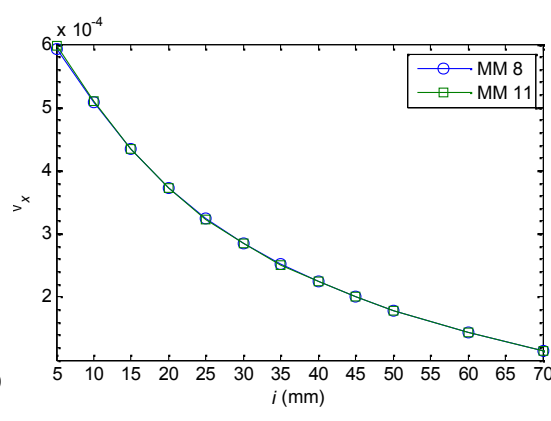
()



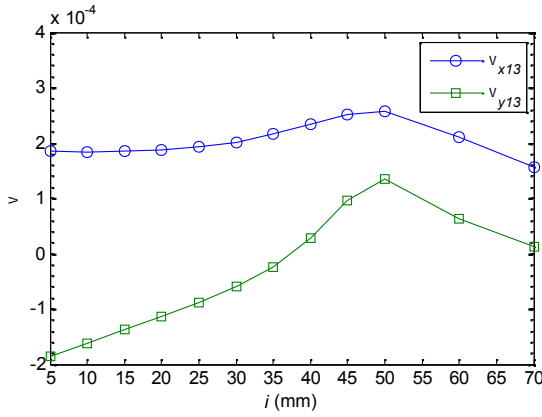
()



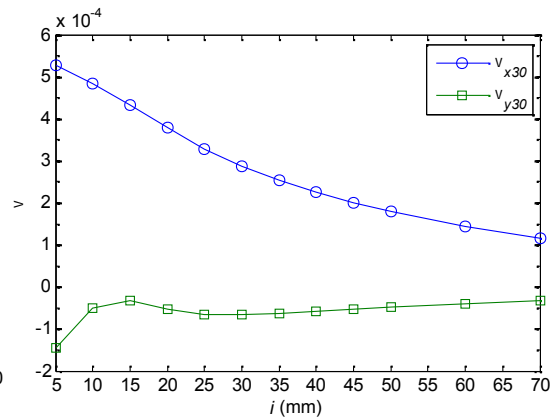
()



()



()



()

3.8: () 7 9; () 8 11; () 13; () 30 : () 1 - 5; () 6 10;

3.4:

(y)

(a) $i=5, 10, \dots, 30$ mm

	<i>i</i> (mm)					
	5	10	15	20	25	30
	y ($\mu\text{m/m}$)*					
7	387,60	373,70	362,20	349,80	336,50	325,30
9	-334,10	-322,40	-311,00	-299,80	-288,80	-278,10
13	-185,90	-161,20	-137,10	-112,70	-87,67	-59,82
30	-144,10	-49,71	-33,15	-53,26	-65,56	-66,28

*

() $i=35, 40, \dots, 70$ mm

	<i>i</i> (mm)					
	35	40	45	50	60	70
	y ($\mu\text{m/m}$)*					
7	313,30	301,60	290,10	278,30	254,70	229,30
9	-267,30	-256,60	-245,90	-235,10	-213,30	-190,30
13	-24,16	28,05	95,41	135,70	63,38	12,99
30	-62,17	-57,04	-52,04	-47,37	-39,16	-32,13

*

3.1

()

2.,

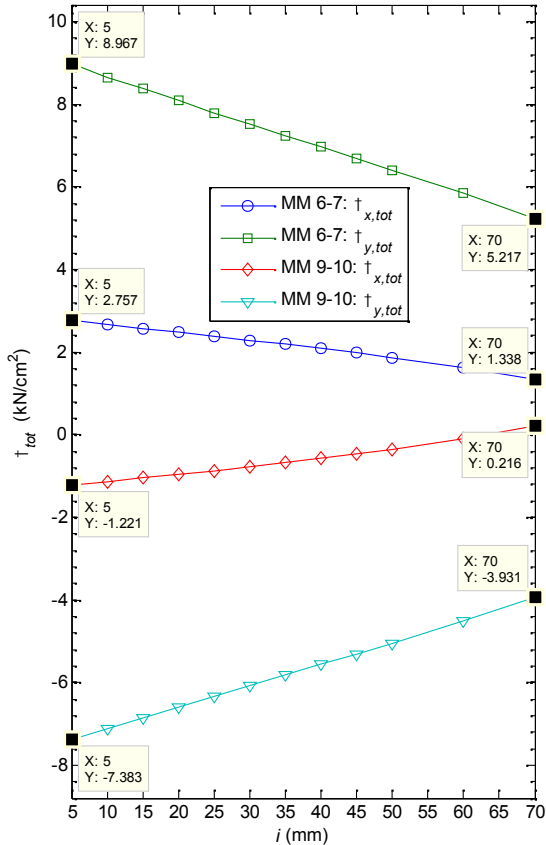
, **3.9, 3.10 3.11.**

13 (x) 30 (y)

(2.),

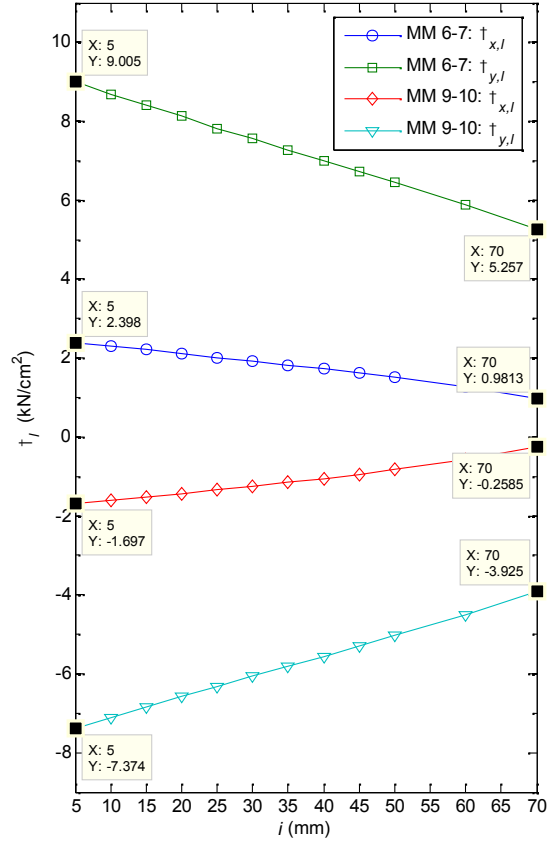
13 30

x y



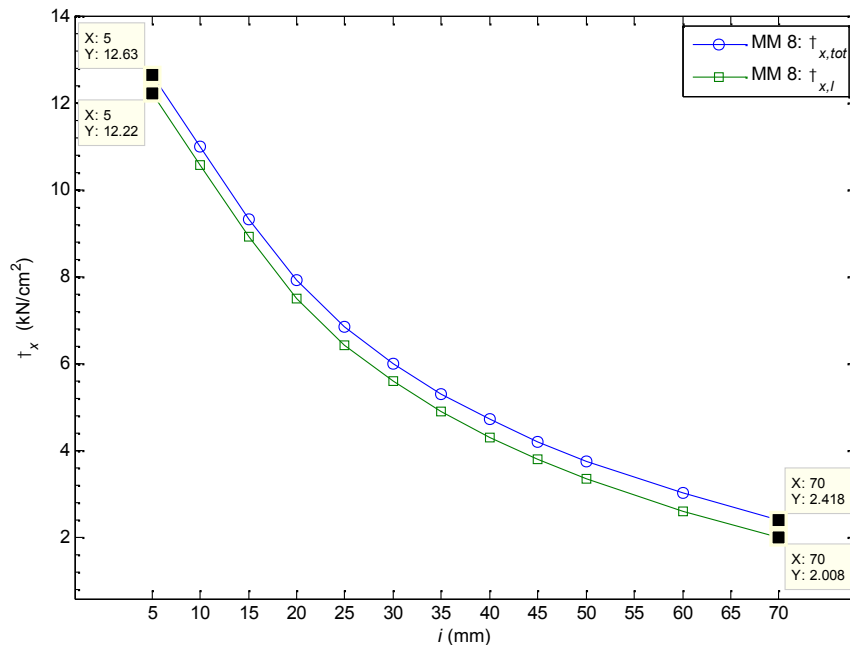
3.9:

() ; ()

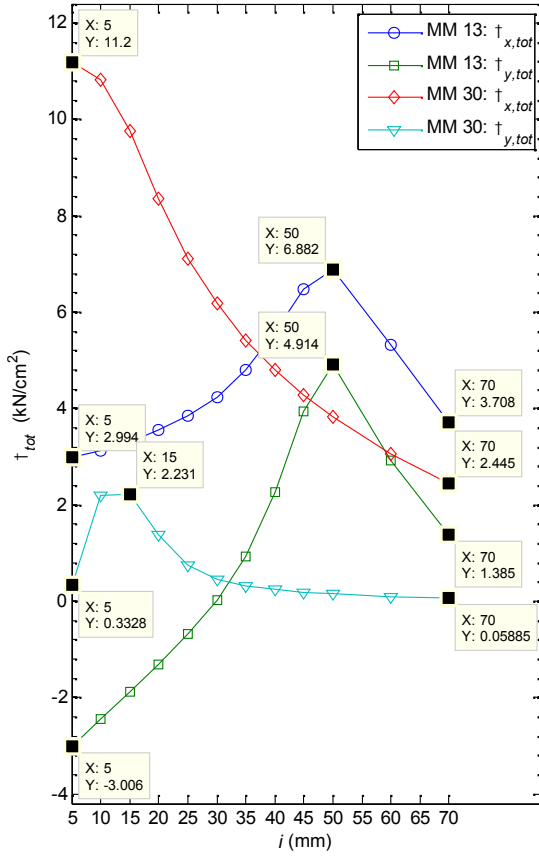


6-7 9-10:

3.10:



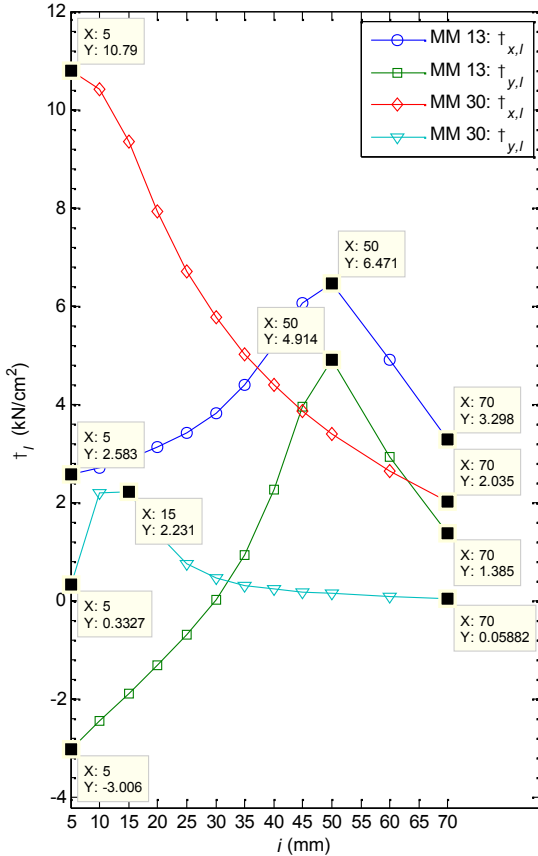
8



()

3.11:

() ; ()



()

13 30:

, 3.9(), 3.10

3.11(), (2.19),

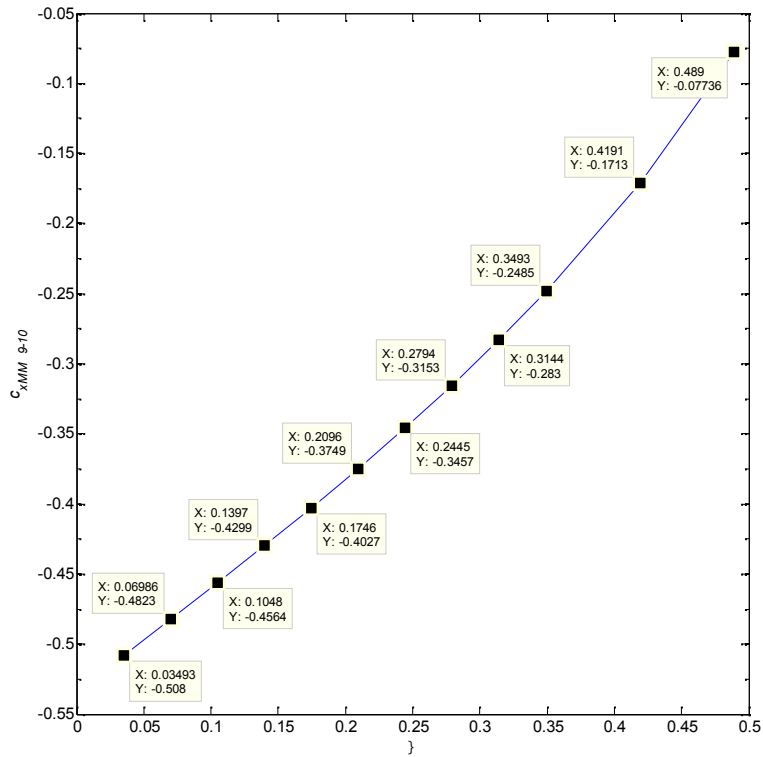
:

- M 6 - 7, M 9 - 10 ;
- 13 30, $i=50$ mm $i=10$ mm, ;
- , M 8;

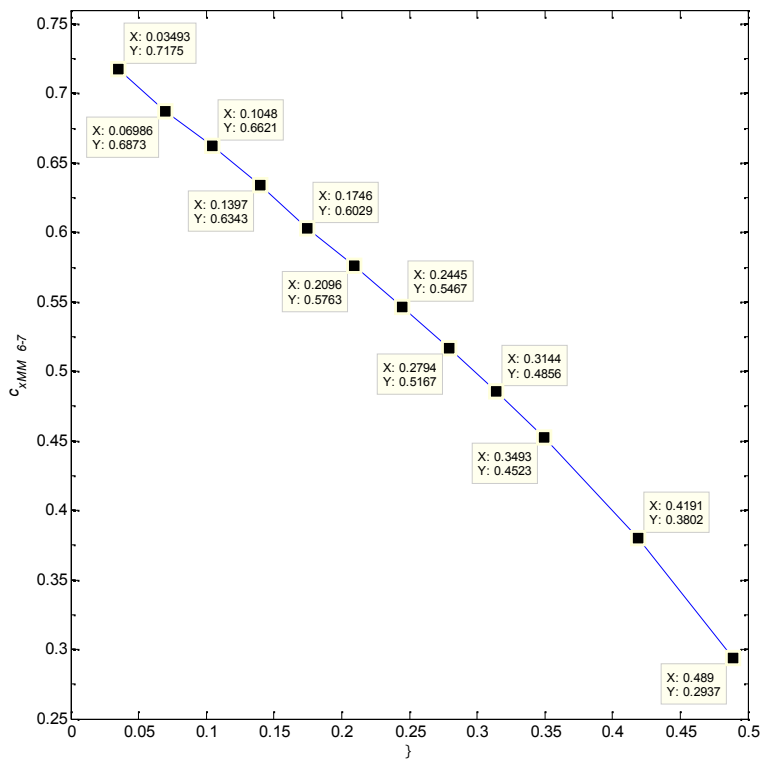
3.12 - 3.15.

, i ,

(3).

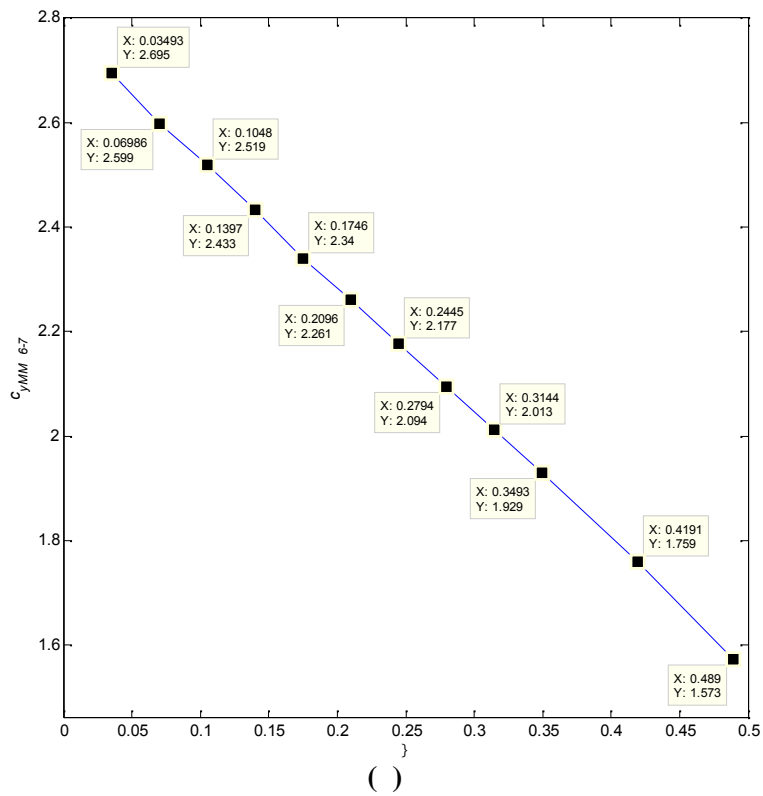
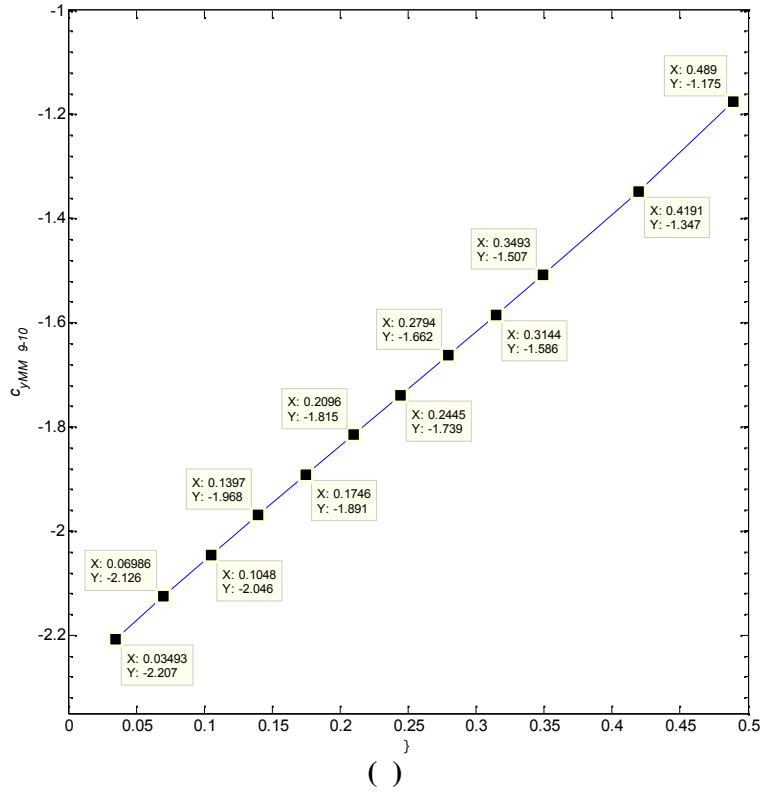


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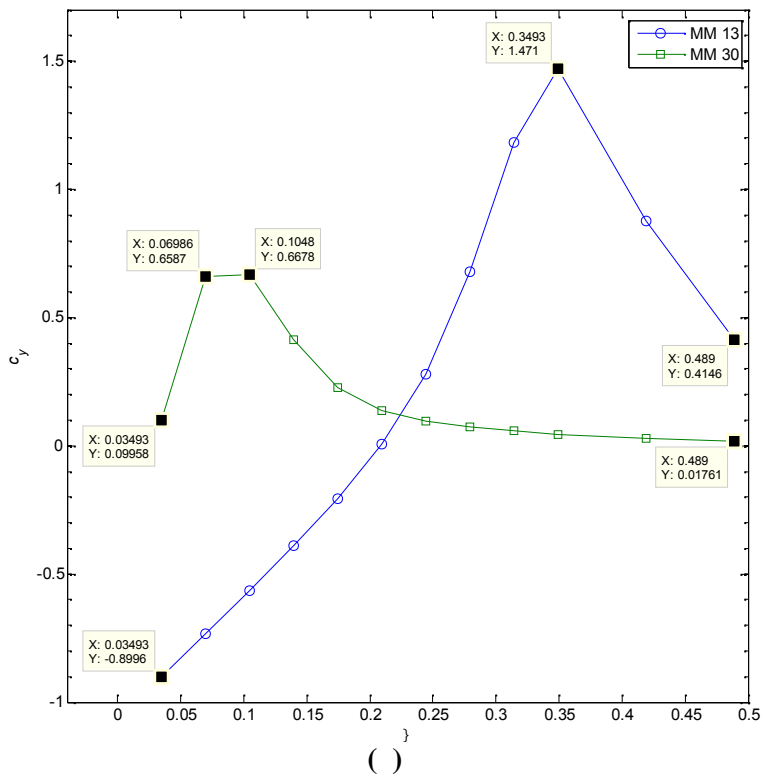
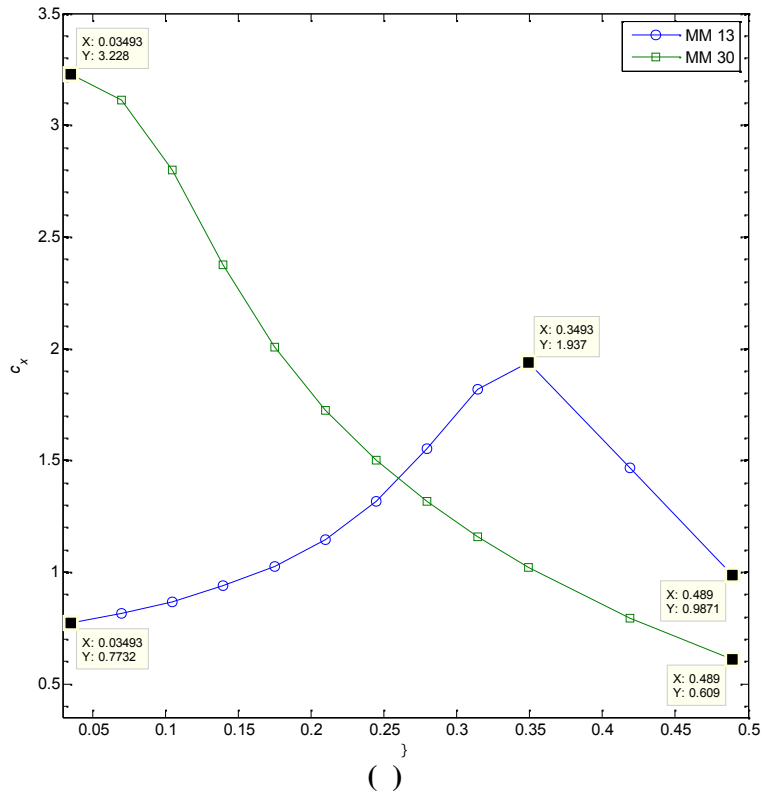


()

3.12: c_x : (a) M 9-10; () M 6-7

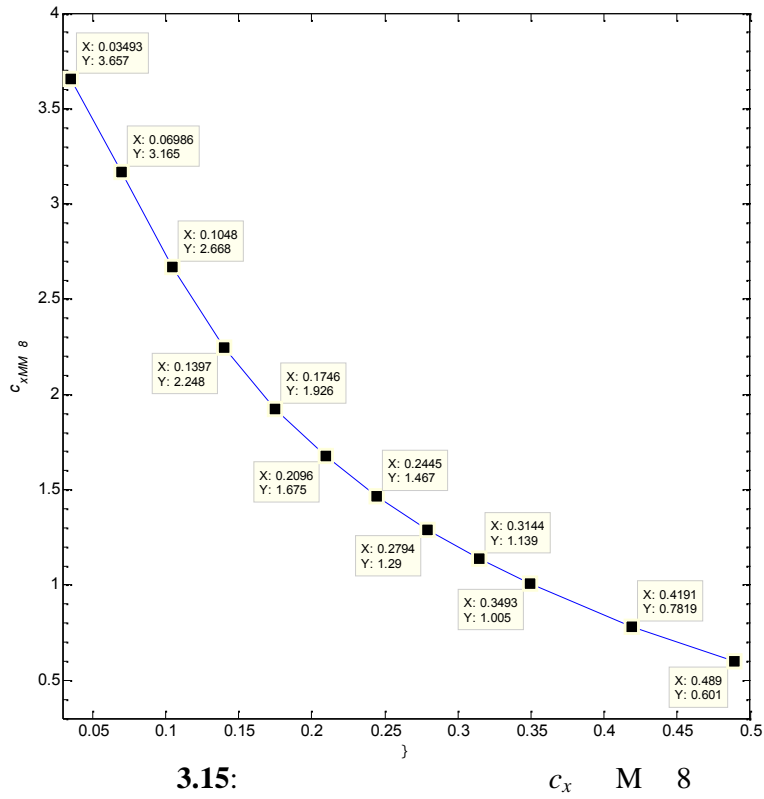


3.13: c_y : (a) M 9 - 10; (b) M 6 - 7



3.14:

13 30: () c_x ; () c_y



3.2

()

(x)

(y),

50 mm

3.4 3.5.

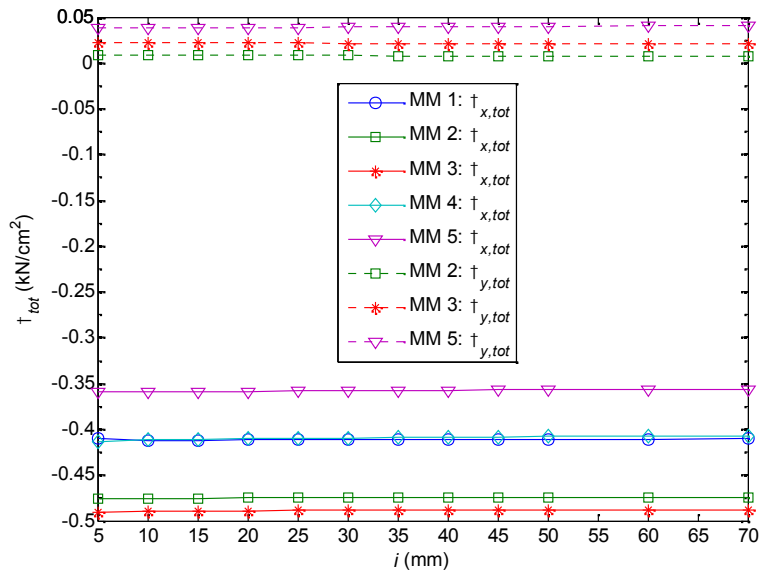
3.1 3.2,

3.16, 3.17(), 3.18(), 3.19, 3.20() 3.21().

$$\dagger_{p,l}^{MMi} = \dagger_{p,tot}^{MMi} - \dagger_{p,tot}^{MMj}, p = x, y, i = 6, 7, \dots, 10, 13, 30, j = 1, 2, 3, 5. \quad \dots(3.1)$$

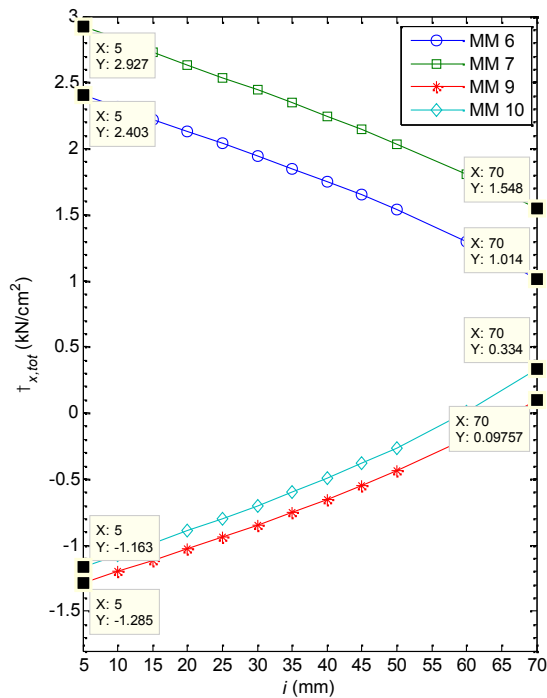
() 6

7 () 5 ; 9
 10 - 2; 8, 13 30 - 1 ()
 2.2().

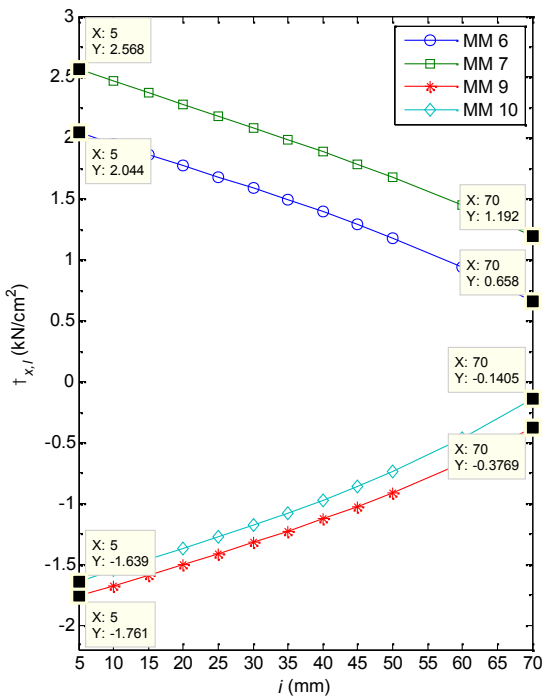


3.16:

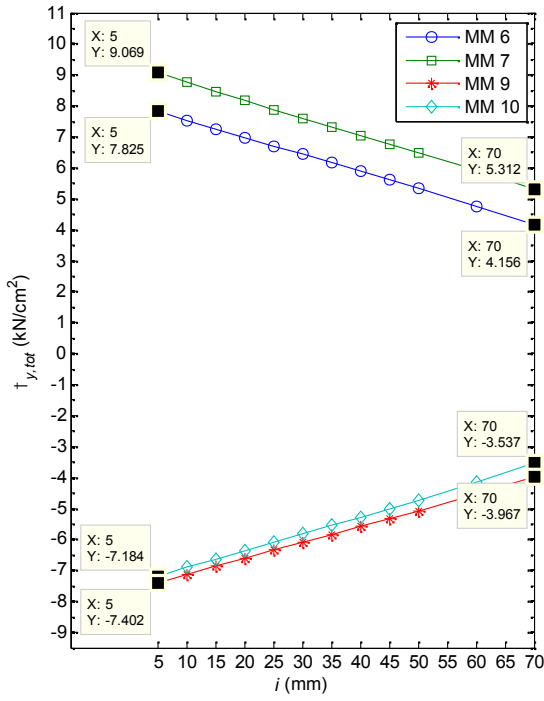
1, 2, 3, 4, 5



3.17: () : ()



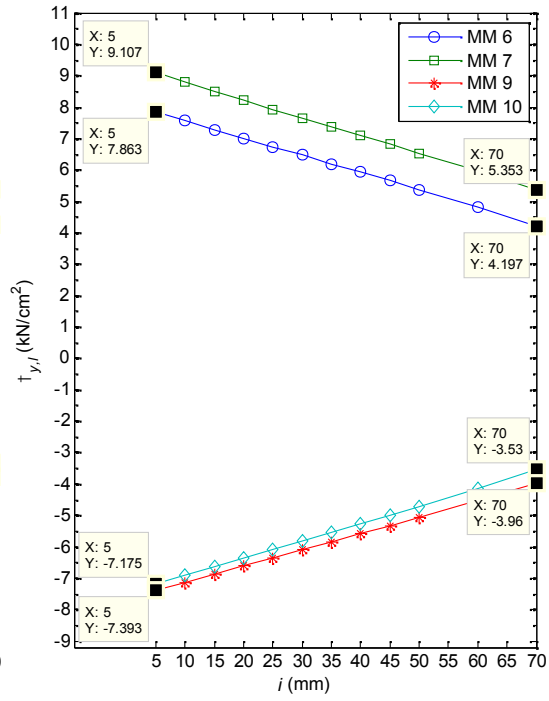
() () 6, 7, 9, 10:



()

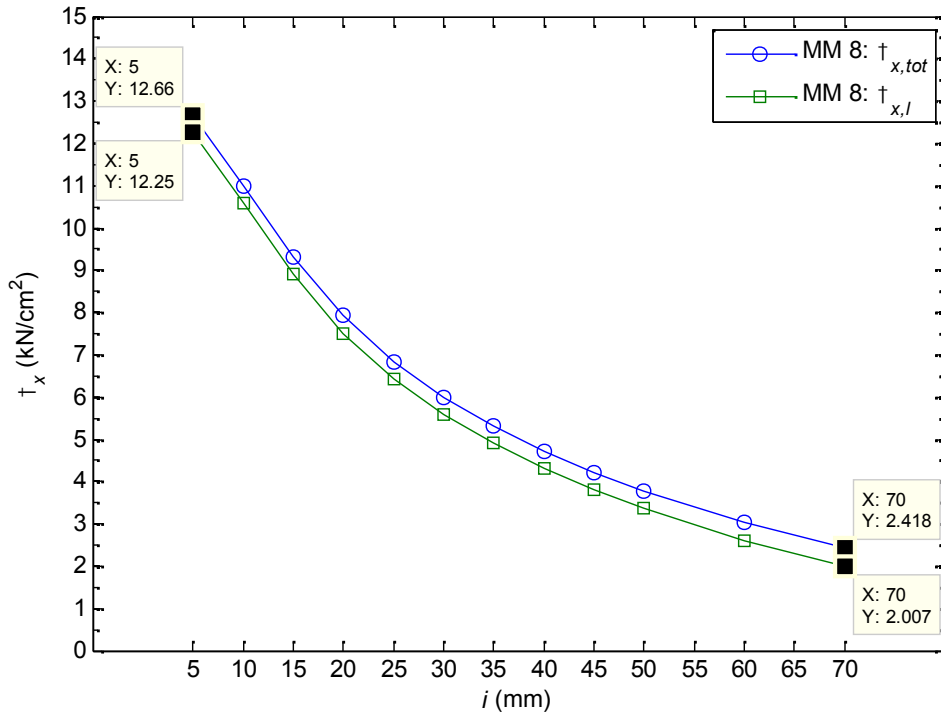
3.18:

() : ()



()

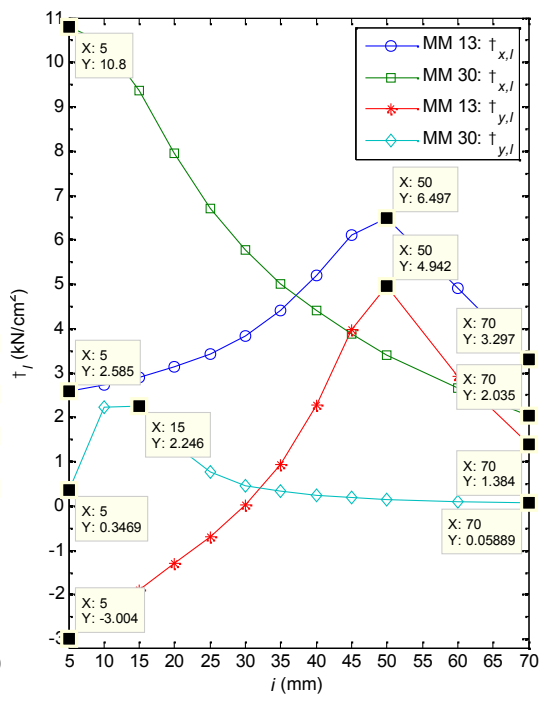
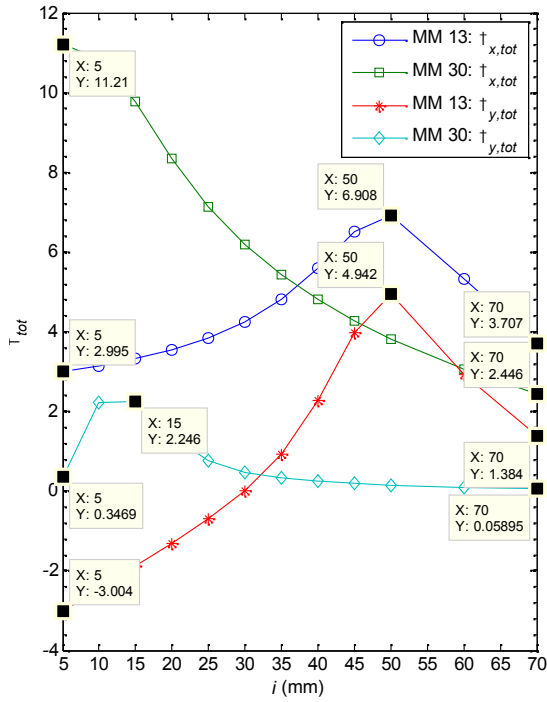
(y) 6, 7, 9, 10:



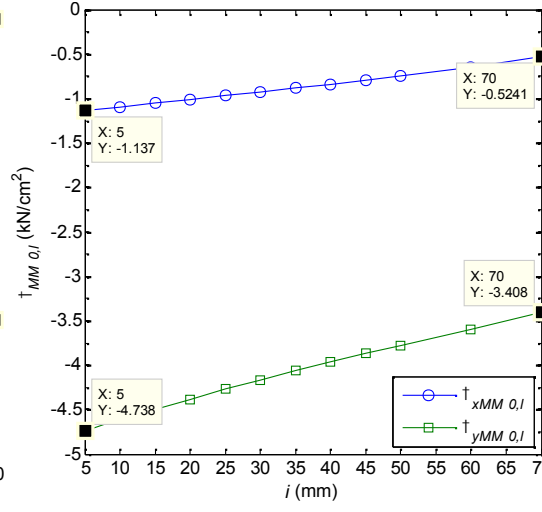
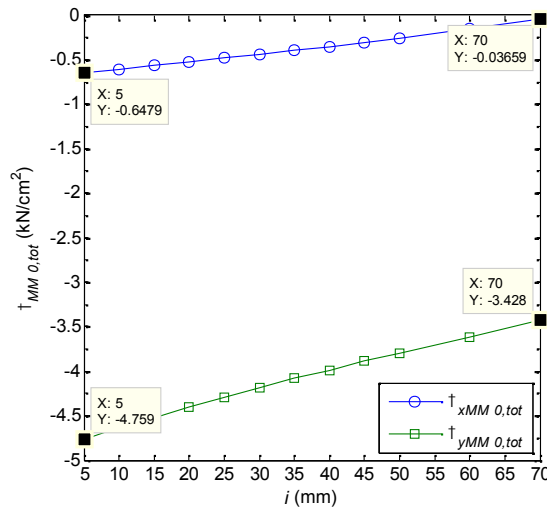
3.19:

(x)

8



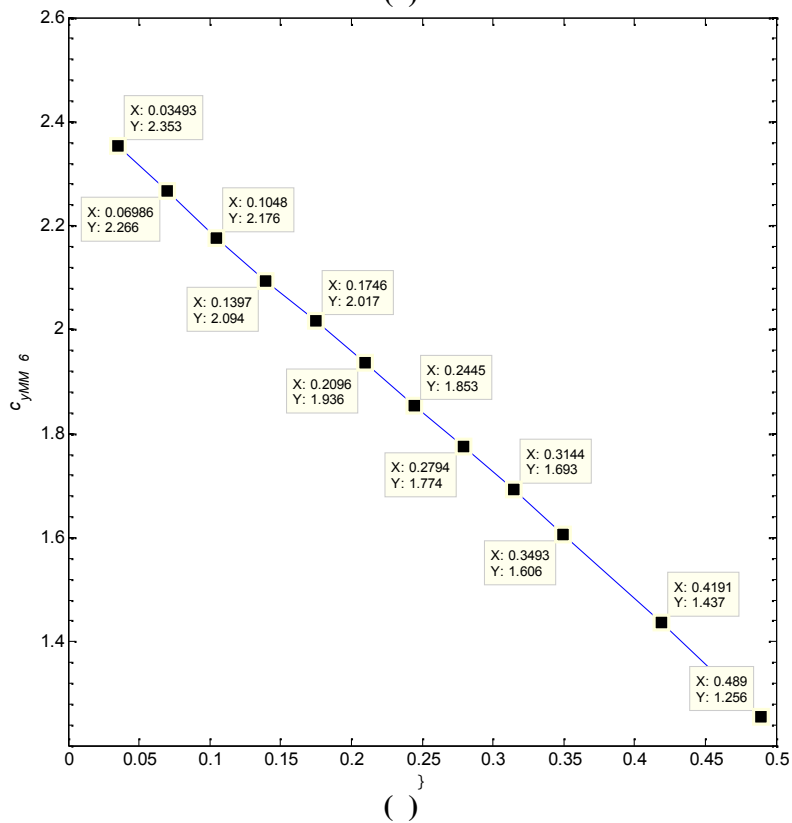
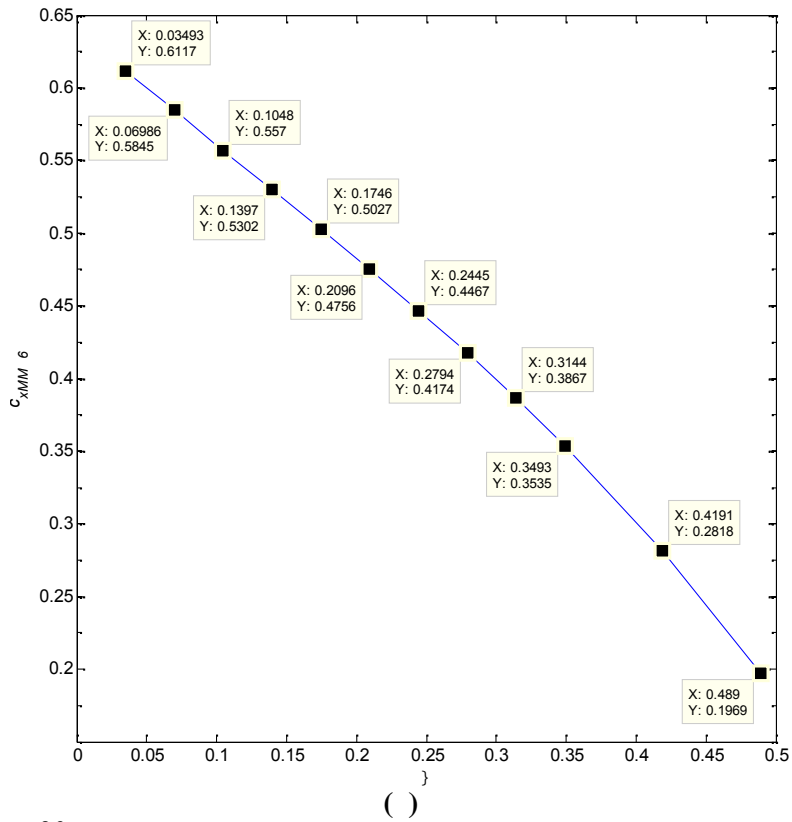
()
3.20: 13 30: () : ()



()
3.21: 0: () : ()

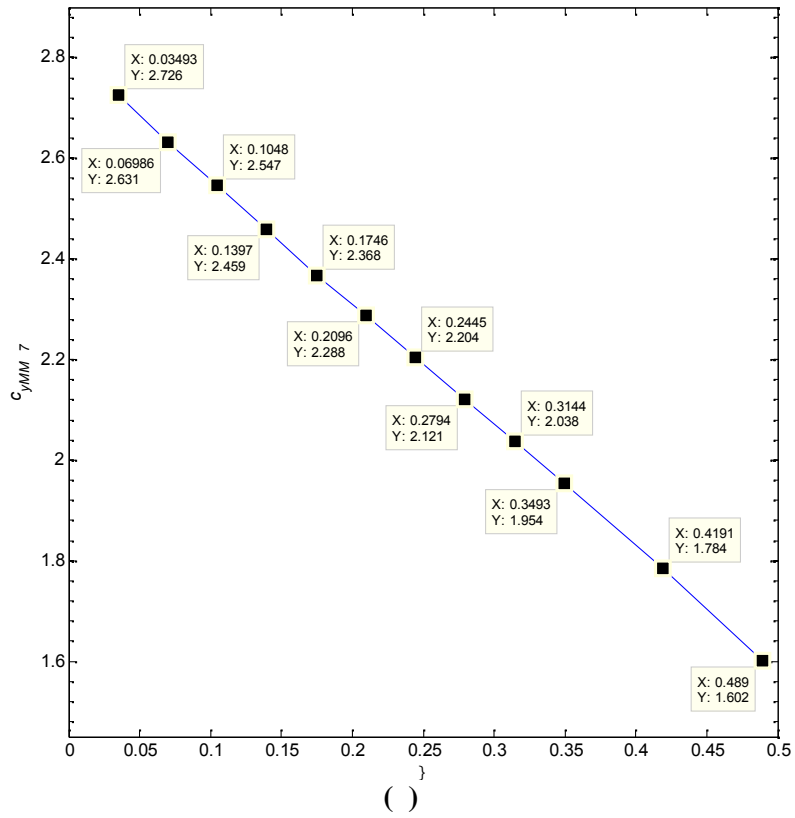
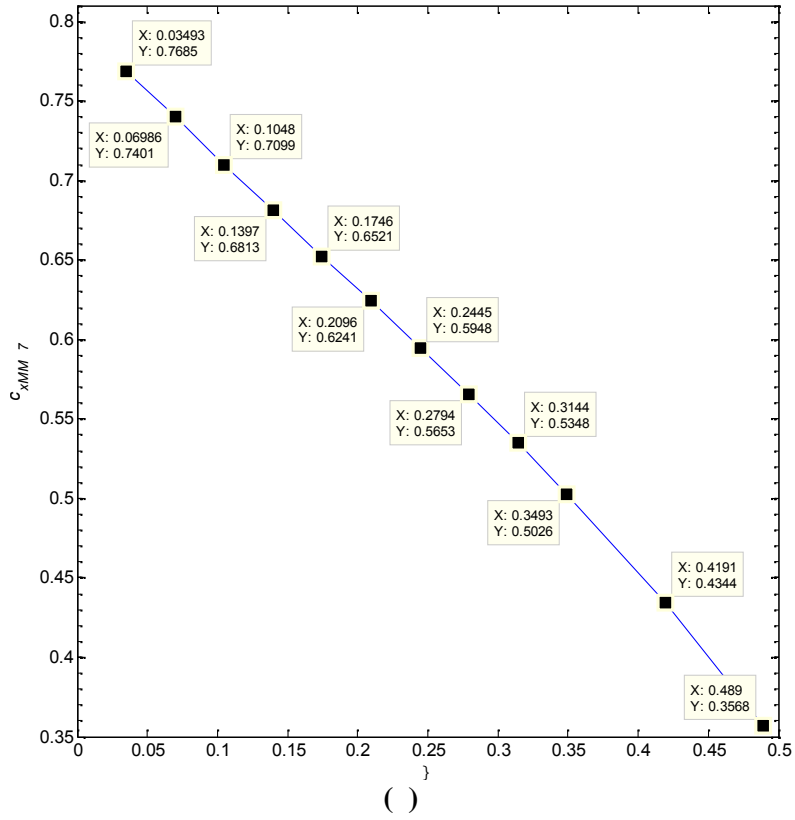
, 3.17(), 3.18(), 3.19, 3.20() 3.21(),
 (2.19),

, 3.22, 3.23, ..., 3.29.



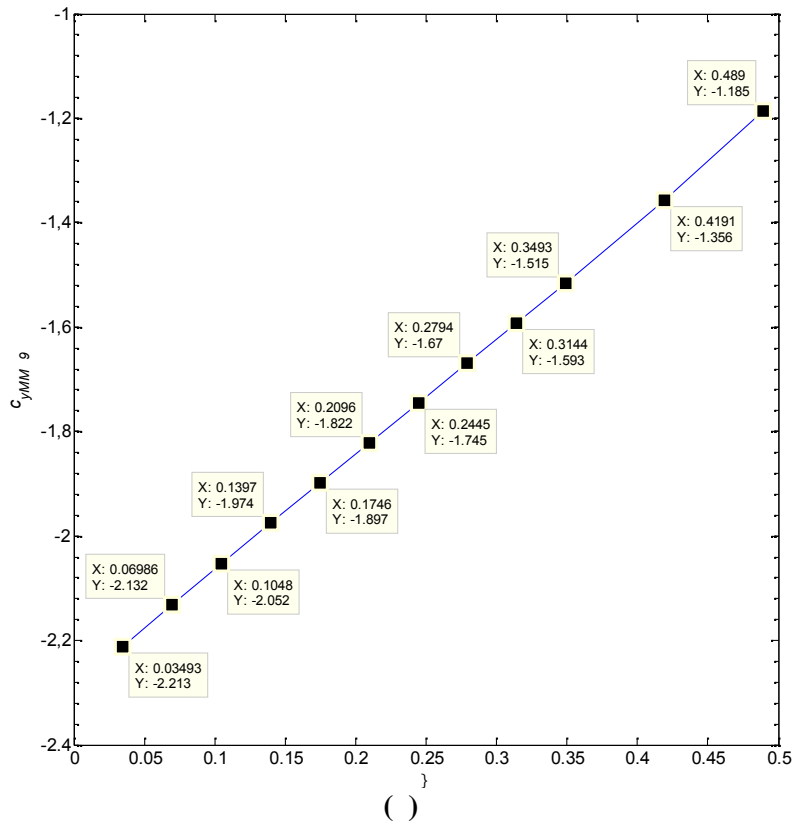
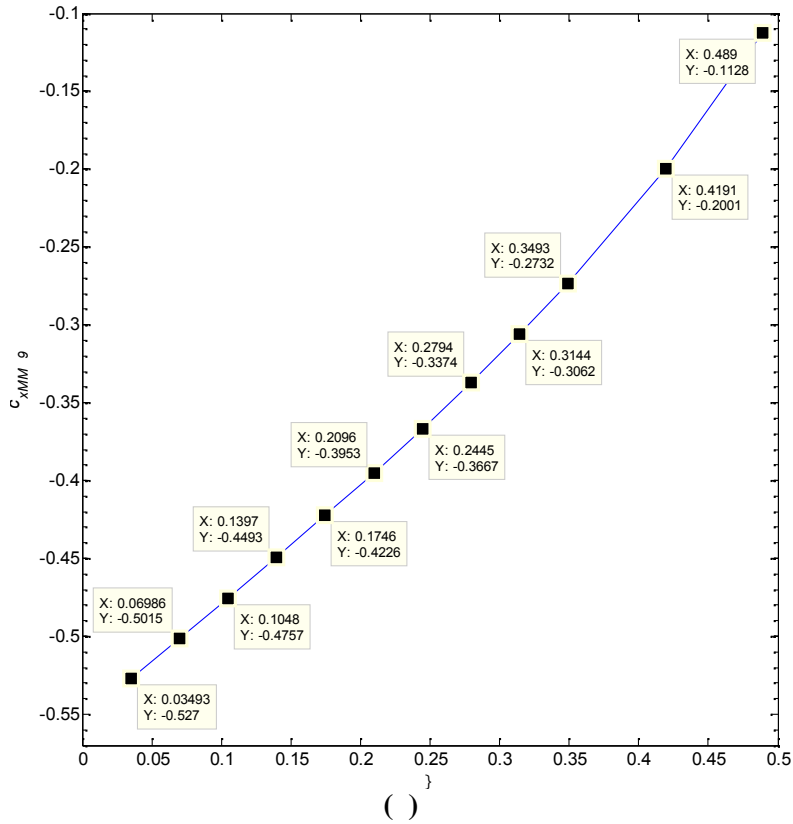
3.22:

M 6: (a) c_x ; () c_y



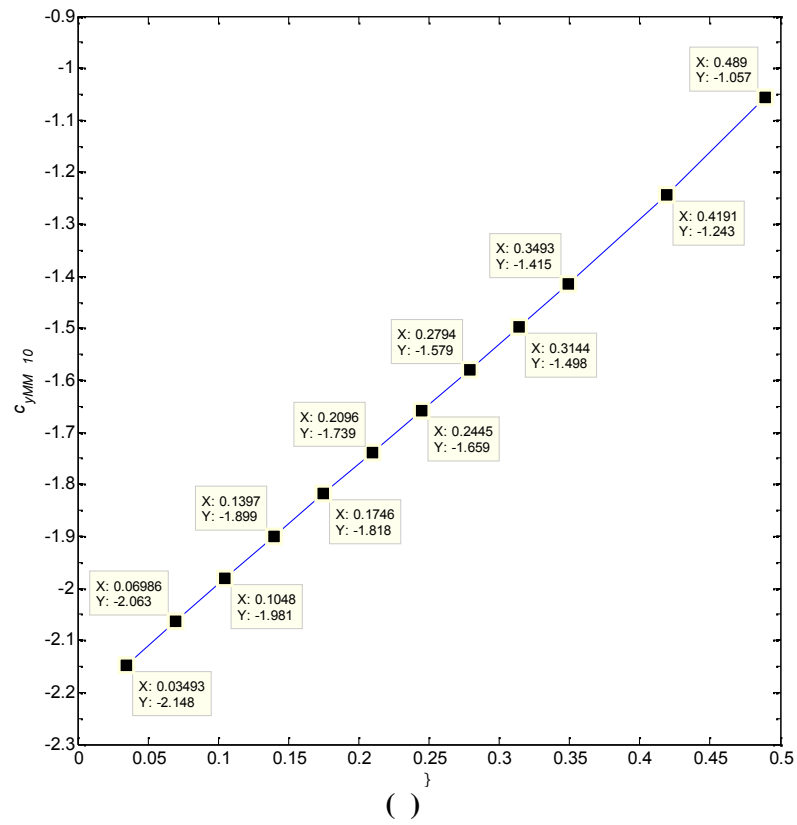
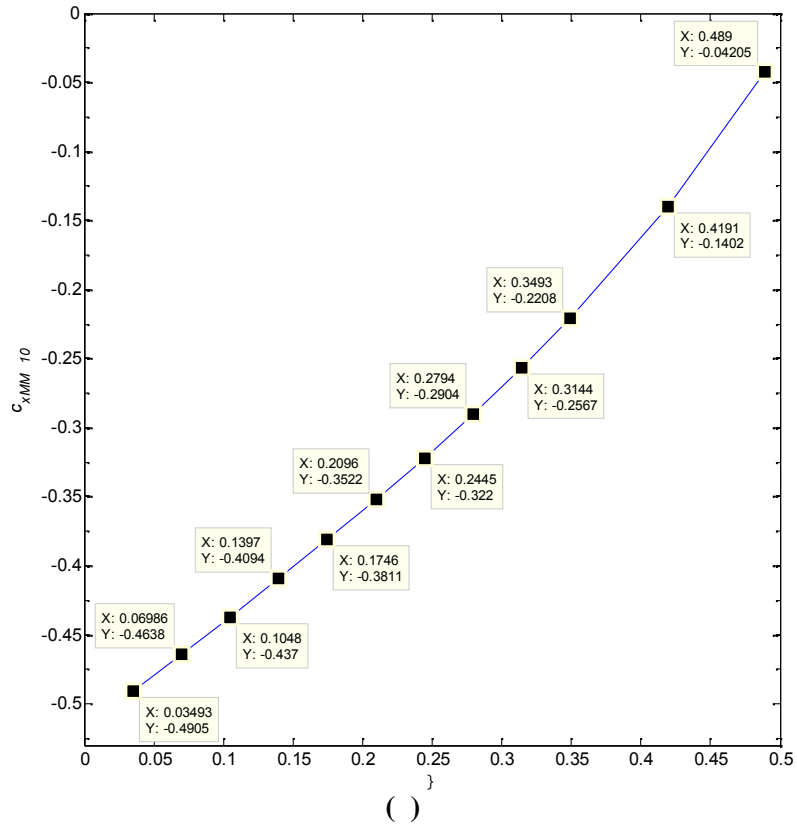
3.23:

M 7: (a) c_x ; () c_y



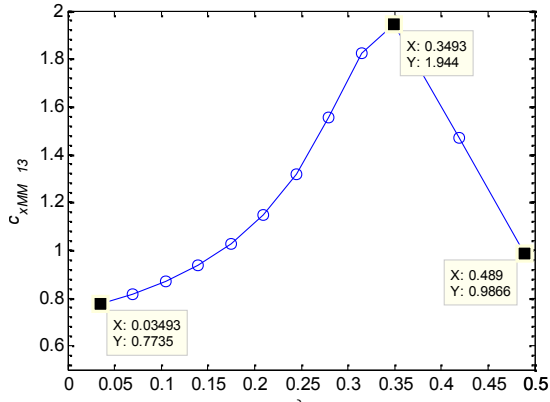
3.24:

M 9: (a) c_x ; () c_y

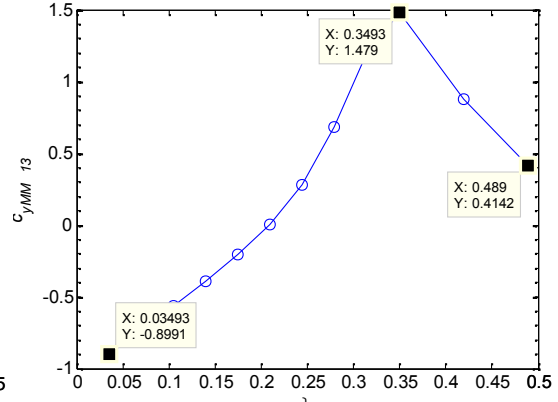


3.25:

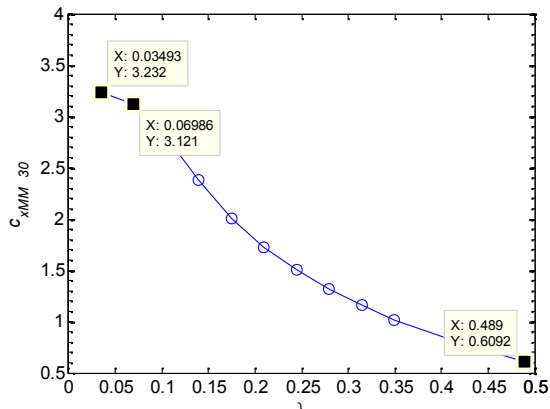
M 10: (a) c_x ; () c_y



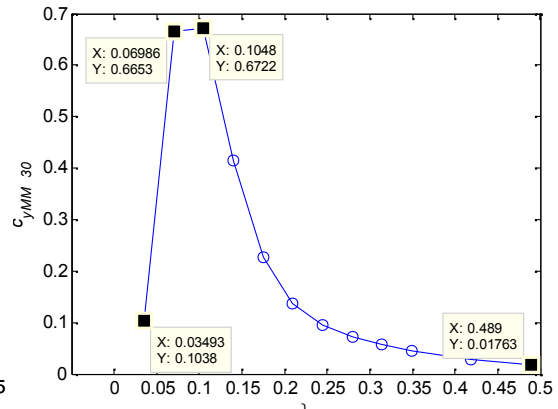
3.26:



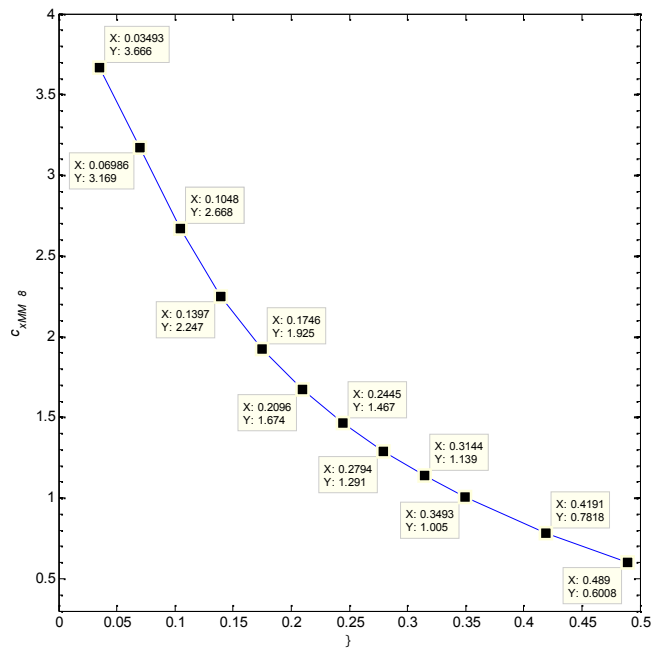
M 13: (a) c_x ; () c_y



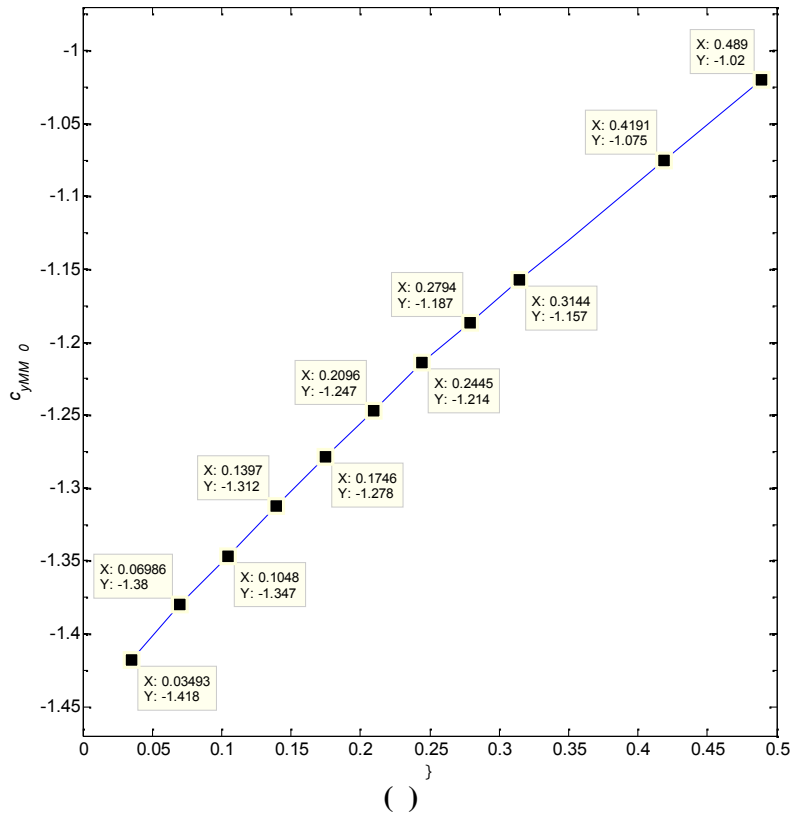
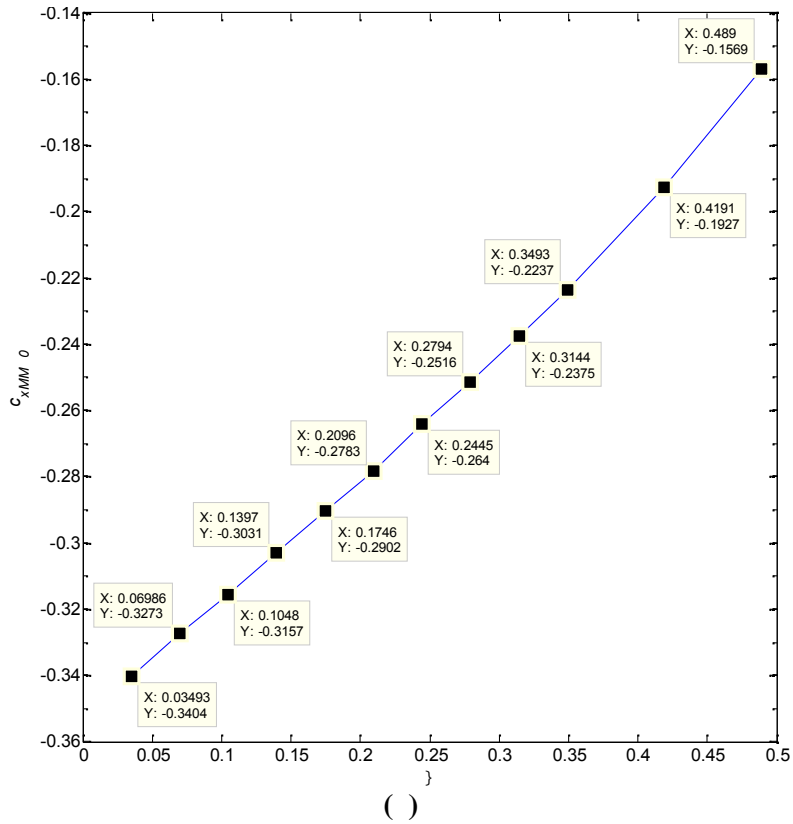
3.27:



M 13: (a) c_x ; () c_y



3.28: c_x M 8



3.29:

M 0: (a) c_x ; (b) c_y

3.3

3.3 3.4,

3.8,

:

- 1 - 5 ,
3.8(), 7 - 11 30,
3.8(-); 6 10,
3.8(), ;
- 3, , 1, 3.8();
1,
2 3,

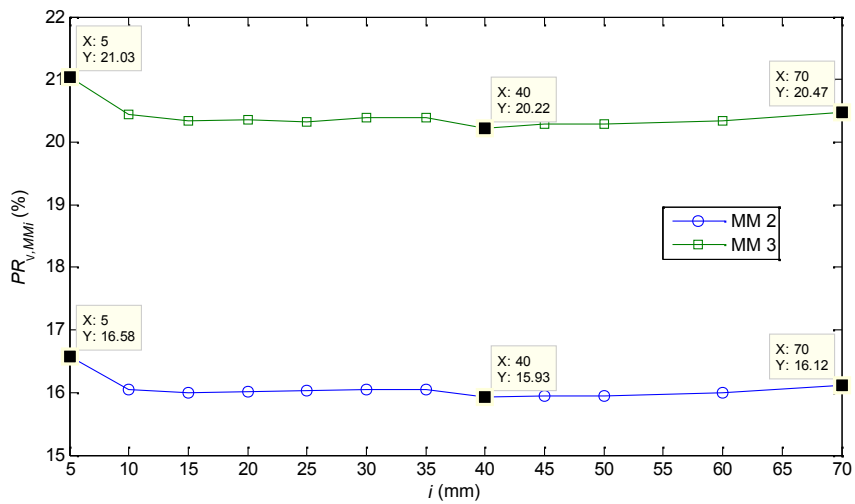
$$PR_{V,MMi} = \frac{V_{xMMi} - V_{x1}}{V_{x1}} \times 100 (\%), i = 2, 3, \dots(3.2)$$

„shear - leg” ,

: 15,9 16,6% 2, , 20,2 21,0

3, 3.30;

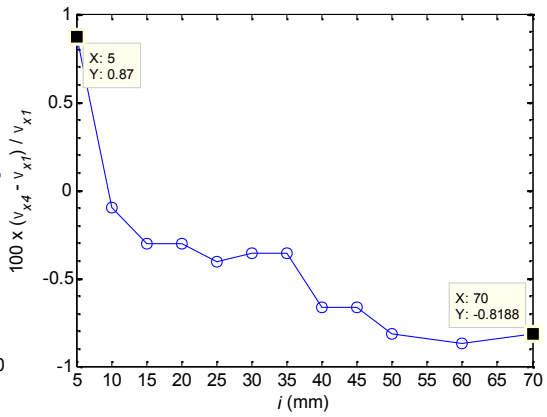
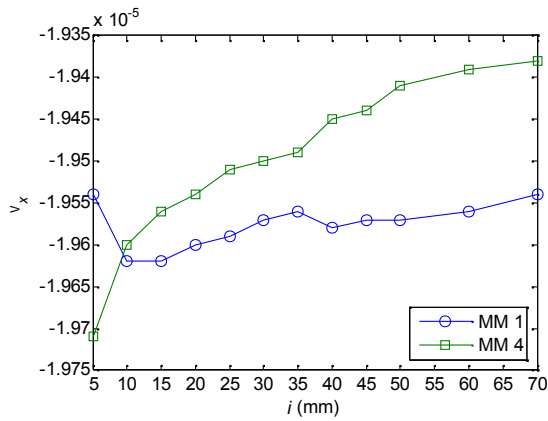
- 1 4, 3.31,
;
0,9%, 3.31().



3.30:

2 3

1



3.31: () 1 4 () ()

6, 3.8(),

$i > 40$ mm. i

() 6,

,

10

, 3.8(),

$$v_{x10} / |v_{x6}| \quad 15$$

(300), 6,

6, 3.32.

(y) 7 9 ,

3.33, 16% 20,5%,

9

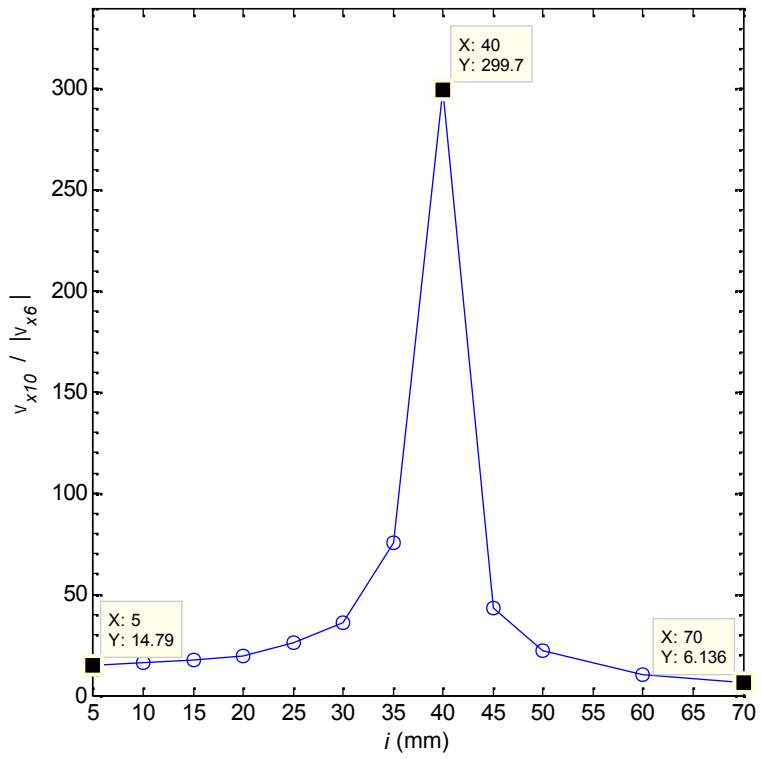
, 3.8().

(x) 8 11 ,

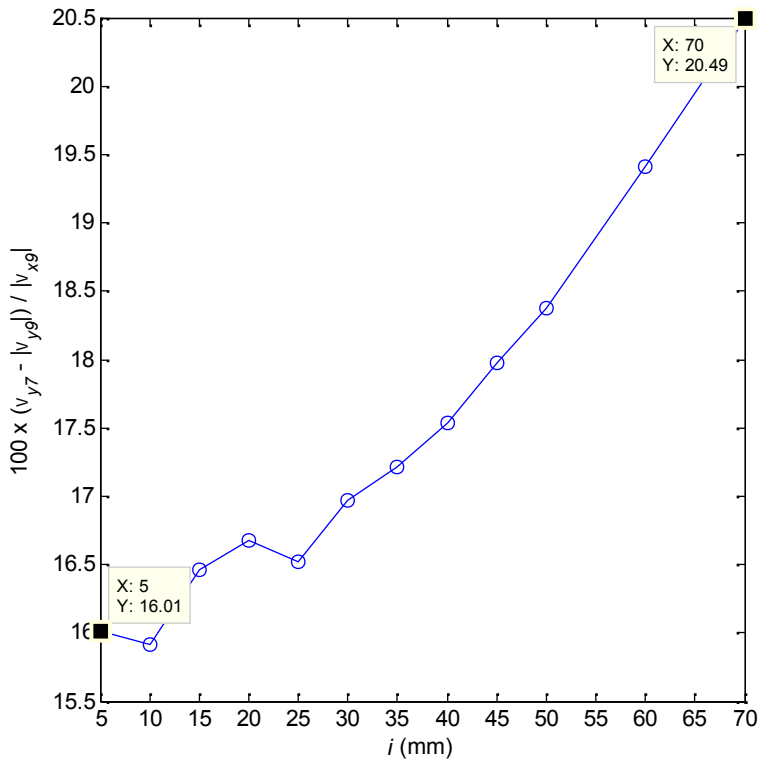
, 3.8().

0,9%, 3.34

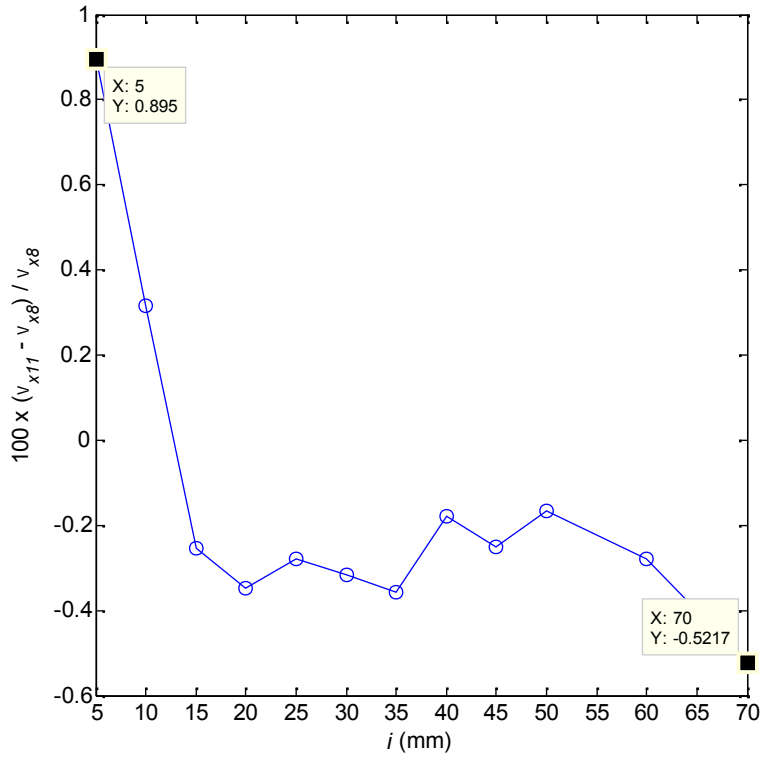
1 4, 3.31().



3.32: $(v_{x10} / |v_{x6}|)$ 10 6



3.33: y 7 9



3.34: x 8 11

(x) 13 ($i_3=50$ mm),

3.8(),

185,5 $\mu\text{m/m}$ $i=5$ mm, 257,5 $\mu\text{m/m}$ $i=50$ mm,

156,8 $\mu\text{m/m}$ $i=70$ mm, 3.3 3.4.

13, ,

$i=$ $i_3=50$ mm. (y)

$i < 37$ mm. -185,9 $\mu\text{m/m}$

$i=5$ mm, 135,7 $\mu\text{m/m}$ $i=50$ mm

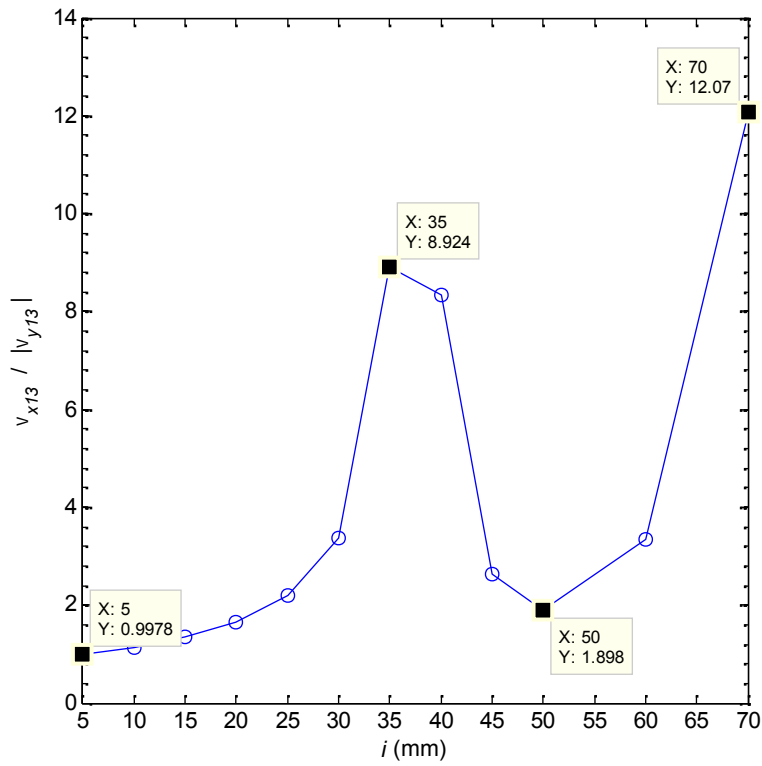
13,0 $\mu\text{m/m}$ $i=70$ mm, 3.3 3.4, ,

13

3.35.

$i = i_3 = 50 \text{ mm}$

1,9



3.35:

$$v_{x13} / |v_{y13}|$$

13

(x) 30 ($i_3 = 10 \text{ mm}$),

3.8(),

528,4 $\mu\text{m/m}$ $i = 5 \text{ mm}$, 115,6 $\mu\text{m/m}$ $i = 70 \text{ mm}$, 3.3 3.4 ,

$i = i_3 = 10 \text{ mm}$.

(y) 30

3.8(). -144,1 $\mu\text{m/m}$

$i = 5 \text{ mm}$

-33,2 $\mu\text{m/m}$ $i = 15 \text{ mm}$,

-66,3 $\mu\text{m/m}$ $i = 30 \text{ mm}$,

-32,1 $\mu\text{m/m}$ $i = 70 \text{ mm}$, 3.3 3.4

(-33,2 $\mu\text{m/m}$) $i = 15 \text{ mm}$,

$i = i_3 = 10 \text{ mm}$,

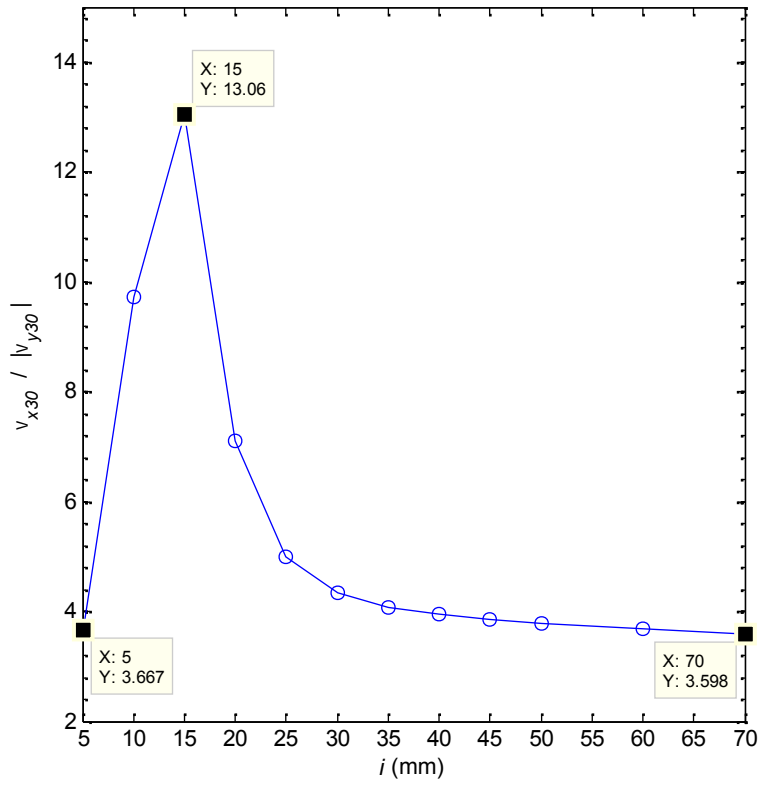
-49,7 $\mu\text{m/m}$. 13,

30

(x)

(y), 3.36.

$i=15$ mm 13.



3.36: $|V_{x30}| / |V_{y30}|$ 30

(x) (y)

13 30

3.37(,).

$i=37,5$ mm, 3.37(). $i<37,5$ mm

30

13,

$i>37,5$ mm

V_{x13} / V_{x30}

0,35 ($i=5$ mm) (1,46)

$i=60$ mm,

1,36 $i=70$ mm, 3.37().

13

30,

3.37().

13 ,, “

13,

30,

3.37().

$i=5$ mm,

$i=10$ mm

30,

3.37().

13

“ ”

13, 3.37().

30

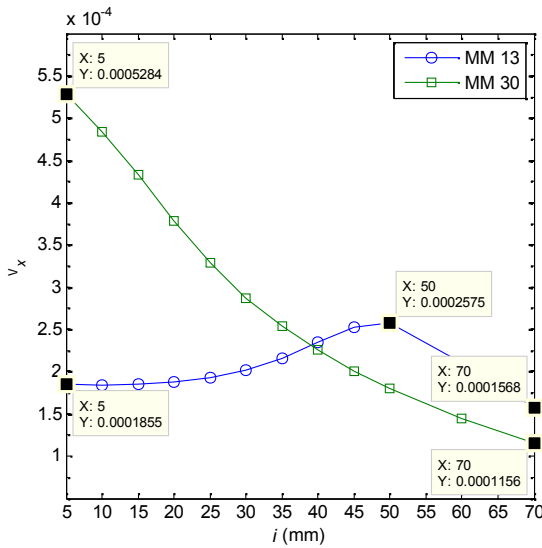
$i=30=10$ mm,

$i=15$ mm,

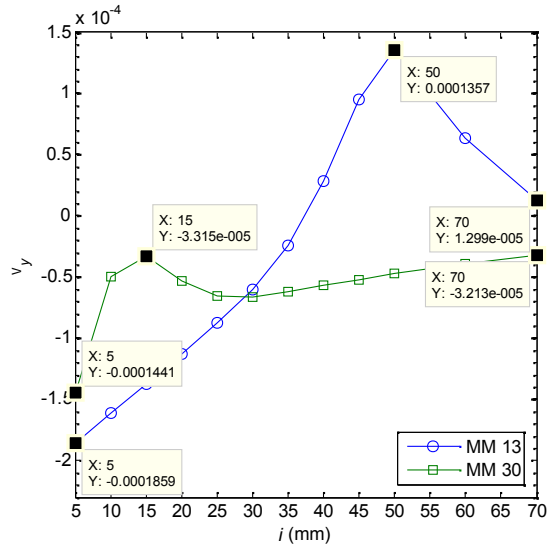
3.37().

$i=29$ mm,

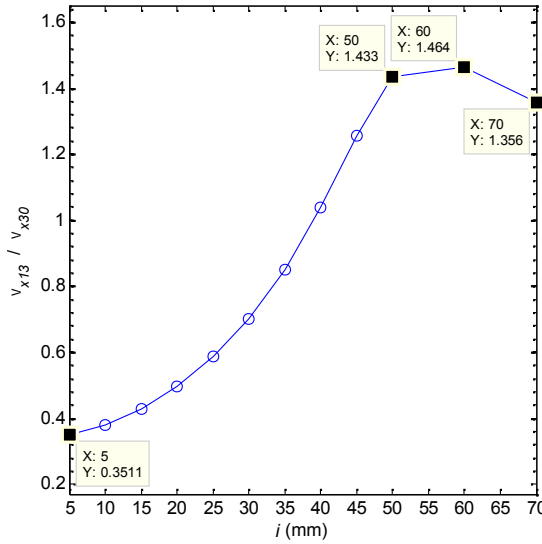
3.37().



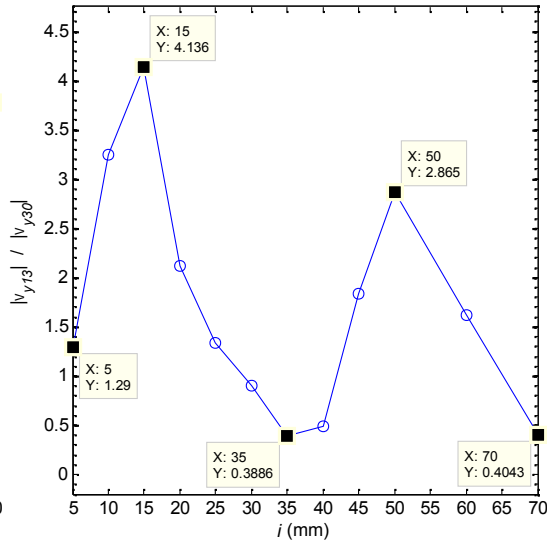
()



()



()



()

3.37:

13 30: () x; () y; () v_{x13}/v_{x30} ; () $|v_{y13}|/|v_{y30}|$

13 30

: 0,39 $i=35$ mm
4,14 $i=15$ mm, **3.37**(). $i=15$ mm,
 $i=50$ mm. ,

$$\left|V_{y13}\right|/\left|V_{y30}\right|$$

13 30 , **3.37**().

3.12 - 3.15,

3.9(), **3.10 - 3.11**().

$C_{xMM9-10}$

(9 - 10) , **3.12**()

$C_{xMM 9-10}$ 0,51 =0,0349 ($i=5$ mm),
=0,489 ($i=70$ mm) 0,08.

6 - 7, 9 - 10,

C_{xMM6-7}

0,72 (=0,0349, , $i=5$ mm) 0,29 (=0,489, , $i=70$ mm),

3.12().

$C_{xMM 6-7}$

$C_{xMM9-10}$,

3.38.

$$C_{xMM 6-7}/\left|C_{xMM 9-10}\right|$$

, 1,4 =0,0349 ($i=5$ mm), 3,8 =0,489,
, $i=70$ mm.

>0,3493 ($i>50$ mm), **3.38.**

$C_{yMM9-10}$ C_{yMM6-7}

3.13,

$C_{xMM 9-10}$ $C_{xMM 6-7}$

3.12.

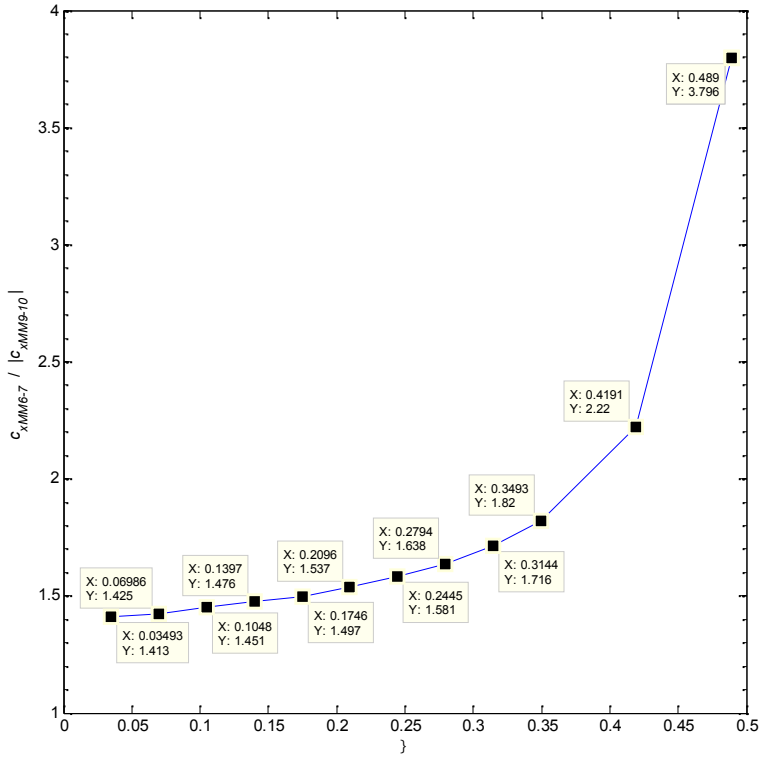
=0,0349, , $i=5$ mm, (1,18) =0,489 ($i=70$ mm),

3.13().

C_{yMM6-7}

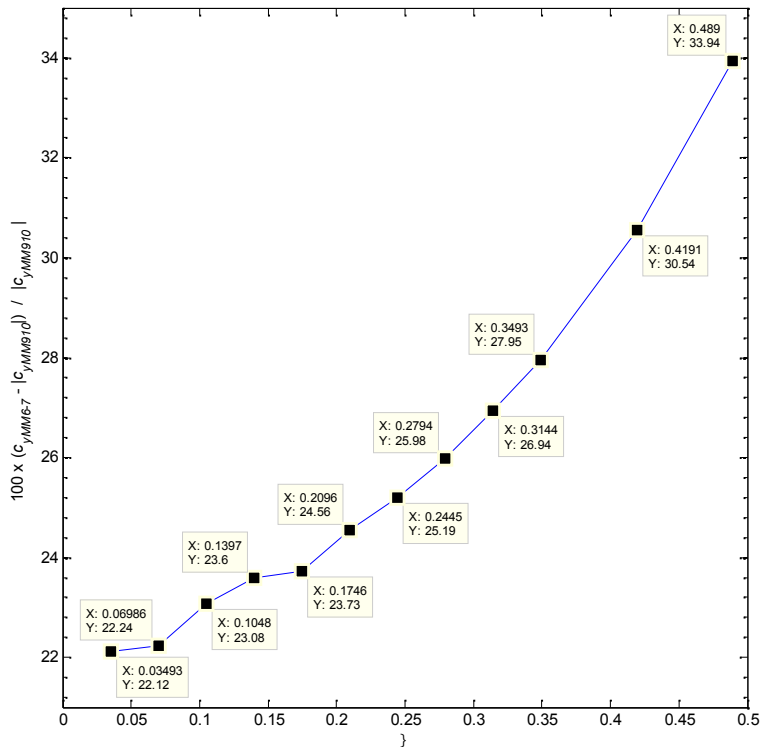
2,7 (=0,0349, , $i=5$ mm) 1,57 (=0,489, ,

$i=70$ mm), **3.13**().



3.38:

$$c_{xMM\ 6-7} / |c_{xMM\ 9-10}|$$



3.39:

6 - 7 9 - 10

c_y

(c_x)

c_{yMM6-7}

$c_{yMM 9-10}$,

3.13.

c_y

6 - 7

9 - 10,

3.39,

22,1%

=0,0349 ($i=5$ mm)

33,9%

=0,489

($i=70$ mm).

6 - 7

9 - 10

1,

3.40.

6 - 7

3,8 (=0,0349,

, $i=5$ mm)

5,4 (=0,489,

, $i=70$ mm),

9 - 10

4,4 (=0,0349,

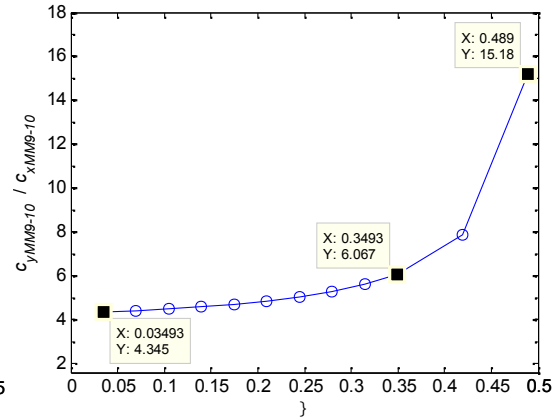
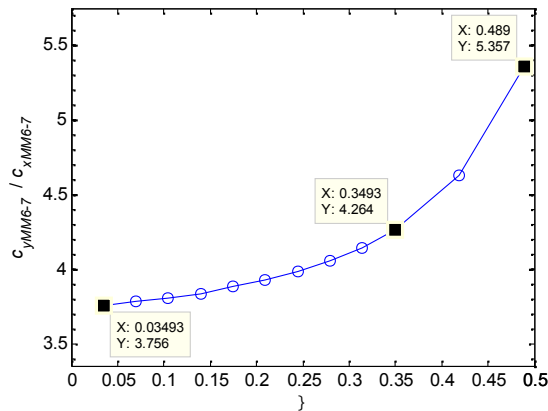
, $i=5$ mm)

15,2 (=0,489,

, $i=70$ mm).

>0,3493 ($i>50$ mm),

3.40.



()

()

3.40:

c_y/c_x : (a)

6 - 7; (b) MM 9 - 10

c_x MM 13

,

3.14(),

0,77 (=0,0349,

,

$i=5$ mm)

1,94 (=0,3493,

, $i=50$ mm),

0,99 (=0,489,

, $i=70$ mm).

,

$i=$ $i_3=50$ mm.

c_x MM 30,

3.14(),

3,23 (

=0,0349,

, $i=5$ mm)

0,61 (=0,489,

, $i=70$ mm).

,

c_x 13.
 c_y MM 13
3.14 (), $-0,90$ ($=0,0349$, ,
 $i=5$ mm) $1,47$ ($=0,3493$, , $i=50$ mm),
 $0,42$ ($=0,489$, , $i=70$ mm). ,
 c_x 13,

$i=$ $i_3=50$ mm. c_y MM 30,
3.14 (), $0,10$ ($=0,0349$, , $i=5$ mm) $0,67$ ($=0,1048$, , $i=15$ mm), $0,02$ ($=0,489$, , $i=70$ mm). , 13
 c_y

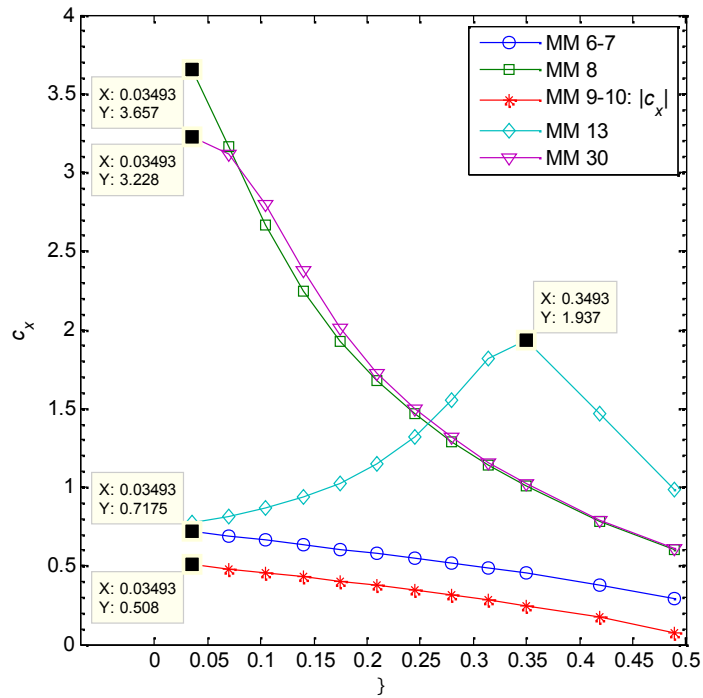
c_x MM 8,
3.15, ($=0,0349$, ,
 5 mm, **2.2** (), **2.2** () $3,66$ ($=0,0349$, ,
 $i=5$ mm) $0,60$ ($=0,489$, , $i=70$ mm).

, ($=0,0349$, ,
 / , ($=0,0349$, ,
), **3.41** **3.42**

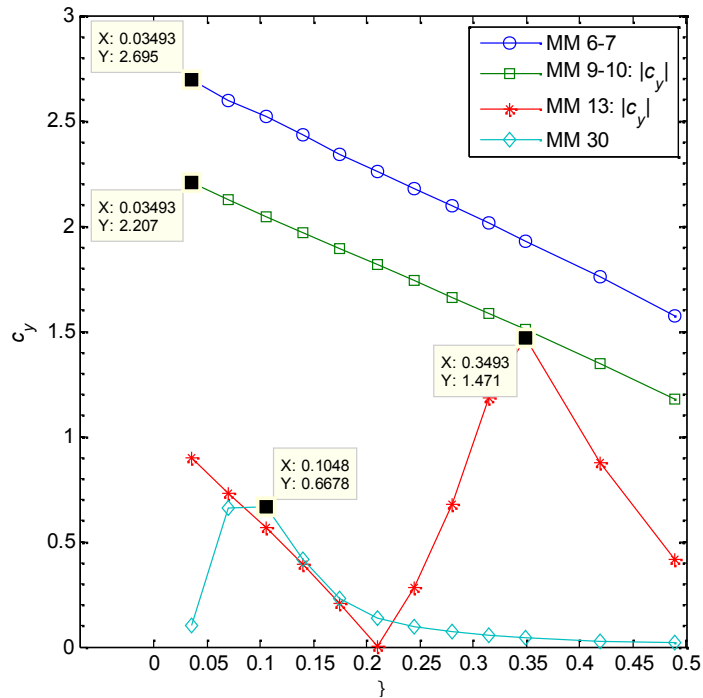
• c_x MM 8 ($=0,0349$, ,
 c_x MM 8 $3,66$, , 30 , 13 , $6 - 7$
 $9 - 10$;

• , **3.20**, ;

;



3.41:
6 - 7, 8, 9 - 10, 13 30 (c_x)



3.42:
6 - 7, 9 - 10, 13 30 (c_y)

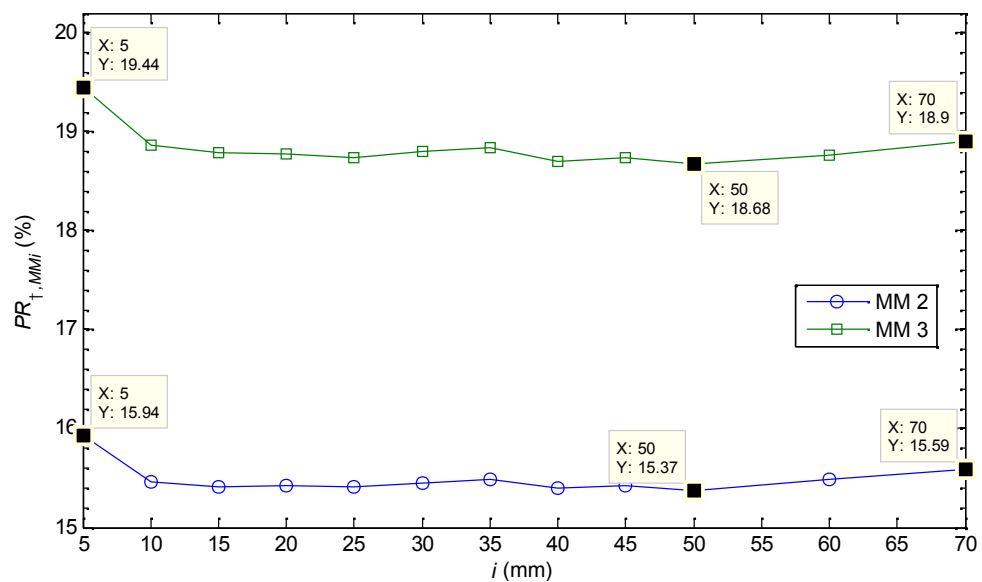
- **3.21,** 6 - 7 (/ , c_{yMM6-7} 2,70) , 9 - 10, 13 30;

- **3.20 3.21,** (8), (x) . (x) , () , **3.16,** , , . 2 3, 1,

$$PR_{\uparrow,MMi} = \frac{\uparrow_{xMMi} - \uparrow_{x1}}{\uparrow_{x1}} \times 100 (\%), i = 2, 3, \dots(3.3)$$

3.43, „shear - leg” .

(x) .



3.43: (x) 2 3 1

, 3.44, 3.45, ..., 3.50.

6 - 7,

7, 6,

3.44() 3.45().

,
/ ,

(y)

(x), 3.8(,), 3.3 3.4,

6 y y

7

x 7 x 6,

c_x c_y 6 - 7 ()

6 (), 3.44(),

=0,03493 (i=5 mm)

17,3% 14,5%,

c_x 49,1%

=0,489 (i=70 mm).

c_y 25,3%, 3.44().

(i=5 mm, =0,03493),

c_x c_y 6 - 7 ()

7 () -6,6% -1,1%,

3.45().

(i=70 mm,

=0,489),

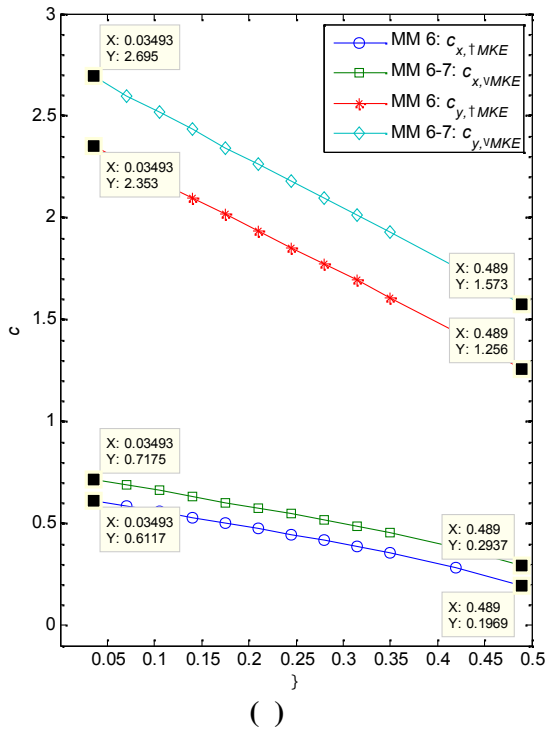
c_x c_y

-17,7% -1,8%, 3.45().

c_y

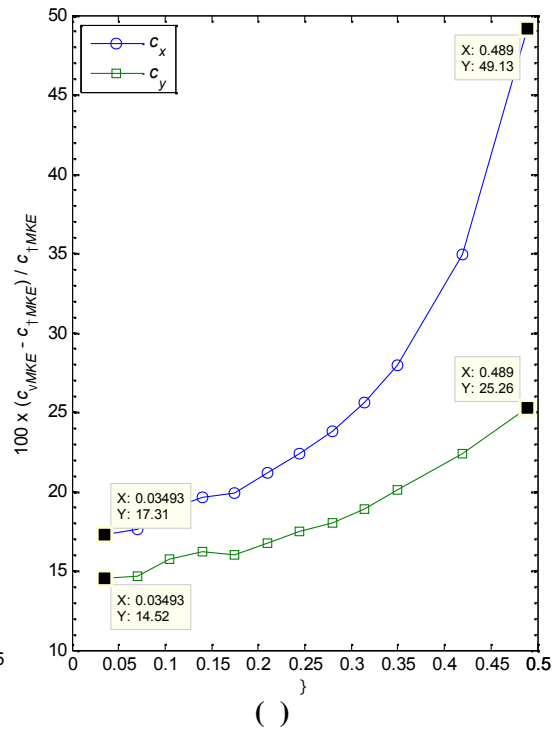
()

6 - 7

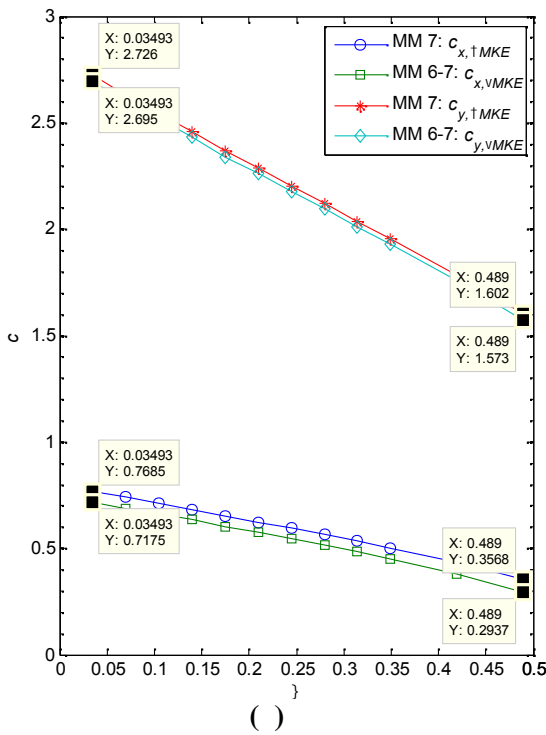


3.44:

() ; ()

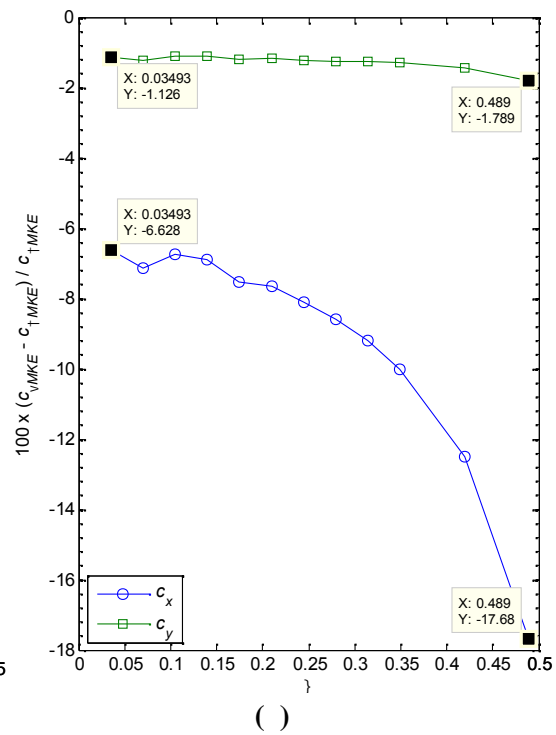


6 - 7 () 6 ():



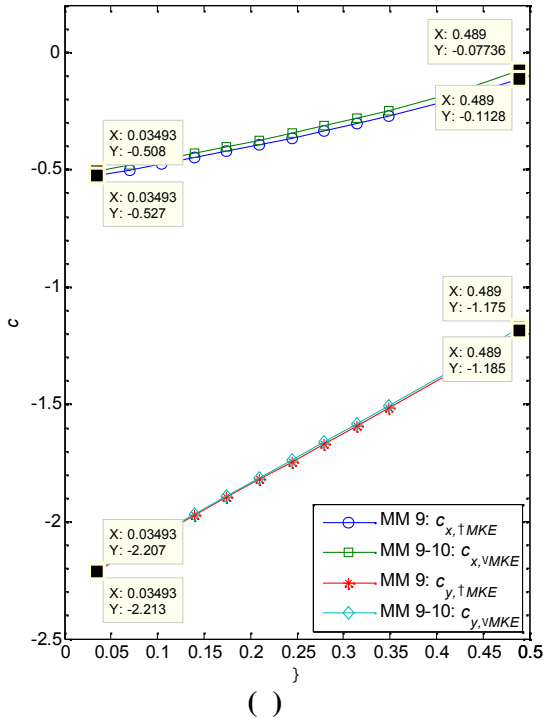
3.45:

() ; ()



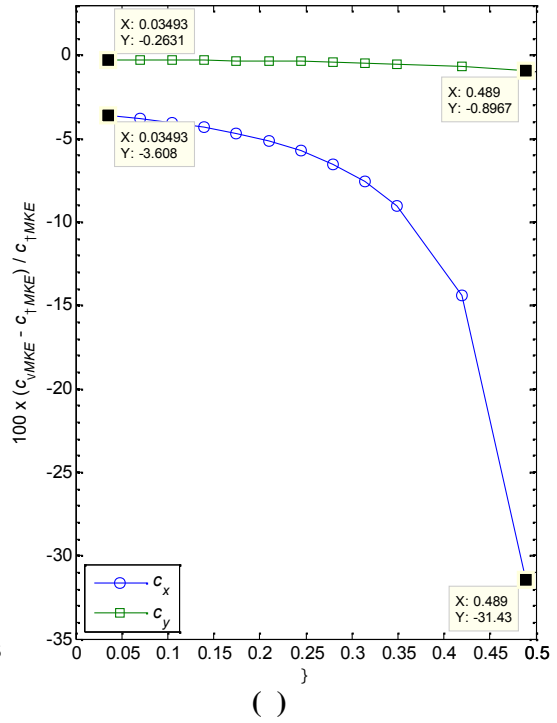
6 - 7 () 7 ():

9 - 10 ,
 6 - 7 ,
 () 9
 (), 10 (), **3.46() 3.47()** ,
 6 - 7, (y)
 , **3.8(,)**, **3.3 3.4.** ,
 (i=5 mm, =0,03493),
 , **3.46() 3.47()**. 9 (),
 c_x c_y 9 - 10 ()
 -2,6‰ -3,6 % , 10 ()
 3,6 % 2,8% , **3.46() 3.47()**.
 ,
 9 - 10 , **3.46() 3.47()**.
 , 3.46()
3.47() ,
 c_x .
 c_x
 9 - 10 i=70 mm (=0,489), 31,4% 9 84%
 10, **3.46() 3.47()**.
 c_x 9 10% 0,4191
 (i 50 mm), **3.46()**, 10
 10% 0,3144 (i 45 mm), **3.47()**.
 c_y 9 9‰
 , **3.46()**,
 10% ,
 i=70 mm (=0,489), 11,2%.
 / c_x
 (6 7, **3.22() 3.23()** ,
) ,

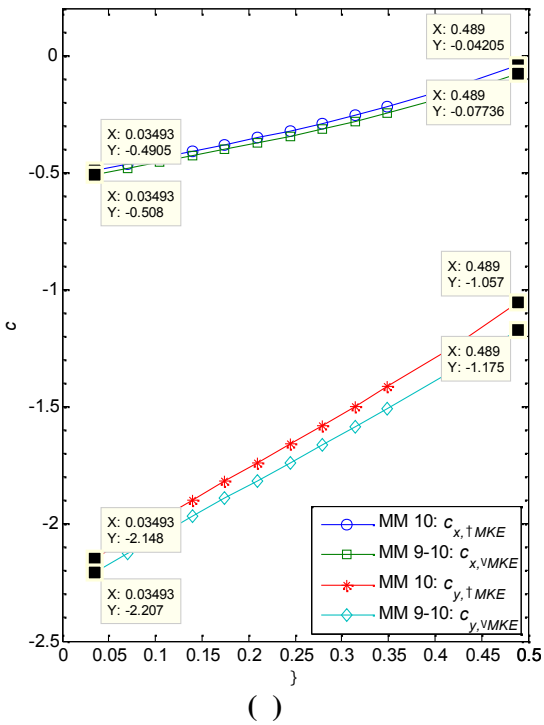


3.46:

() ; ()

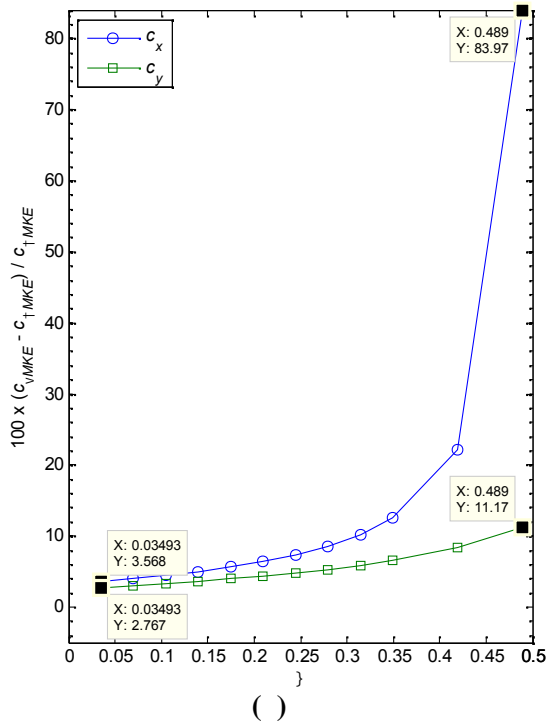


9 - 10 () 9 () :



3.47:

() ; ()



9 - 10 () 10 () :

(9, 10 0, 3.24(), 3.25() 3.29(),)
 c_x

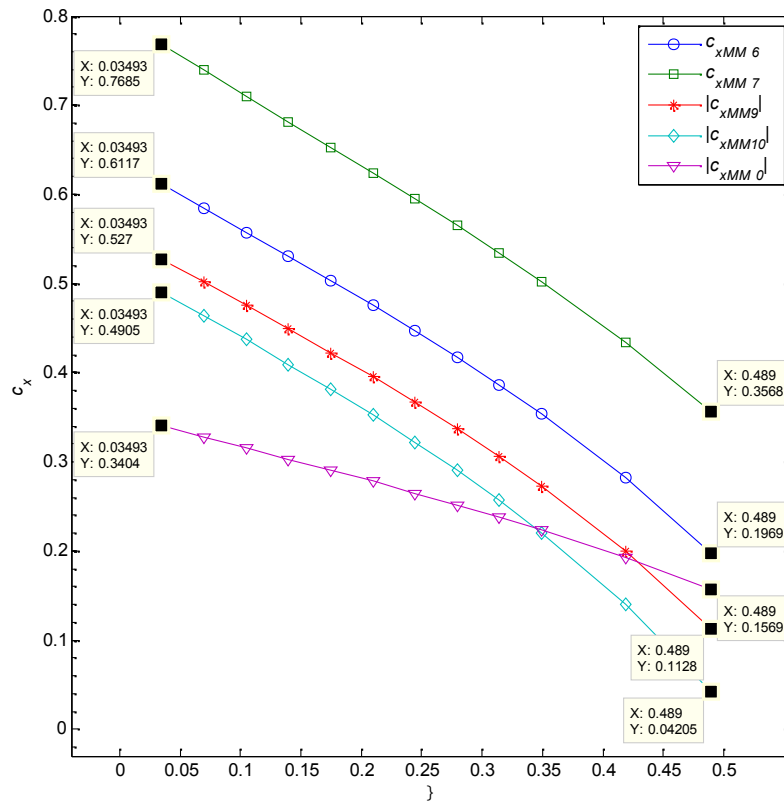
, 3.48. [5]
 0

(0), c_x
 0

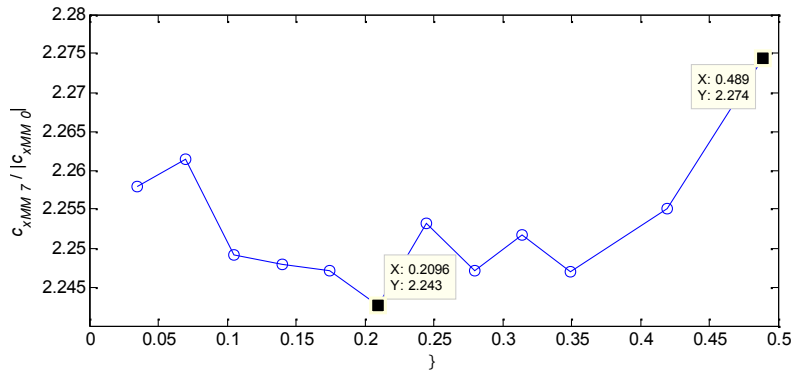
7, 3.49. $c_{xMM7}/|c_{xMM0}|$ 2,2
 – 2,24 =0,03493 (i=5 mm) 2,27

=0,489 (i=70 mm), 3.49.

0



3.48: c_x /



3.49:

$$c_{xMM7} / |c_{xMM0}|$$

(c_y),

, 3.22() 3.23(), 6 7 (9, 10 0, 3.24(), 3.25() 3.29()).

(c_x),

c_y

3.50.

c_y

0,

$$c_{yMM7} / |c_{yMM0}|,$$

3.51,

1,9

$$=0,03493 (i=5 \text{ mm})$$

$$1,6 =0,489 (i=70 \text{ mm}).$$

0

/ , 0

[5]

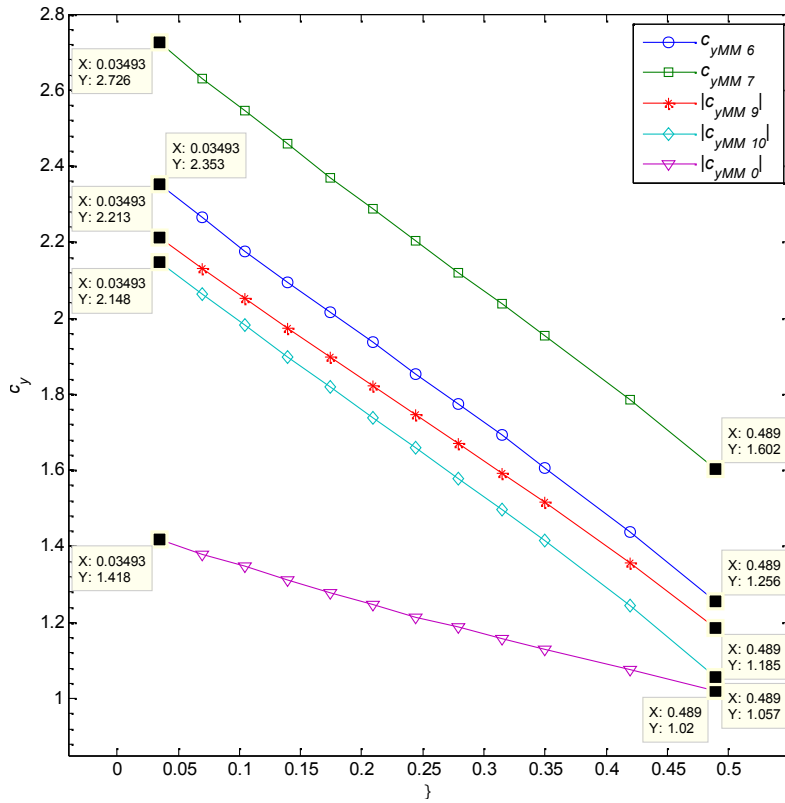
0

13 30

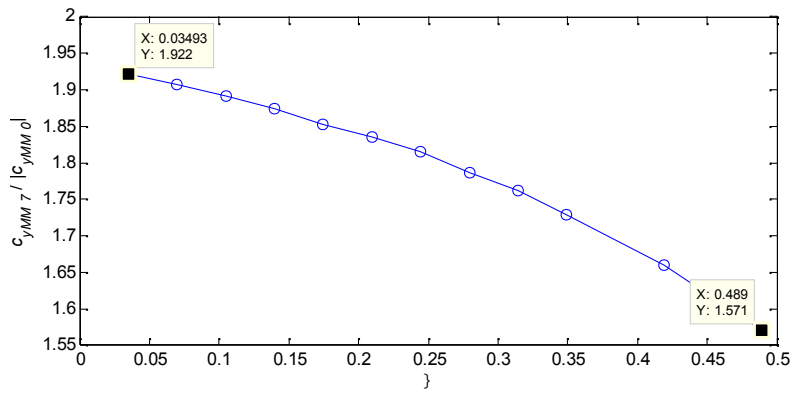
, $i= MM13=50 \text{ mm}$

(=0,3493),

, $i= MM30=10 \text{ mm}$ (=0,06986).



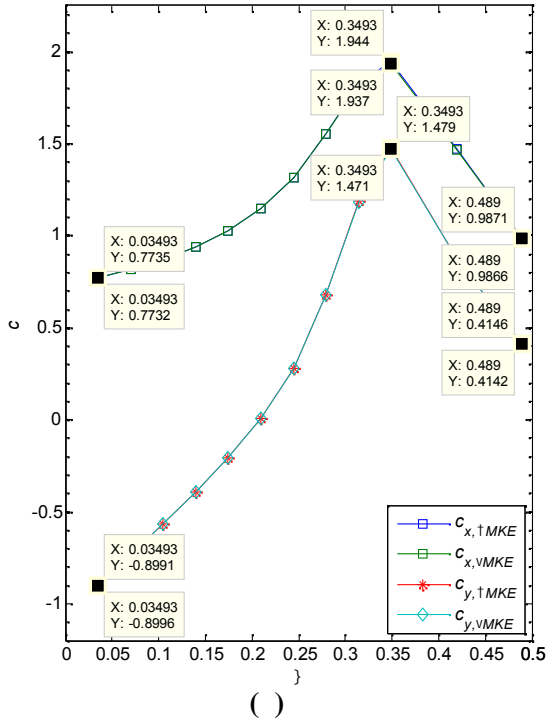
3.50: c_y /



3.51: $c_{yMM\ 7} / |c_{yMM\ 0}|$

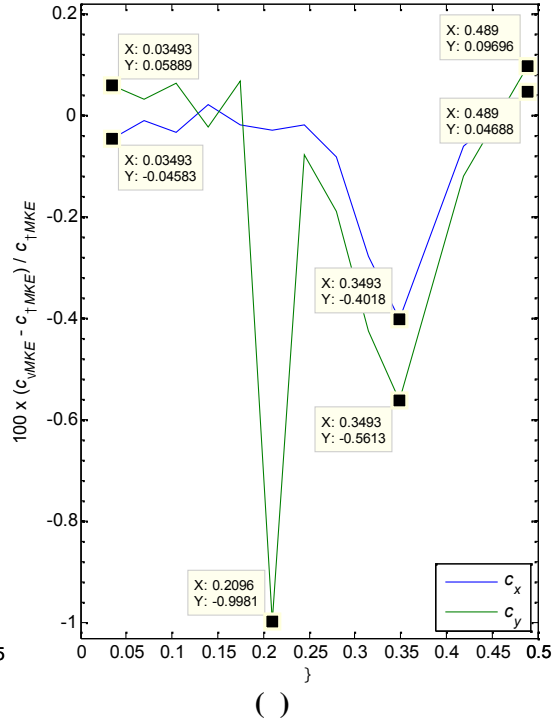
3.52 3.53.

6 - 7 9 - 10.



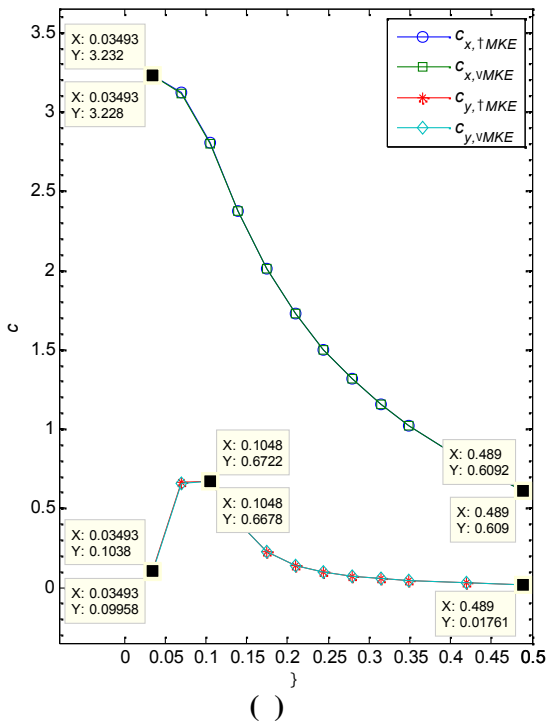
3.52:

()



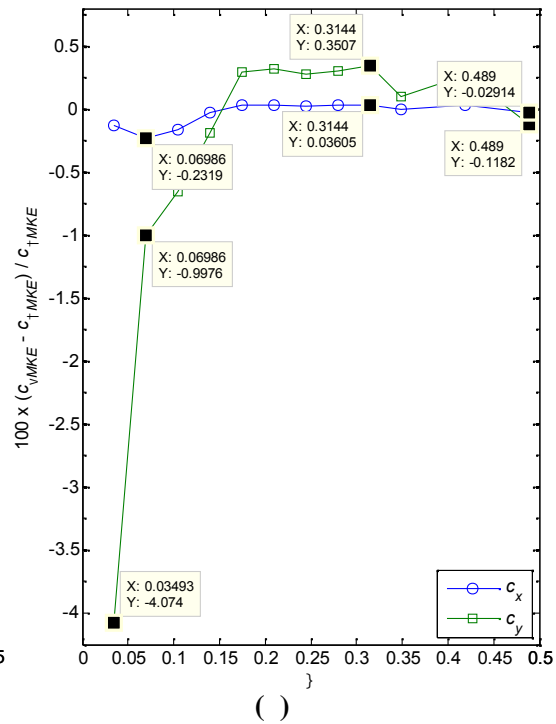
13: ()

;



3.53:

()



30: ()

;

c_x c_y

1%

3.52() 3.53()

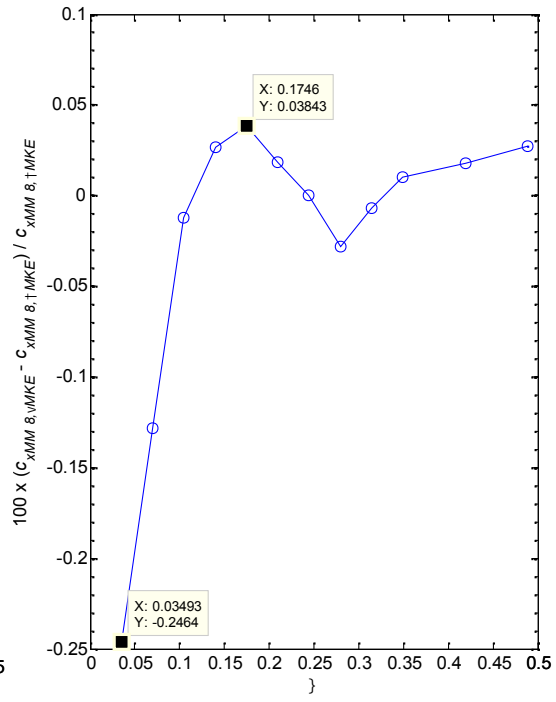
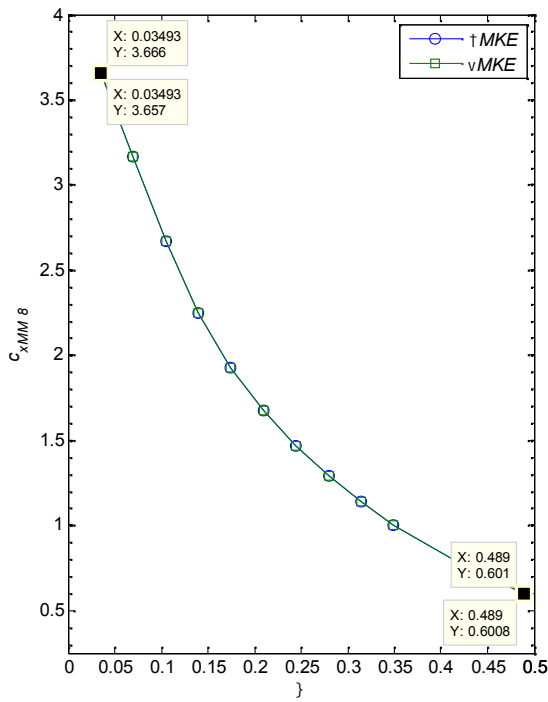
c_x

8,

3.54,

8.

c_x 2,5%, 3.54()



3.54:
()
()

c_x 8: () ;

3.4

()

• () .

σ

, ()

. ,

(2.), () . ,

.

,

() ,

(13 30, 3.3).

.

3.3, :

•

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• , ,

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;

;

- ;
- / c_x
- , ;
- , ;

EN 15011 [5];

- c_x /
- ;
- c_y /
- ;

- („0“)
- EN 15011 [5]
- ,
- ,

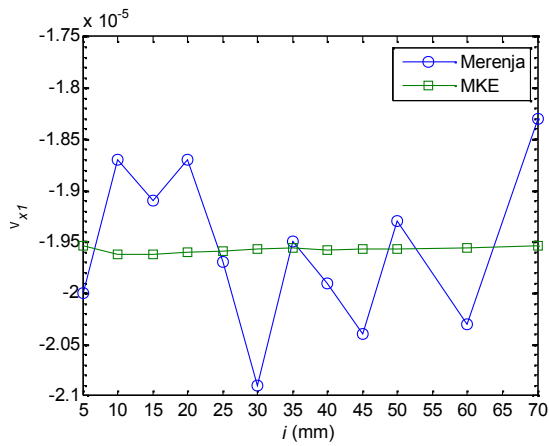
4.

2. 3.

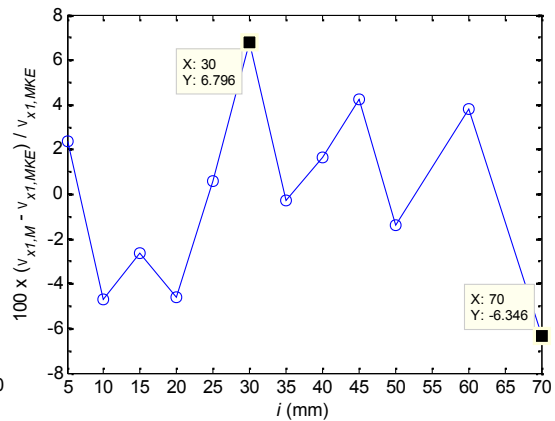
4.1

(-),

4.1 4.2.

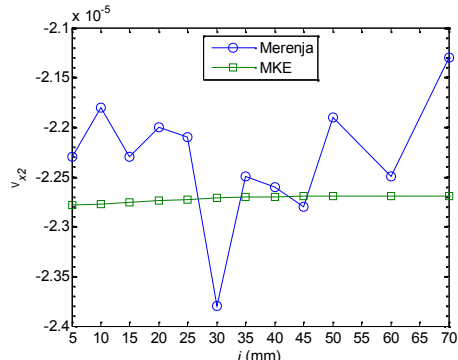


()
4.1:

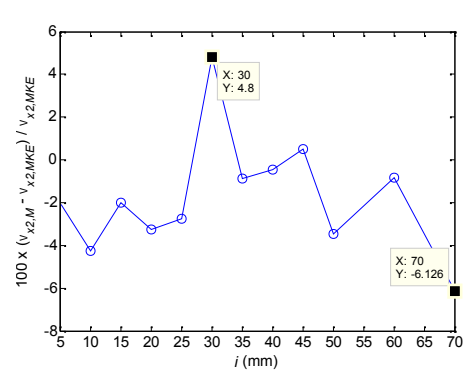


()
1:

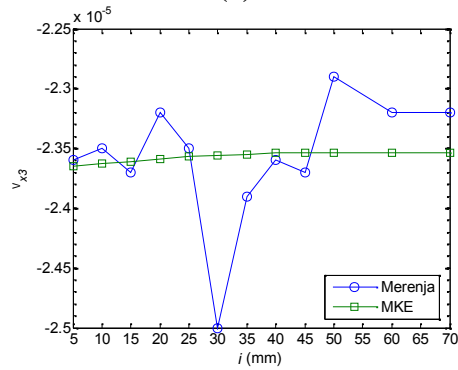
; ()



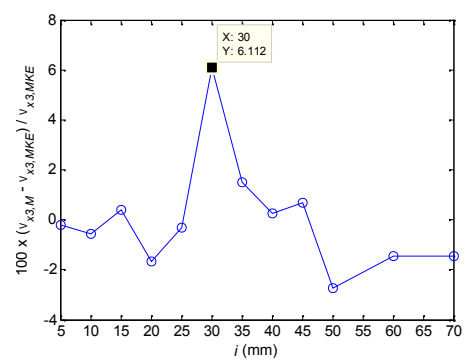
()



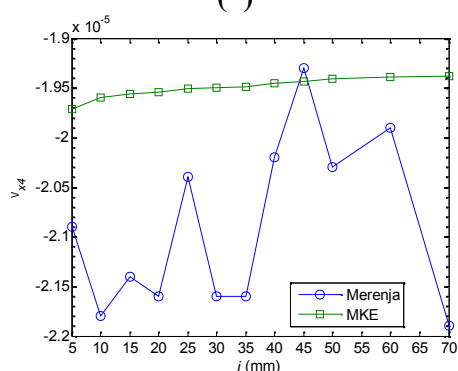
()



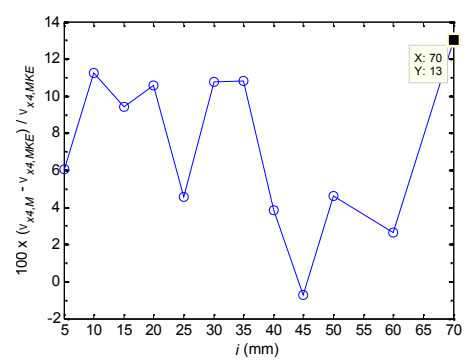
()



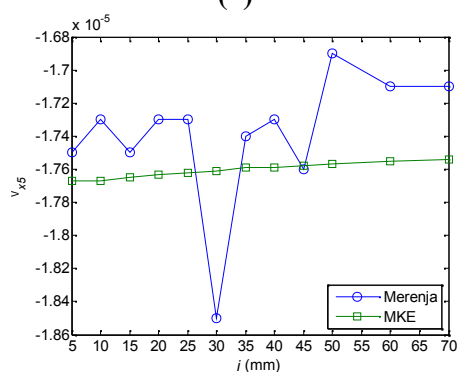
()



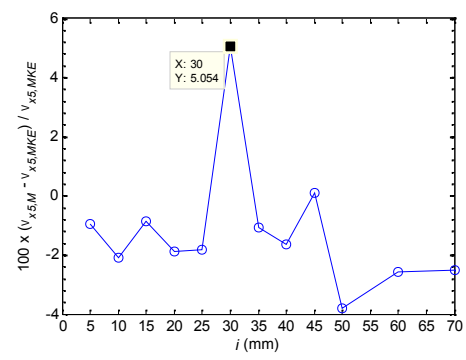
()



()



()



()

4.2:

(,) 2; (,) 3; (,) 4; (,) 5

4 13%, 4.2().

6,1% ()

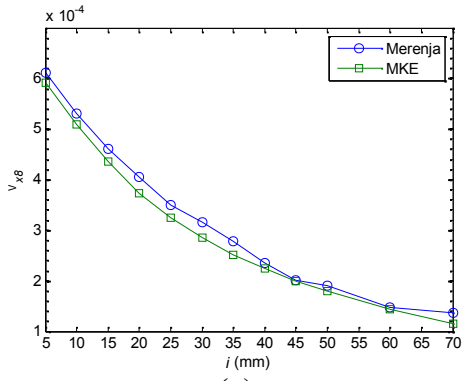
4.2() 5,1% 5, 4.2().

2, 4.2(), 6,1% 3,

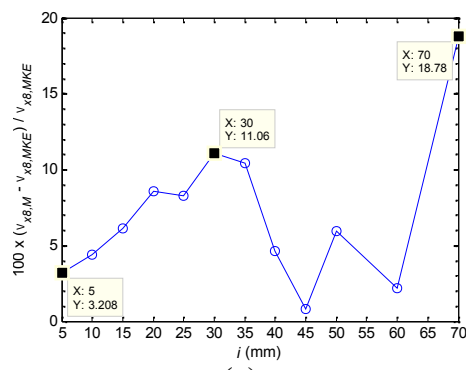
8 11,

2.2, 2.2(,),

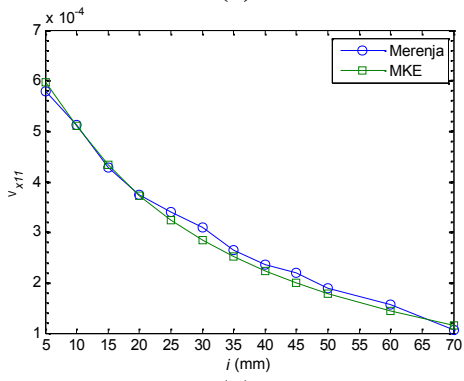
4.3(,).



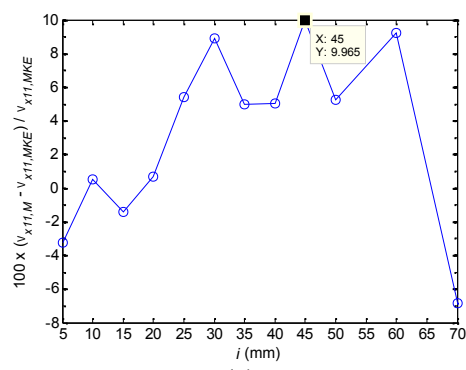
()



()



()



()

4.3: (,) 8; (,) 11

8 (i = MM8 = 5 mm)

3,2%

4.3().

, **4.3()**, 18,8%
i=70 mm, **4.3()**. 11

, **4.3()**.
i=45 mm, **4.3()**. 10,0%

/ , 6 7
9 10,
(*x*) (*y*)
, **4.4.**

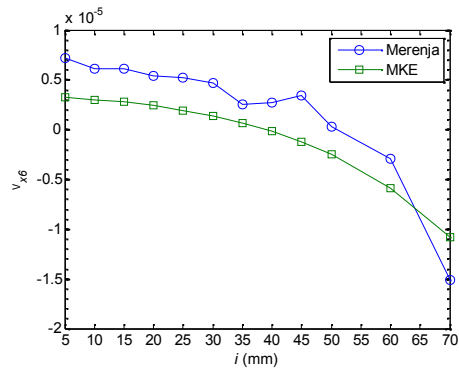
(*x*) 6
,
4.4(), , **4.4()**. ,
, 6 ,

,
5 mm *i*<64 mm
,
, 5 mm *i*<42 mm, **4.4()**.

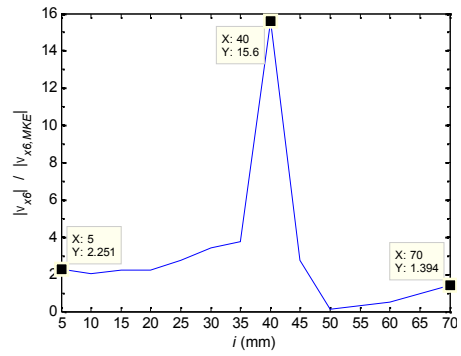
(*y*)
, **4.4()**,
6
, , , .
7
, **4.4()**.

5,9% *i*=30 mm, **4.4()**.
9 (*y*) ,
4.4() .

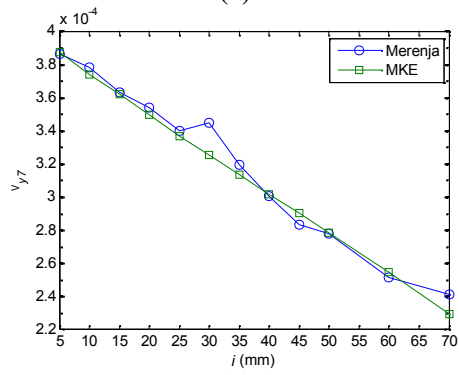
15,9% *i*=30 mm, **4.4()**.



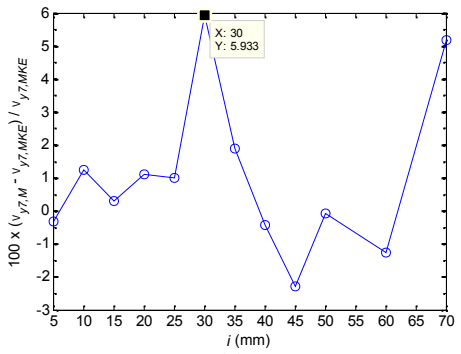
()



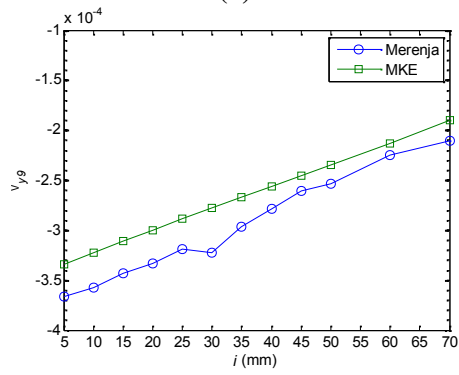
()



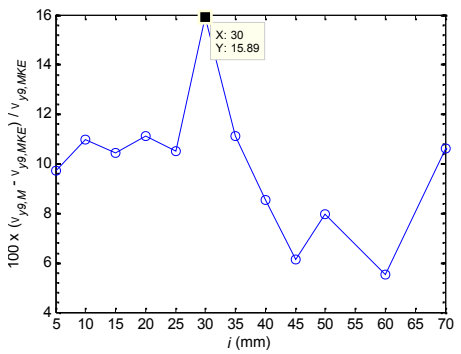
()



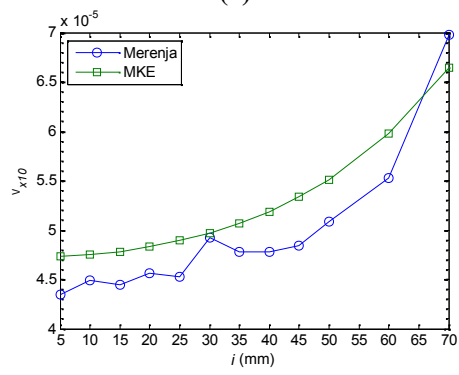
()



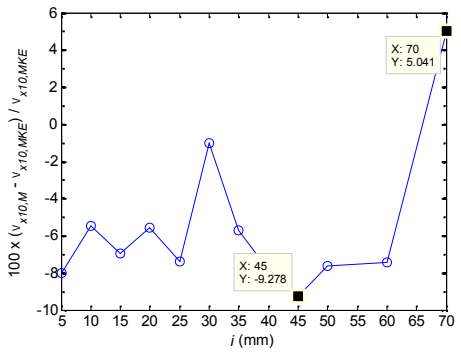
()



()



()



()

4.4:

(,) 6; (,)

7; (,)

9; (,)

10

(x) 10, 4.4 (),
 5 mm $i < 66$ mm.

$i < 66$ mm,

-9,3%, 5,0%.

13, 4.5 (),

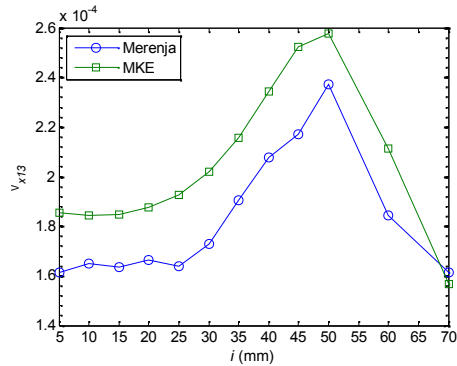
($i = 70$ mm),

-15,0%.

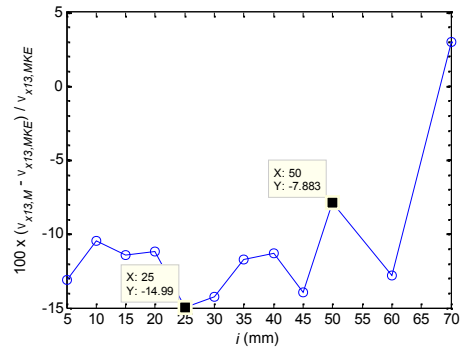
13 ($i = MM13 = 50$ mm)

-7,9%.

(
 19,3 $\mu\text{m/m}$ $i = 5$ mm 35,2 $\mu\text{m/m}$ $i = 45$ mm, $i = 70$ mm,
 -4,7 $\mu\text{m/m}$, 4.6)



4.5:



()

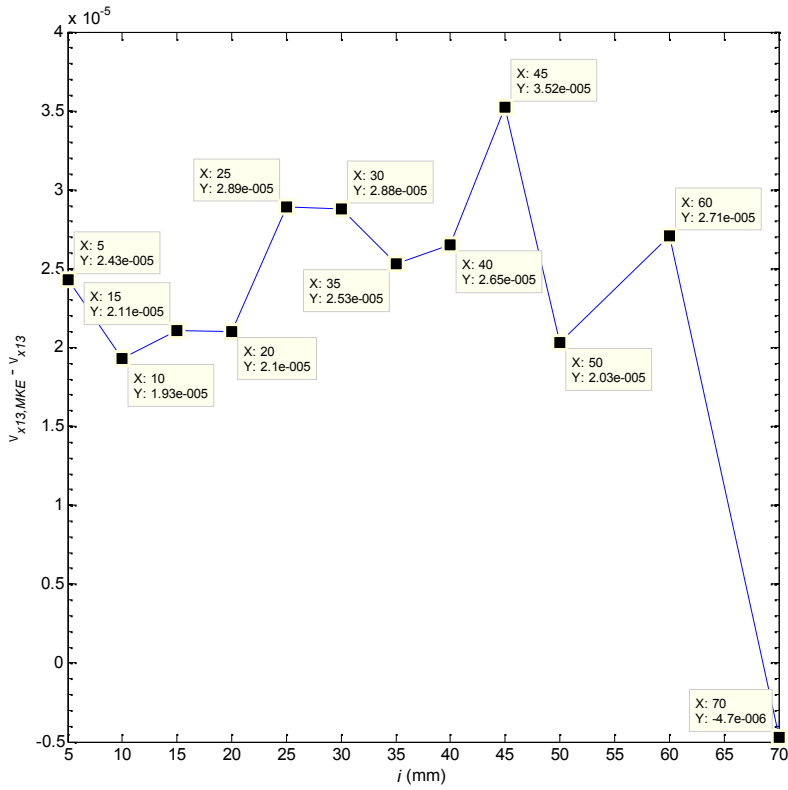
13

(y) 30

4.7 ().

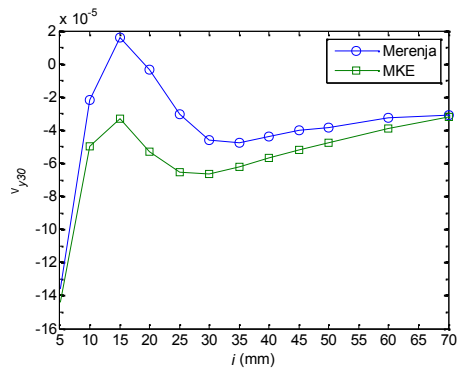
13 mm $i < 18$ mm, 4.7 ().

30 ($MM_{30}=10$ mm),
 4.7().
 30
 (x) 29 31,
 30, 2.3.

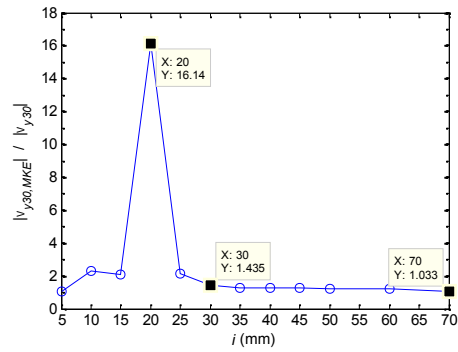


4.6:

13



4.7:



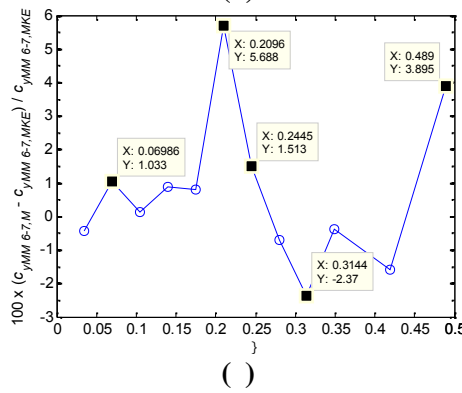
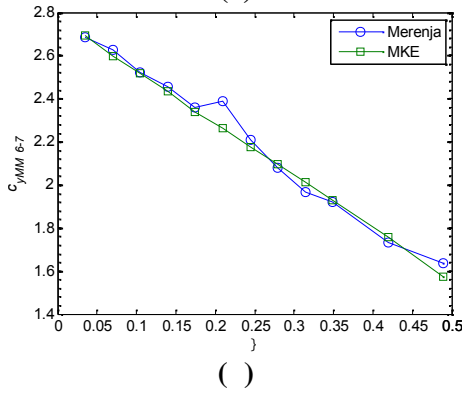
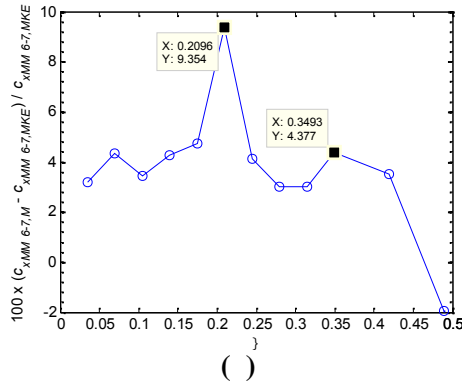
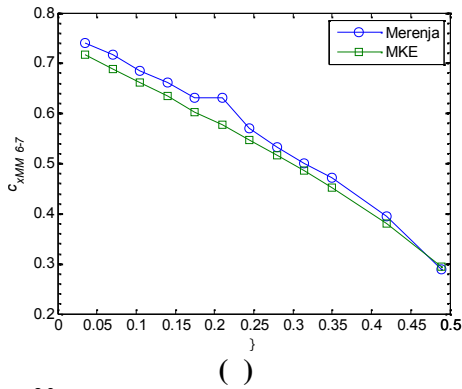
30

, 4.8(,),

C_{xMM6-7} C_{yMM6-7} =0,2096 ($i=30$ mm) 9,4% 5,7%,
 , 4.8(,).

C_{xMM6-7} C_{yMM6-7} 4,5%, , 3,9%, 4.8(,).

$i=30$ mm



4.8:

6 - 7:

(,) C_{xMM6-7} ; (,) C_{yMM6-7}

9 - 10

4.9(,).

, 4.9(,).

9 10,

$C_{xMM9-10}$ 31,9%

4.9().

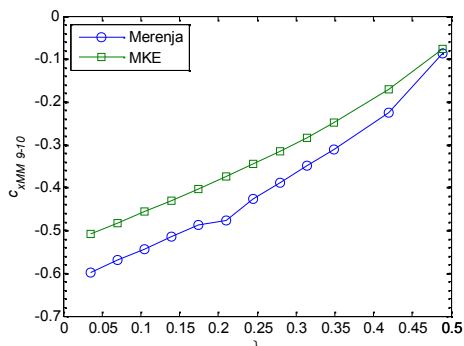
20%, 4.9().

$C_{xMM9-10}$ 17%,

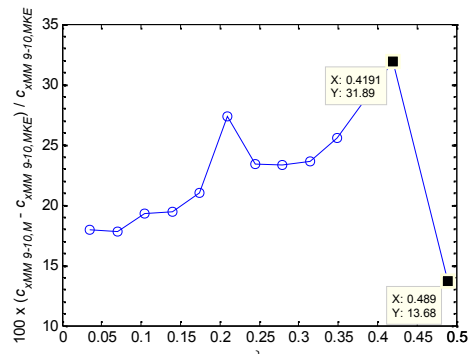
4.9() =0,2096 ($i=30$ mm).

$C_{xMM9-10}$

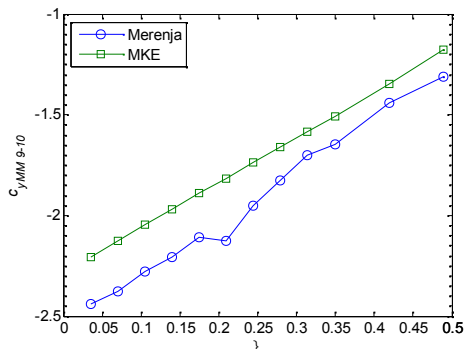
12,8%, 4.9().



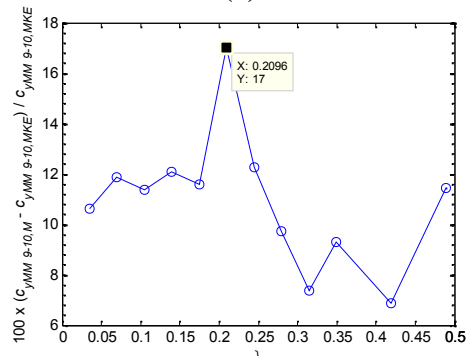
()



()



()



()

4.9:

9 - 10:

(,) $C_{xMM9-10}$; (,) $C_{yMM9-10}$

8

($\delta=5$ mm)

$i = \delta=5$ mm (=0,03493).

C_{xMM8}

4.10()

4.10(), 23,7%

=0,489 ($i=70$ mm).

11%.

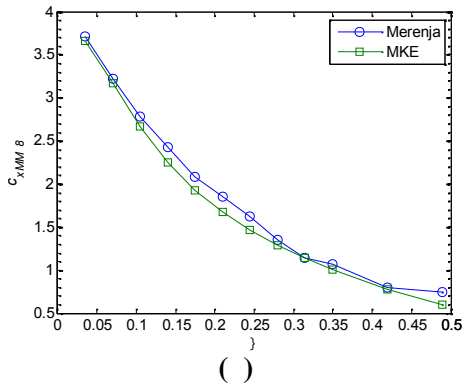
C_{xMM8} 1, 4.10()

, $C_{xMM8} > 2,5$,

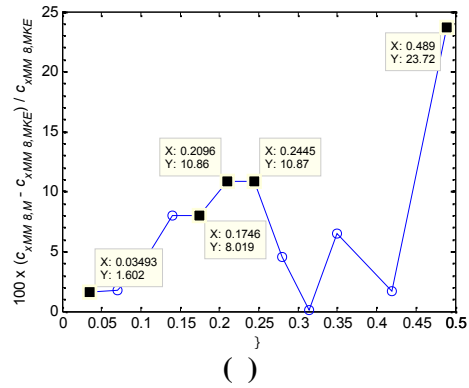
5%, 4.10()

8,

C_{xMM8} 1,6%, 4.10()



4.10:



8

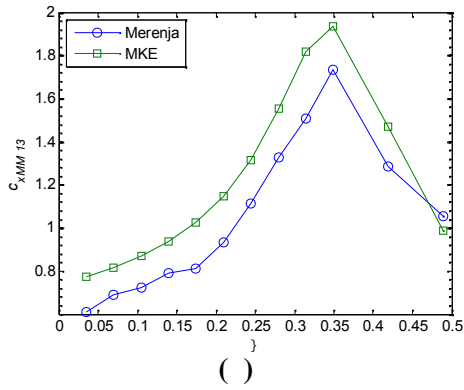
C_{xMM13} , 4.11()

13, 4.5()

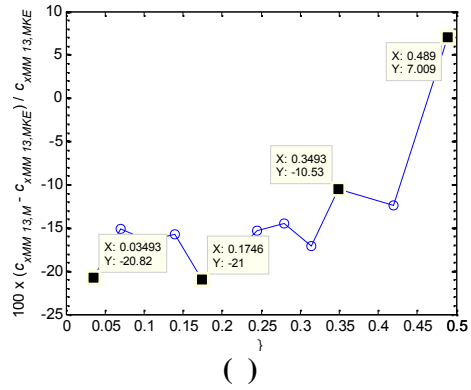
C_{xMM13}

$i=70$ mm,

4.11()



4.11:



C_x

13

C_{xMM13},

4.11() .

30

, , i = 30 = 50 mm,
= 0,3493 (i = 50 mm)

-10,5%

13.

13,

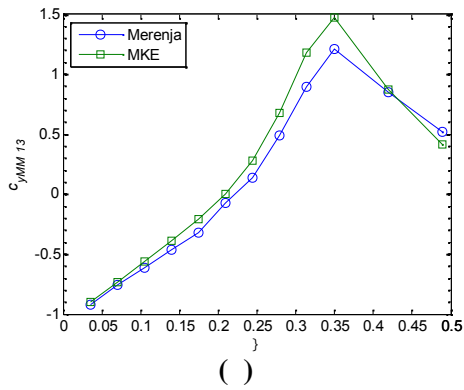
4.12() ,

12

14,

2.2,

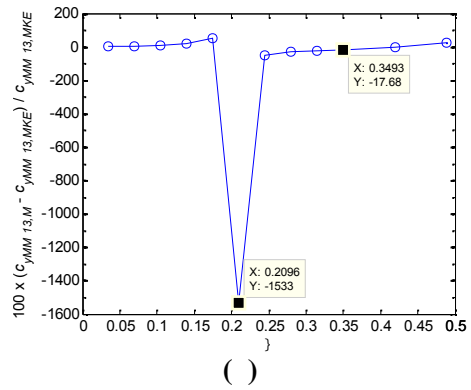
2.2() ,



4.12:

C_y

13



C_{xMM13} -17,7% (= 0,3493,

4.12() .

, i = 13 = 50 mm)

4.12()

13, 30

(y)

30

29 30, 2.2, 2.2()

C_{xMM30} , 4.13()

$i = 30 = 10 \text{ mm}$, $= 0,06986$, $4,7\%$, 4.13()

29 31,

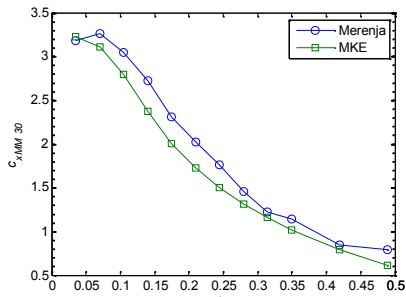
C_{yMM30} , 4.14(), $i = 30 = 10 \text{ mm}$,

$= 0,06986$, $33,3\%$, 4.14()

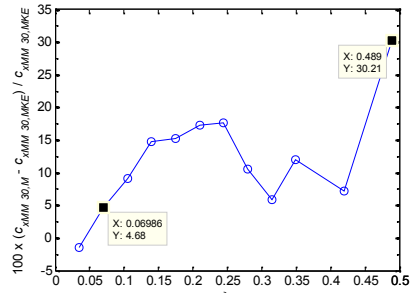
4.7.

C_{yMM30}

30,

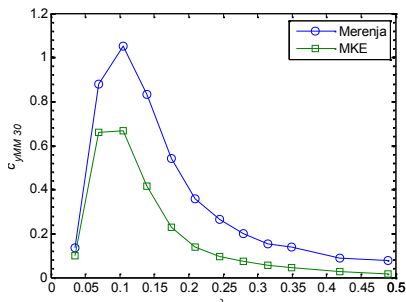


4.13:

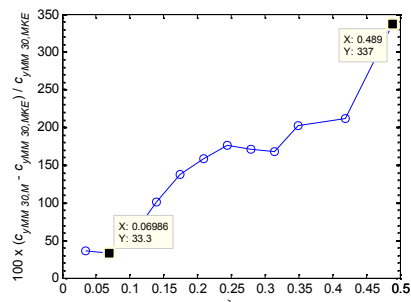


C_x

30



4.14:



C_y

30

: $E=21000 \text{ kN/cm}^2$ $\nu=0,3$.

4.2

6 - 7 ()

6 (-

),

, **4.15** (,).

4.16,

$=0,2096$ ($i=30$

mm).

6 (**4.4** ()).

$=0,2096$

c_x , **4.15** (),

21% $=0,03493$ ($i=5$ mm)

32,5%

$=0,2096$ ($i=30$ mm),

27,5%

$=0,2445$ ($i=35$ mm),

46,2% $=0,489$ ($i=70$ mm).

c_y , **4.15** (),

c_x , **4.15** ().

c_y 14,0%

$=0,03493$ ($i=5$ mm).

20%

,

$=0,2096$ ($i=30$ mm),

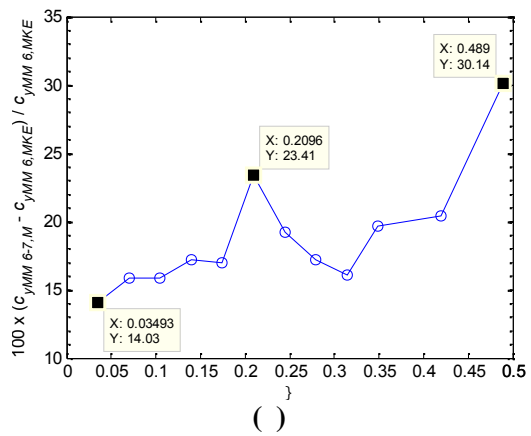
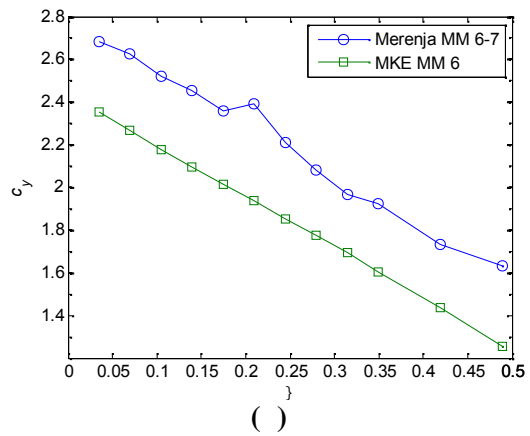
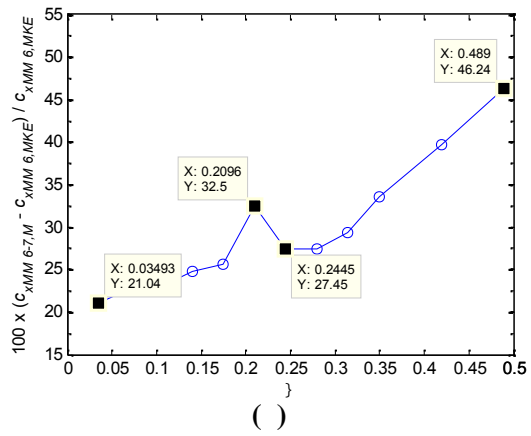
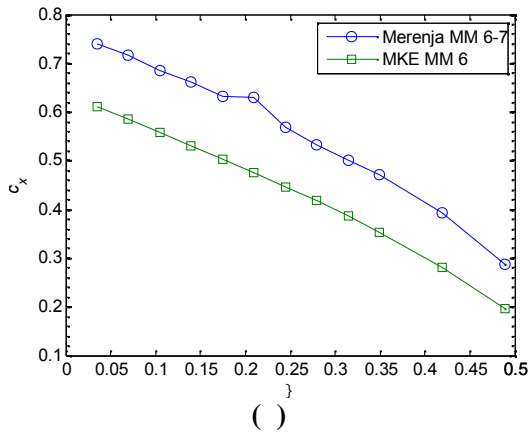
23,4%,

$=0,489$ ($i=70$ mm),

30,1%,

4.15 ().

, **4.15**.



4.15:

6 - 7

6: (,) c_x ; (,) c_y

6 - 7

7 (-

), 4.17(,),

c_x 10%

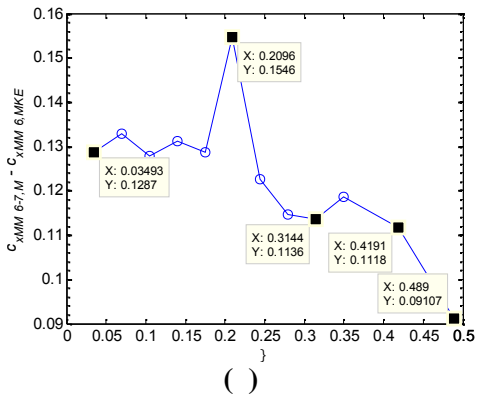
=0,489 ($i=70$ mm), 4.17().

19,3%

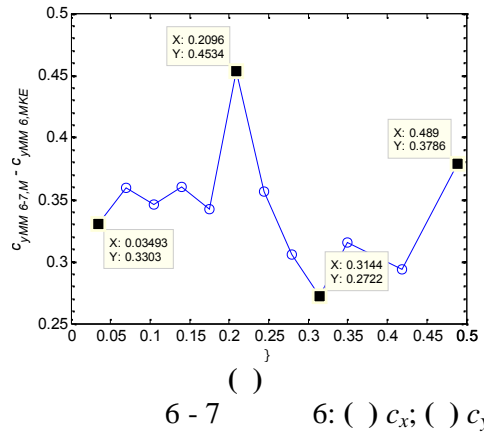
, 4.17(,).

c_y 4,5%

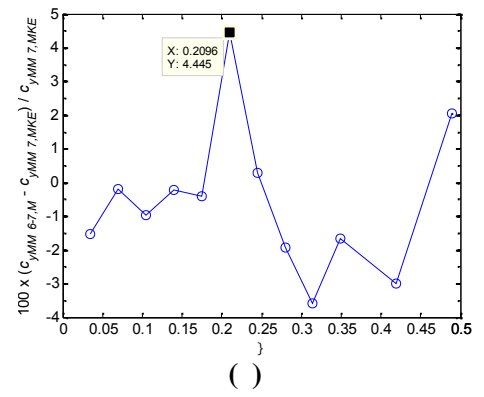
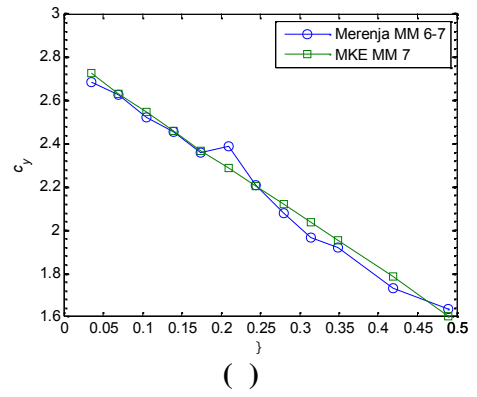
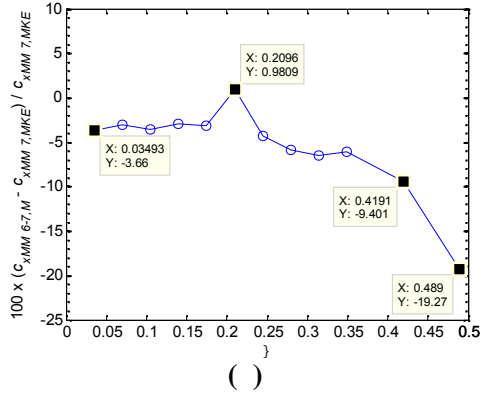
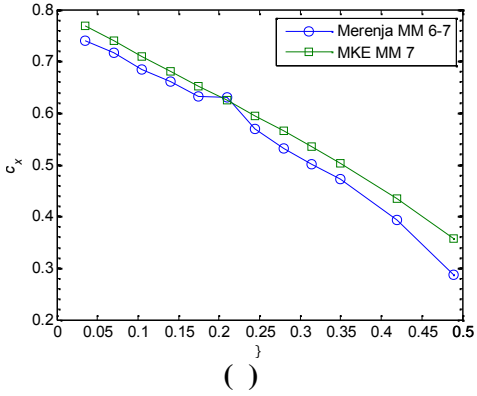
, 4.17().



4.16:



6 - 7 6: () c_x; () c_y



4.17:

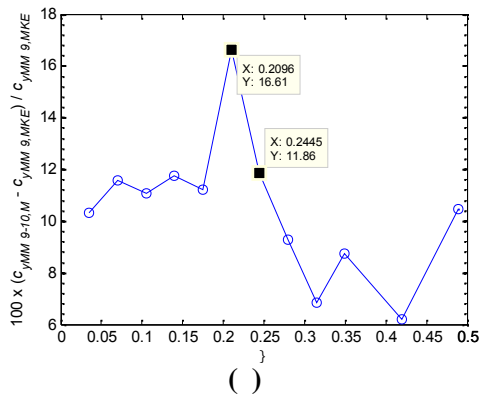
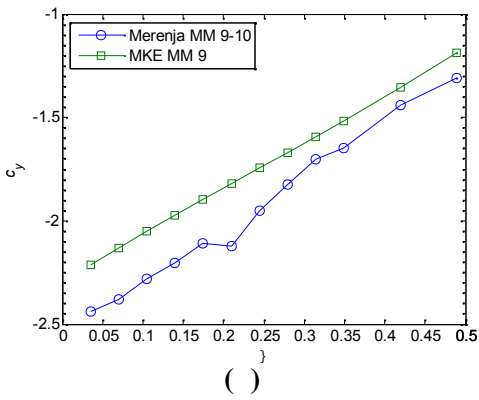
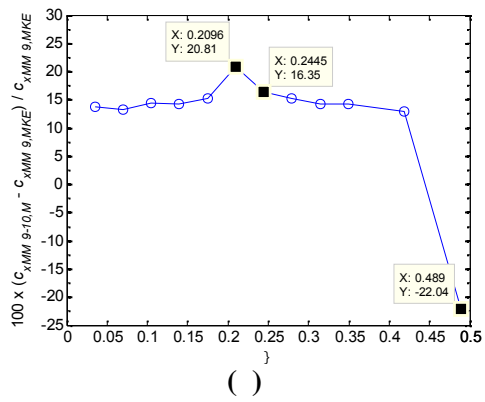
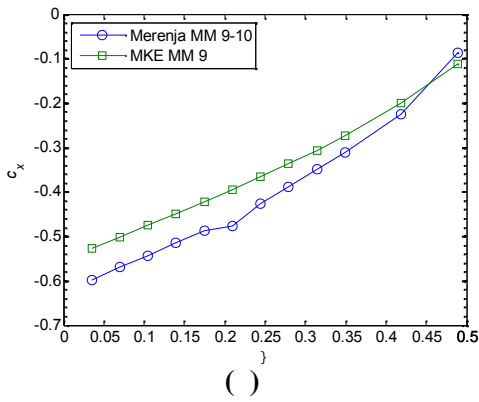
6 - 7 7: (,) c_x; (,) c_y

9 - 10

()

9 (-), 4.18(,).

c_x $> 0,4548$ ($i > 65,1$ mm), **4.18** (,),
 c_x $= 0,2096$ ($i = 30$ mm), **4.18** (,),
 c_x $= 0,489$ ($i = 70$ mm), $20,8\%$ $22,0\%$,
 c_y $16,6\%$
 $= 0,2096$ ($i = 30$ mm), **4.18** (,),
 $11,9\%$, **4.18** (,).



4.18:

9 - 10

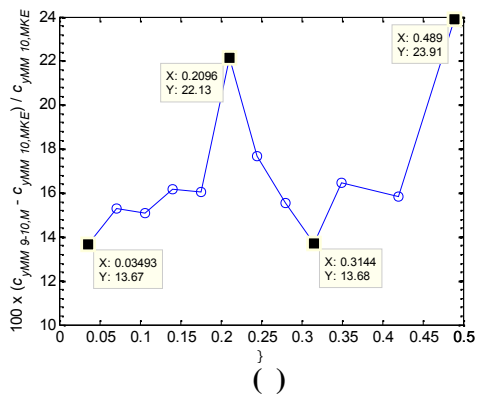
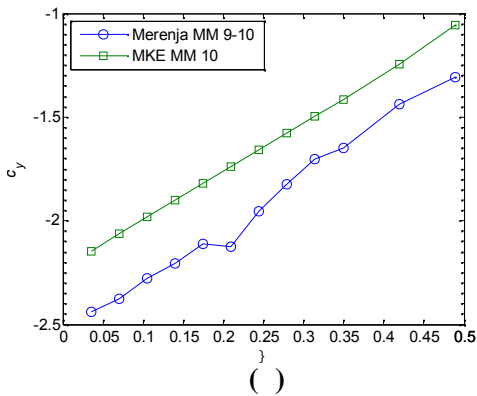
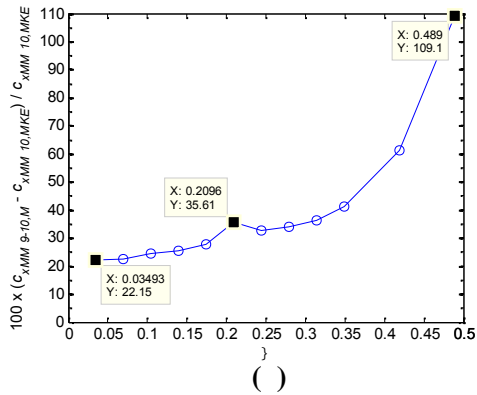
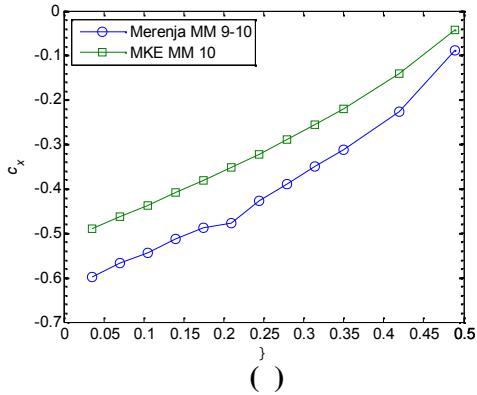
9: (,) c_x ; (,) c_y

9 - 10 ()

10 (-),

4.19 (,).

, **4.19** (,),



4.19:

9 - 10

10: $(,) c_x; (,) c_y$

4.20,

9 (4.4()).

=0,03493 ($i=5$ mm)

22,2% c_x ,

13,7% c_y ,

419(,).

(109,1% c_x ; 23,9% c_y)

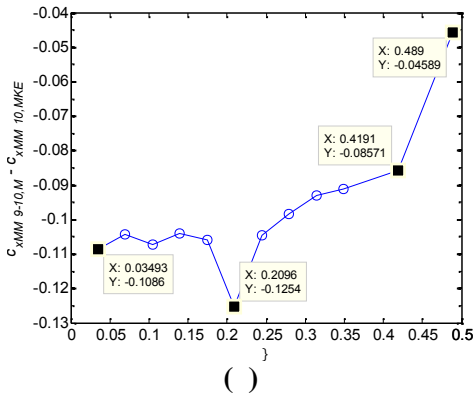
(=0,489,

$i=70$ mm), 419(,).

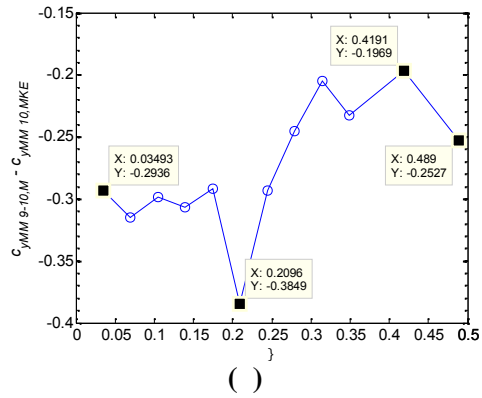
$c_x = 0,489$

- -0,1 0,

4.19().



4.20:



9 - 10 10: () c_x; () c_y

c_x 8,

4.21().

11%, =0,489 (i=70 mm) 23,8%, 4.21().

8 (i= 8=5 mm)

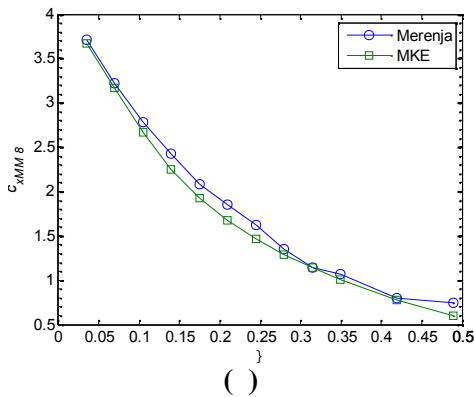
c_x

(: c_x=3,716; - : c_x=3,666),

1,4%, 4.21().

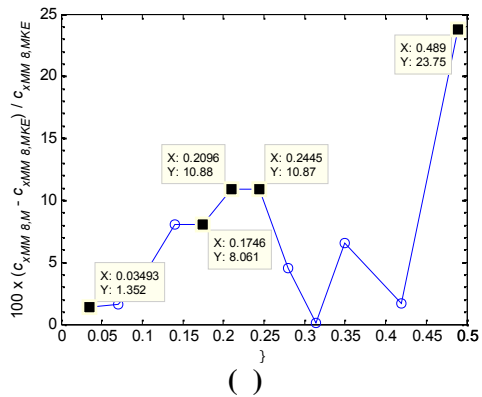
() 1,

4.21().



4.21:

8: ()



; ()

13

, 4.22(,),

(=0,3493, i= 13=50 mm),

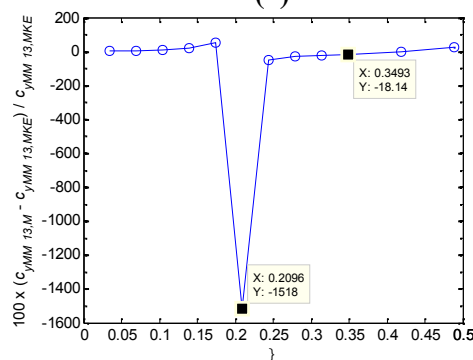
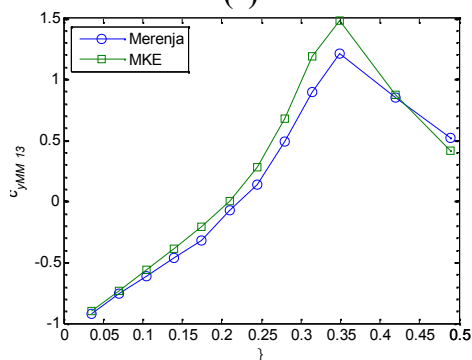
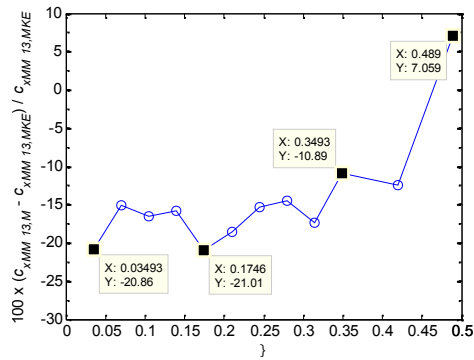
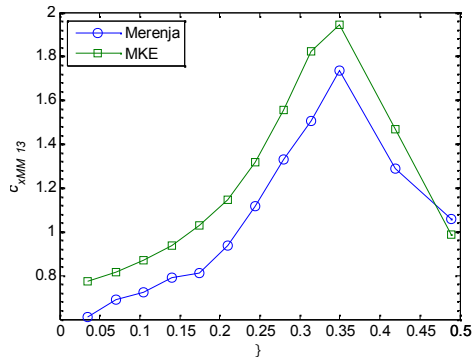
c_x

4.22()

=0,489 ($i=70$ mm).

c_y

4.22()



4.22:

13:

(,) c_x ; (,) c_y

($i=70$ mm),

4.22()

4.22(,)

: -10,9% c_x -18,1% c_y , 4.22(,)

4.1,

13 (

x)

(y)

(12 14).

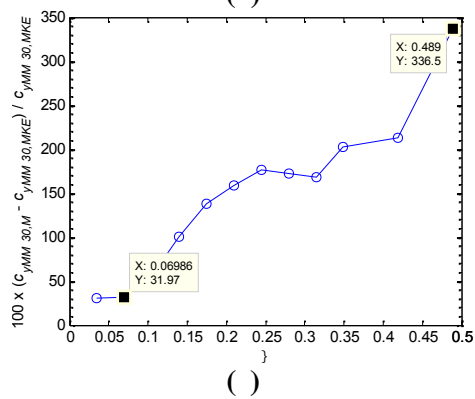
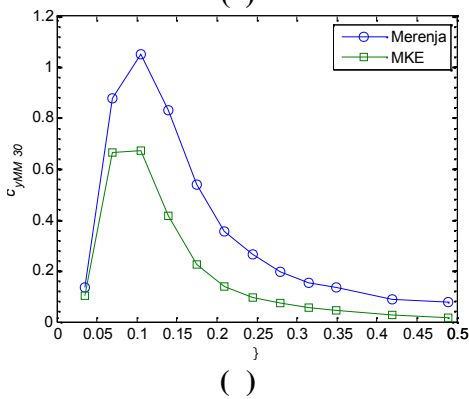
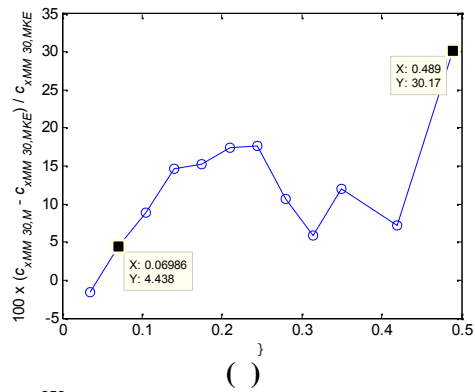
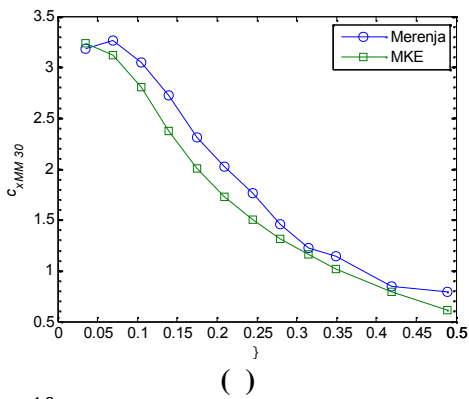
30

$i = 30 = 10 \text{ mm}$

(=0,06986).

13,

, **4.23**(,),



4.23:

30:

(,) c_x ; (,) c_y

, **4.23**(,),

=0,03493 ($i=5 \text{ mm}$),

c_x

, **4.23**().

c_x c_y

4,4% 32,0%, **4.23**(,).

c_x

($c_x > 2,5$), **4.23**(,).

c_y

c_y

4.1.

4.1 4.2.

(6 - 7,

8, 9 - 10),

(13 30),

•

c_x

5%

6 - 7, 8 30,

•

c_x

11%

13 (

x),

(12 14);

y

•

c_x

9 - 10

17,9% 13,7%,

9,

;

4.1:

c_x						$\frac{E - MKE_D}{MKE_D} \times 100$	$\frac{E - MKE_N}{MKE_N} \times 100$
(E)							
(MKE _D)		(MKE _N)					
MM	c_x	MM	c_x	MM	c_x	(%)	(%)
6 - 7*	0,740	6 - 7*	0,718	7*	0,769	3,2	-3,7
8*	3,716	8*	3,657	8*	3,666	1,6	1,4
9 - 10*	-0,599	9 - 10*	-0,508	9*	-0,527	17,9	13,7
13**	1,733	13**	1,937	13**	1,945	-10,5	-10,9
30**	3,260	30**	3,114	30**	3,121	4,7	4,4

*
**

•

c_y

6 - 7

1,5,

,

,

-

;

•

9 - 10

c_y

11%,

-

;

•

c_y

13

-17,7%

-18,1%

,

y

;

•

c_y

30 (33,3% 32,0%)

,

,

x

(29 31).

4.2:

c_y						$\frac{E - MKE_D}{MKE_D} \times 100$	$\frac{E - MKE_N}{MKE_N} \times 100$
(E)	(MKE _D)		(MKE _N)				
MM	c_y	MM	c_y	MM	c_y	(%)	(%)
6 - 7*	2,684	6 - 7*	2,695	7*	2,726	-0,4	-1,5
9 - 10*	-2,441	9 - 10*	-2,207	9*	-2,213	10,6	10,3
13**	1,211	13**	1,471	13**	1,479	-17,7	-18,1
30**	0,878	30**	0,659	30**	0,665	33,3	32,0

*
**

4.1 4.2)

·
 c_x

9 - 10,

(c_x 10 c_y 9),

10 (c_x) 9 (c_y)

17,9%.

c_x

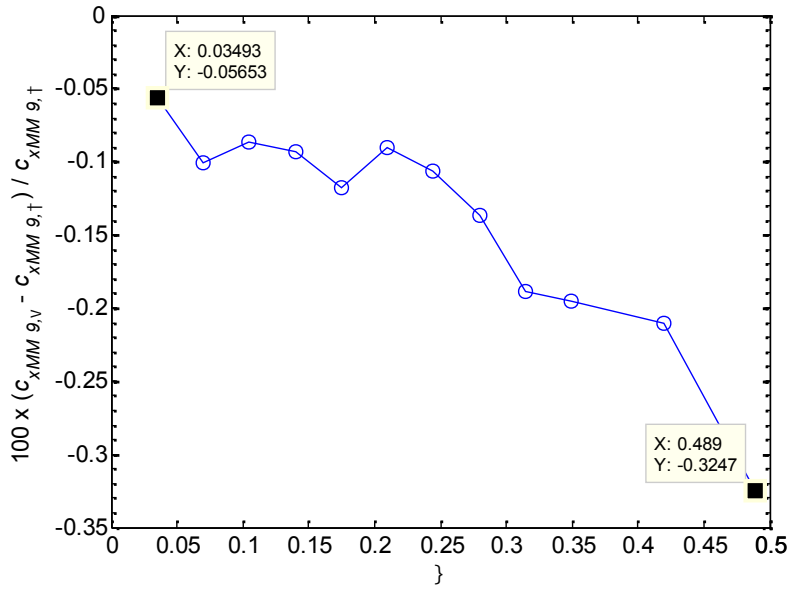
9 13,7%.

4,2%.

c_x c_x c_y 9

9,

3,3%, **4.24.**



4.24: c_x

4.3

2.,

-
-

;

-
-

;

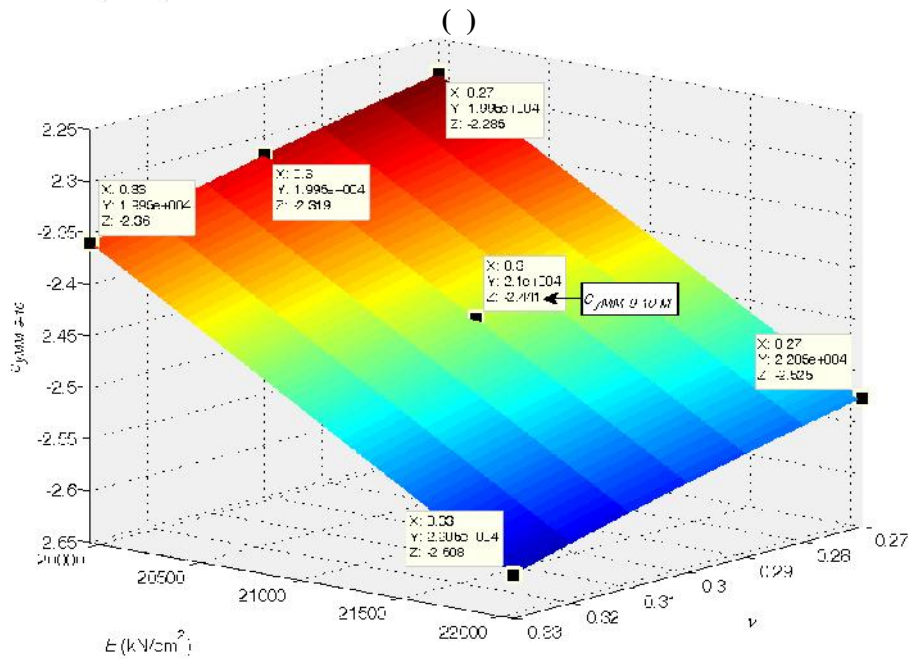
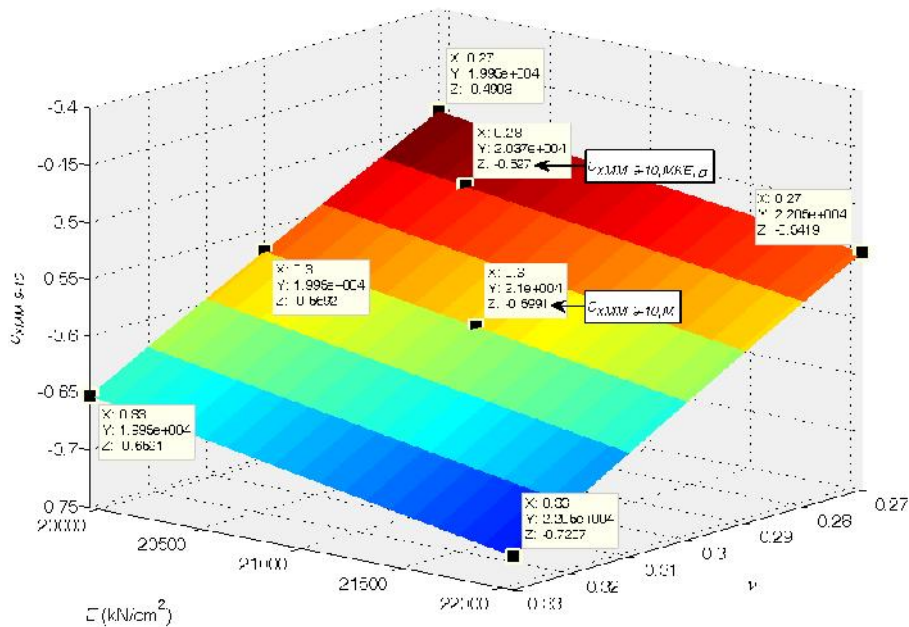
$$E=21000 \text{ kN/cm}^2 = 0,3,$$

[15]

() ()

: / $\pm 0,05\%$; / $\pm 0,10\%$.

$E=21000 \text{ kN/cm}^2$ $\nu=0,3$, 4.25.



4.25:

9 - 10

: () c_x ; () c_y

4.3,

$E=21000 \text{ kN/cm}^2$ $=0,3$ ($|c_{xMM \ 9-10,M}|=0,599$;
 $|c_{yMM \ 9-10,M}|=2,441$, 4.25),

$$pro(c_{x/y}) = \frac{|c_{x/y}^{E,\xi}| - |c_{x/y,M}|}{|c_{x/y,M}|} \times 100 (\%), \quad \dots(4.1)$$

4.4, (c_x)

4.3: 9 - 10

	$E \text{ (kN/cm}^2\text{)}$			
	19950		22050	
	c_x	c_y	c_x	c_y
0,27	-0,490	-2,285	-0,542	-2,525
0,33	-0,652	-2,360	-0,721	-2,608

4.4: 9 - 10

	$E \text{ (kN/cm}^2\text{)}$			
	19950		22050	
	c_x	c_y	c_x	c_y
0,27	-18,2%	-6,4%	-9,5%	3,4%
0,33	8,9%	-3,3%	20,3%	6,8%

4.25(), $c_{xMM9-10,M} = -0,527$,
 $E=21000 \text{ kN/cm}^2$
 $=0,3$,

$E=20370 \text{ kN/cm}^2$ $=0,28$.

$$=0,3 \quad E^*=19950 \text{ kN/cm}^2$$

$$c_{xMM9-10,M}=-0,569, \quad \mathbf{4.25()}.$$

$$pro(c_{xMM9-10}) = \frac{c_{xMM9-10,M}^{E^*} - c_{xMM9-10,MKE,\uparrow}}{c_{xMM9-10,MKE,\uparrow}} \times 100 =$$

$$= \frac{-0,569 - (-0,527)}{-0,527} \times 100 = 8,0 \%, \quad \dots(4.2)$$

$$E=21000 \text{ kN/cm}^2 \quad 13,7\%,$$

4.1.

$$c_{yMM9-10,M} = -2,213,$$

$$E=21000 \text{ kN/cm}^2 \quad =0,3,$$

, **4.25()**, **4.4.**

$$E^*=19950 \text{ kN/cm}^2, \quad c_{yMM9-10,M}=-2,319, \quad \mathbf{4.25()}.$$

$$pro(c_{yMM9-10}) = \frac{c_{yMM9-10,M}^{E^*} - c_{yMM9-10,MKE,\uparrow}}{c_{yMM9-10,MKE,\uparrow}} \times 100 =$$

$$= \frac{-2,319 - (-2,213)}{-2,213} \times 100 = 4,8 \%, \quad \dots(4.3)$$

$$E=21000 \text{ kN/cm}^2 \quad 10,3\%,$$

4.2.

4.1 4.2.

4.4

-

4.1, 4.2 4.3,

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[9]

EN 15011 [5].

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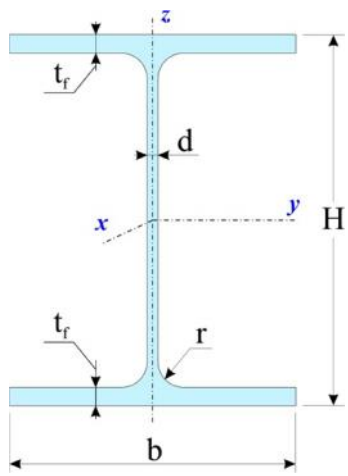
5. |

(IPE)
 [DIN 1025 (Blatt 5)], 300 mm 360 mm (IPE 300 IPE
 360), IPB HEA 360,
 5.1, 5.1. IPE 300 IPE 360
 [9,10]
 [5], HEA 360
 (2)

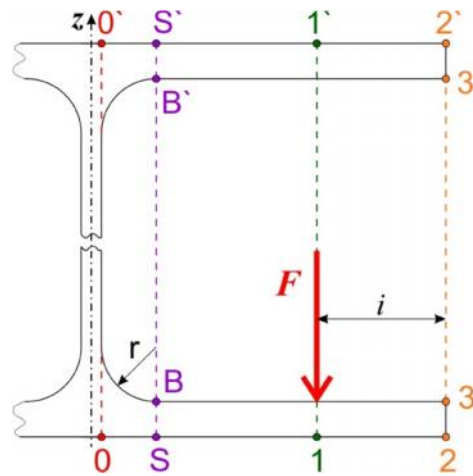
DIN 1025 (Blatt 5), 2.1.

(3).
 10 kN , 30 mm

5.2, 5.3 5.4.



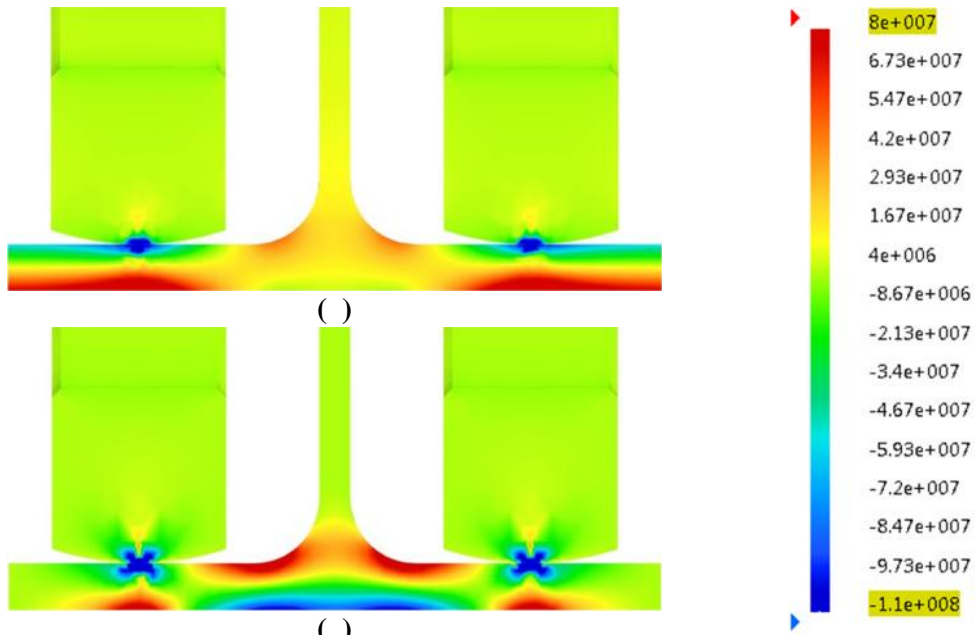
()
 5.1:



()
 ; ()

5.1:

		IPE 300	IPE 360	HE - A 360
(mm)	H	300	360	350
(mm)	b	150	170	300
(mm)	t_f	10,7	12,7	17,5
(mm)	s	7,1	8,0	10
(mm)	r	15	18	27

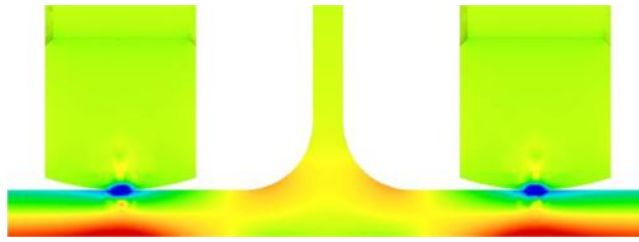


5.2: IPE 300 -

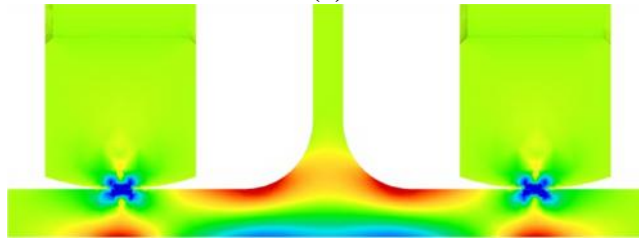
$i=30$ mm:

(a) $x_{,tot}; () y_{,tot}$

(0 -
; B -
/ ; S - B ; 1 -
; 2
3 -),
(0', B', S', 1', 2' 3'), 2.1.
(x) (y)
8 , 5.2, 5.3,..., 5.7, 5.5, 5.6,
5.14, 5.15, 5.23 5.24.



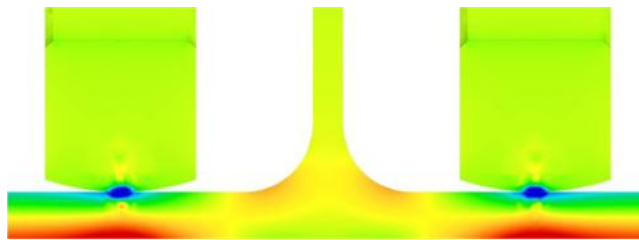
()



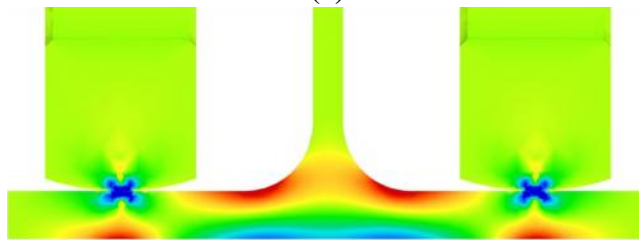
()

5.3: IPE 360 -

(a) $x_{,tot}; () y_{,tot}$



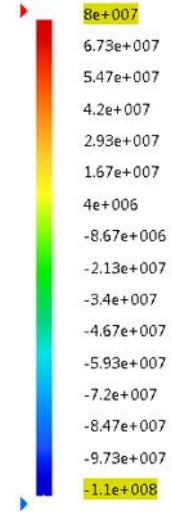
()



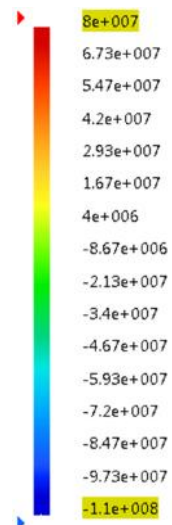
()

5.4: HEA 360 -

(a) $x_{,tot}; () y_{,tot}$



$i=30$ mm:



$i=30$ mm:

5.9, 5.16 - 5.18, 5.25 - 5.27,

3.2).

5.7 -

(2.19),

5.10 - 5.13, 5.19 - 5.22, 5.28 - 5.31.

5.2: IPE 300 -

(x)

	<i>i</i> (mm)							
	5	10	15	20	25	30	40	50
	x (kN/cm ²)*							
0	-0,97	-0,74	-0,50	-0,25	0,03	0,33	1,09	2,25
0'	-1,50	-1,50	-1,50	-1,50	-1,50	-1,50	-1,49	-1,49
S	-2,20	-1,69	-1,20	-0,59	0,06	0,82	2,94	7,63
S'	-1,48	-1,48	-1,48	-1,48	-1,48	-1,48	-1,47	-1,47
B	6,26	5,70	5,17	4,57	3,90	3,13	1,02	-2,91
B'	-1,28	-1,28	-1,28	-1,28	-1,28	-1,28	-1,28	-1,28
1	26,43	22,05	19,56	17,89	16,76	16,30	14,14	12,98
1'	-1,41	-1,41	-1,42	-1,42	-1,42	-1,43	-1,44	-1,46
2	25,82	19,60	15,20	12,16	9,81	7,96	5,20	3,33
2'	-1,41	-1,41	-1,41	-1,40	-1,40	-1,40	-1,40	-1,40
3	-20,05	-15,85	-12,43	-9,59	-7,42	-5,64	-2,97	-1,10
3'	-1,22	-1,21	-1,21	-1,21	-1,21	-1,21	-1,21	-1,21

*

5.3: IPE 300 -

(y)

	<i>i</i> (mm)							
	5	10	15	20	25	30	40	50
	y (kN/cm ²)*							
0	-12,00	-11,36	-10,76	-10,19	-9,64	-9,11	-8,04	-6,77
0'	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
S	-17,97	-16,47	-15,07	-13,56	-12,07	-10,50	-6,85	0,22
S'	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
B	20,10	18,36	16,83	15,21	13,59	11,86	7,70	2,82
B'	0,04	0,04	0,04	0,03	0,04	0,04	0,04	0,04
1	4,07	8,43	10,23	11,03	11,21	11,66	10,99	9,73
1'	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01
2	-0,16	-0,15	-0,07	-0,04	-0,03	-0,02	-0,01	0,00
2'	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	0,94	0,18	0,05	0,03	0,02	0,01	0,01	0,00
3'	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

*

5.4: IPE 360 -

(x)

	<i>i</i> (mm)							
	5	10	15	20	25	30	40	50
	x (kN/cm ²)*							
0	-0,75	-0,60	-0,46	-0,30	-0,13	0,05	0,48	1,06
0'	-0,93	-0,92	-0,92	-0,92	-0,92	-0,92	-0,92	-0,92
S	-1,45	-1,11	-0,78	-0,42	0,00	0,28	1,39	3,84
S'	-0,91	-0,91	-0,91	-0,91	-0,91	-0,91	-0,91	-0,90
B	4,16	3,82	3,46	3,08	2,68	2,22	1,08	-0,72
B'	-0,78	-0,78	-0,78	-0,78	-0,78	-0,78	-0,78	-0,77
1	19,28	16,21	14,43	13,28	12,30	11,66	10,57	9,60
1'	-0,87	-0,87	-0,87	-0,87	-0,87	-0,88	-0,88	-0,89
2	18,80	14,79	11,71	9,48	7,78	6,43	4,41	2,97
2'	-0,87	-0,86	-0,86	-0,86	-0,86	-0,86	-0,86	-0,86
3	-16,16	-12,36	-9,76	-7,82	-6,28	-5,01	-3,07	-1,66
3'	-0,74	-0,73	-0,73	-0,73	-0,73	-0,73	-0,73	-0,73

*

5.5: IPE 360 -

(y)

	<i>i</i> (mm)							
	5	10	15	20	25	30	40	50
	y (kN/cm ²)*							
0	-8,48	-8,08	-7,70	-7,34	-6,99	-6,65	-5,99	-5,29
0'	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
S	-12,52	-11,53	-10,60	-9,66	-8,68	-7,98	-5,90	-2,26
S'	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
B	14,08	13,03	12,01	10,97	9,94	8,87	6,50	3,45
B'	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
1	2,34	5,44	6,82	7,57	7,77	8,04	7,94	7,36
1'	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01
2	0,08	-0,02	-0,02	-0,01	0,00	0,00	0,00	0,00
2'	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	1,90	0,19	0,06	0,04	0,02	0,02	0,01	0,00
3'	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

*

5.6: HEA 360 -

(x)

	i (mm)							
	5	10	15	20	25	30	40	50
	x (kN/cm ²)*							
0	-0,51	-0,47	-0,44	-0,40	-0,36	-0,32	-0,24	-0,15
0'	-0,50	-0,50	-0,49	-0,49	-0,49	-0,49	-0,49	-0,49
S	-1,19	-1,11	-1,02	-0,93	-0,84	-0,75	-0,56	-0,34
S'	-0,48	-0,48	-0,48	-0,48	-0,48	-0,48	-0,48	-0,48
B	2,43	2,34	2,25	2,16	2,06	1,97	1,77	1,55
B'	-0,36	-0,36	-0,36	-0,36	-0,36	-0,36	-0,35	-0,35
1	12,26	10,51	9,45	8,83	8,20	7,88	7,25	6,79
1'	-0,42	-0,42	-0,42	-0,42	-0,42	-0,42	-0,42	-0,43
2	11,94	10,21	8,70	7,48	6,52	5,74	4,54	3,63
2'	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41	-0,41
3	-11,96	-9,11	-7,60	-6,55	-5,72	-5,02	-3,90	-3,04
3'	-0,30	-0,30	-0,30	-0,30	-0,30	-0,30	-0,30	-0,30

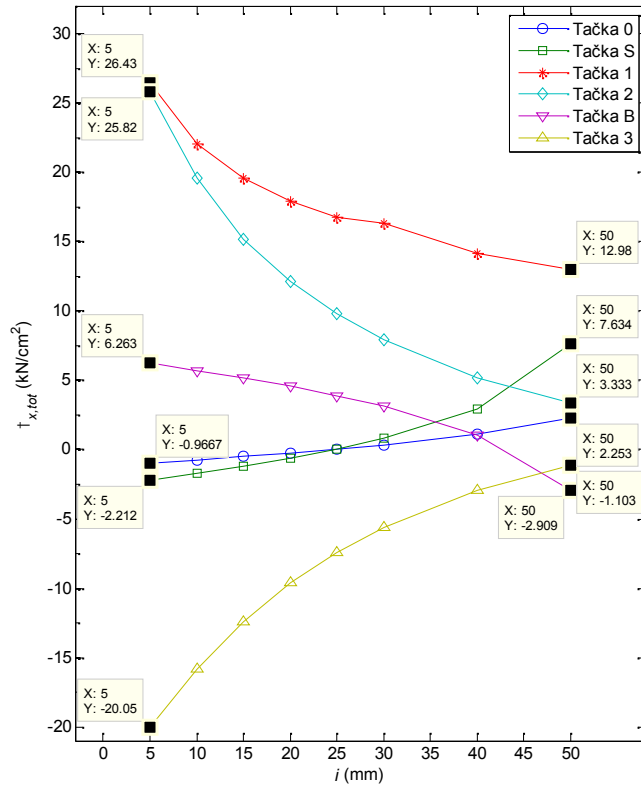
*

5.7: HEA 360 -

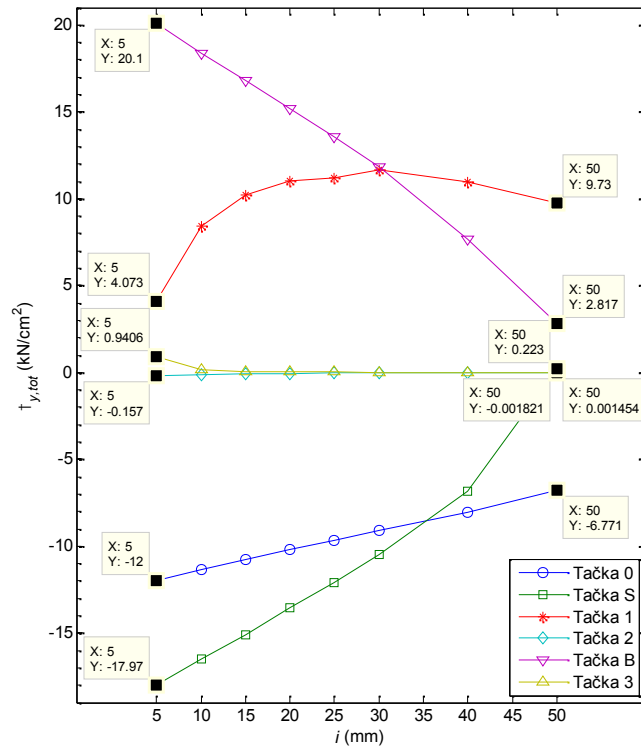
(y)

	i (mm)							
	5	10	15	20	25	30	40	50
	y (kN/cm ²)*							
0	-4,32	-4,21	-4,11	-4,01	-3,91	-3,81	-3,63	-3,46
0'	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
S	-7,13	-6,87	-6,61	-6,35	-6,09	-5,84	-5,33	-4,82
S'	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
B	7,94	7,65	7,36	7,07	6,80	6,52	5,97	5,41
B'	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
1	0,62	2,11	3,10	3,75	4,05	4,39	4,71	4,85
1'	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	0,00	-0,06	-0,05	-0,03	-0,02	-0,01	-0,01	0,00
2'	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	1,26	0,24	0,04	0,02	0,01	0,01	0,01	0,00
3'	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00

*



()



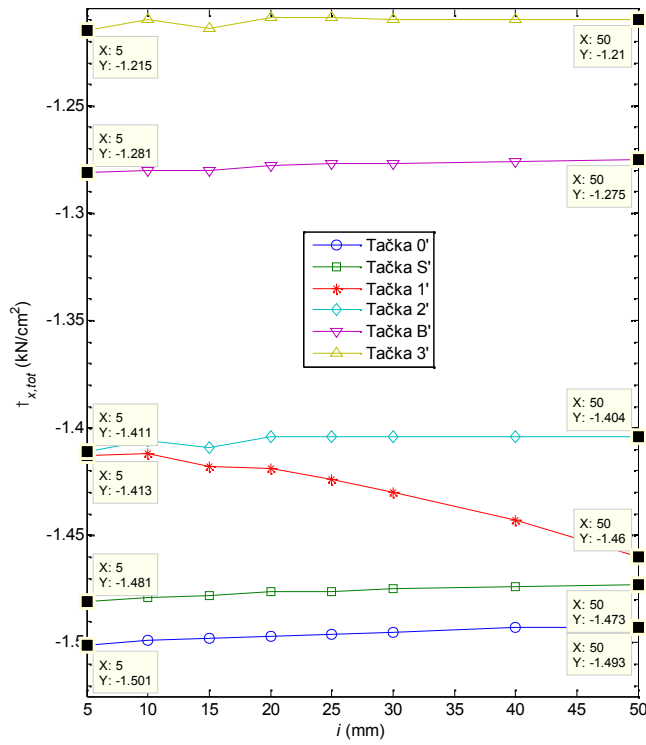
()

5.5: IPE 300 -

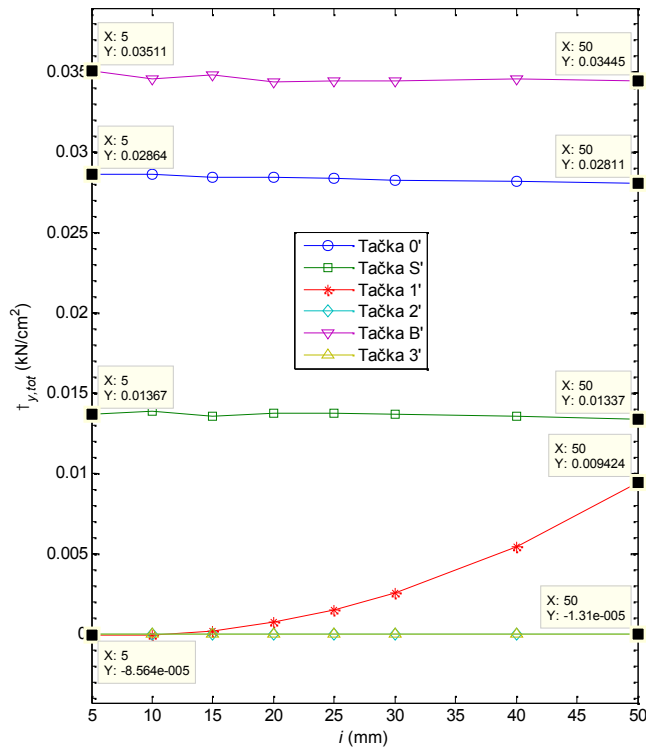
()

; ()

:



()



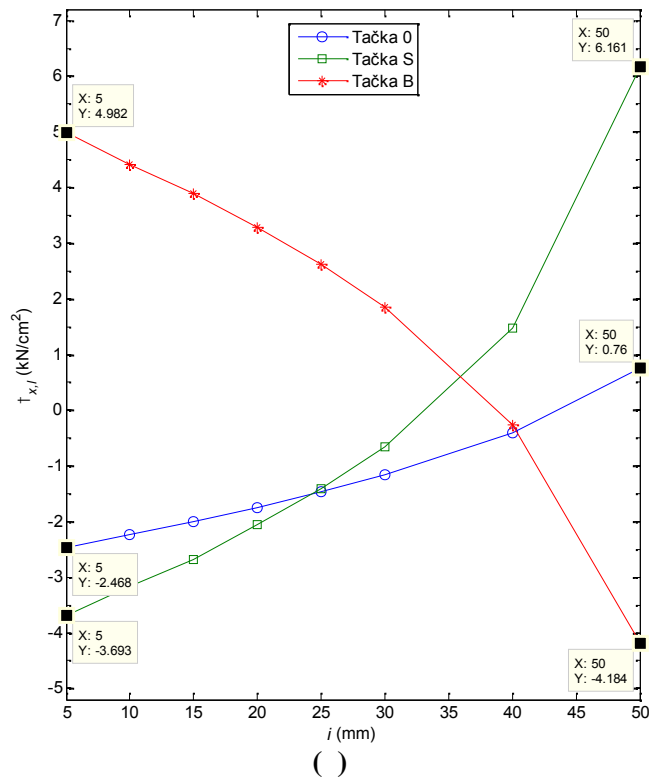
()

5.6: IPE 300 -

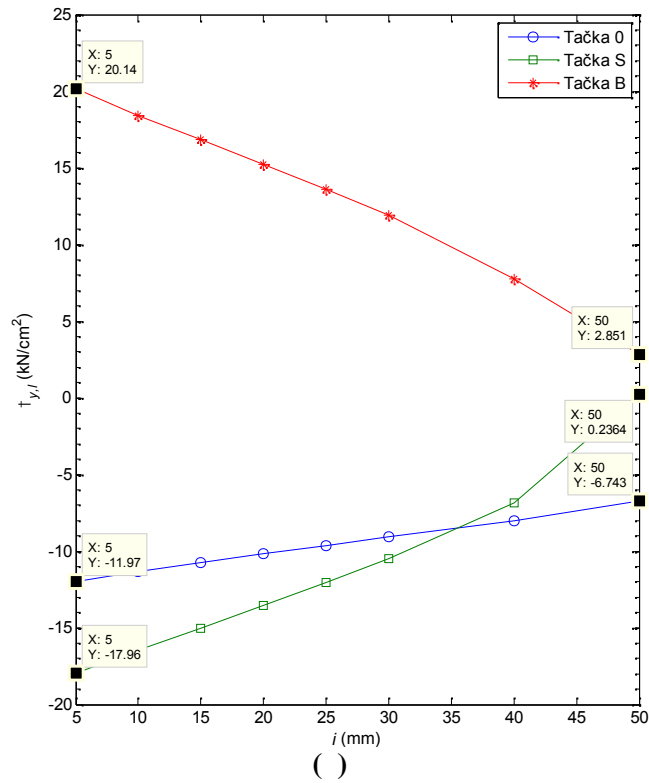
()

; ()

:



()



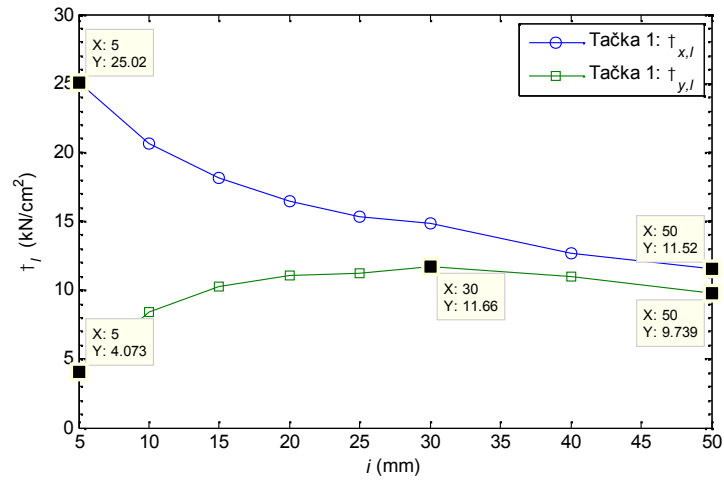
()

5.7: IPE 300 -

()

; ()

/ :

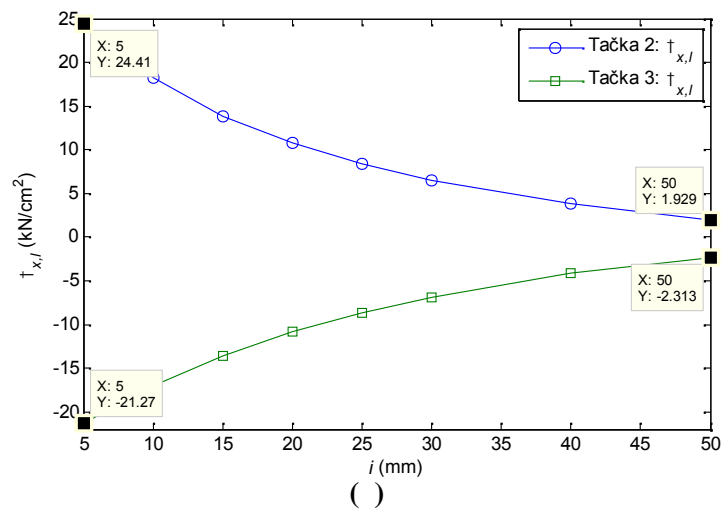


5.8: IPE 300 -

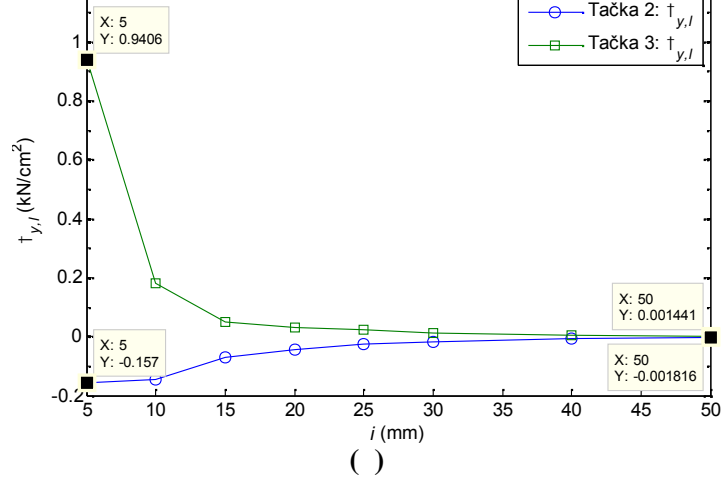
1: ()

;

()



()

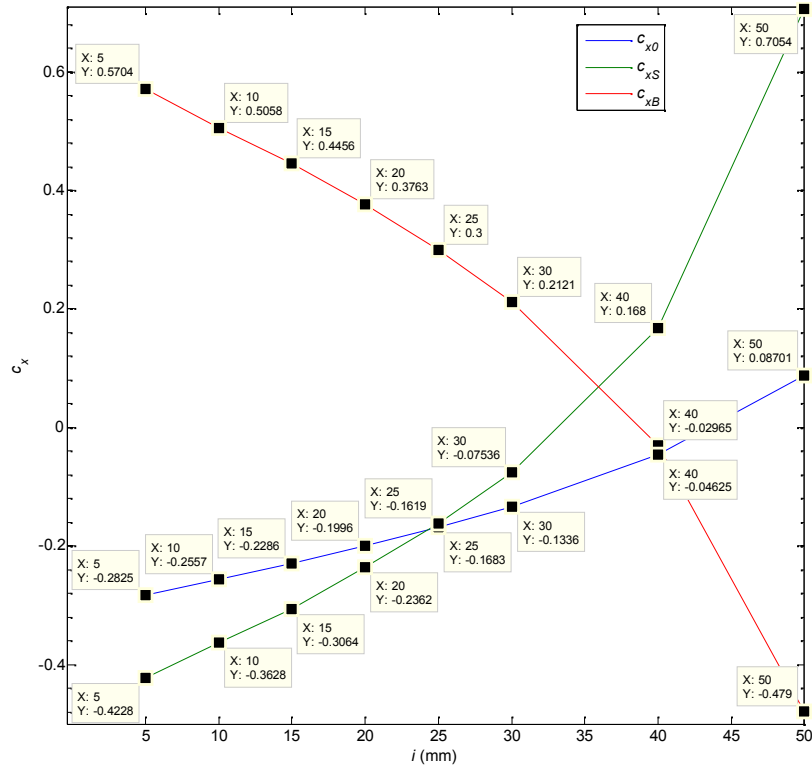


5.9: IPE 300 -

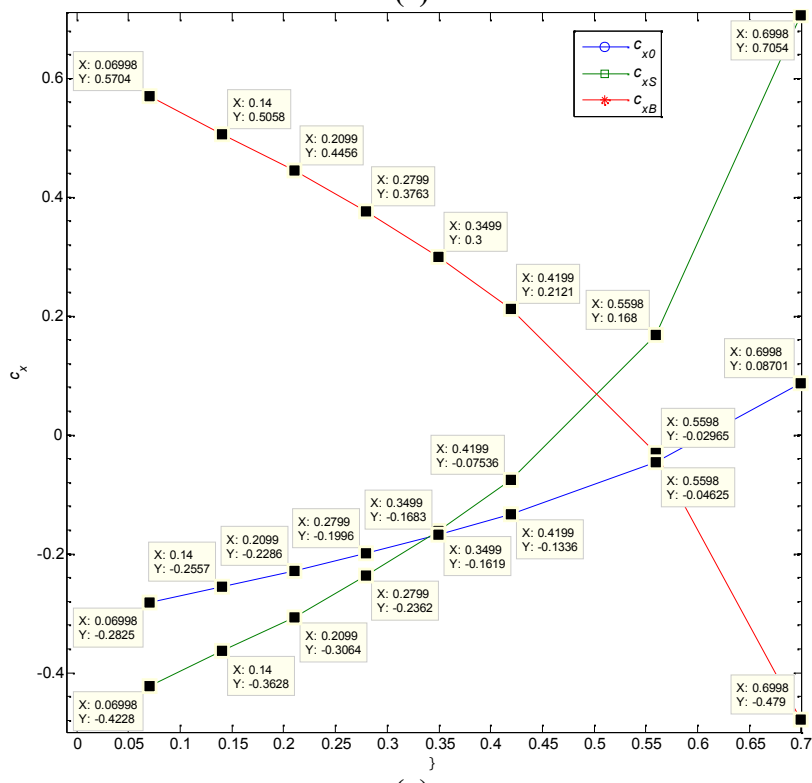
; ()

:

()



()



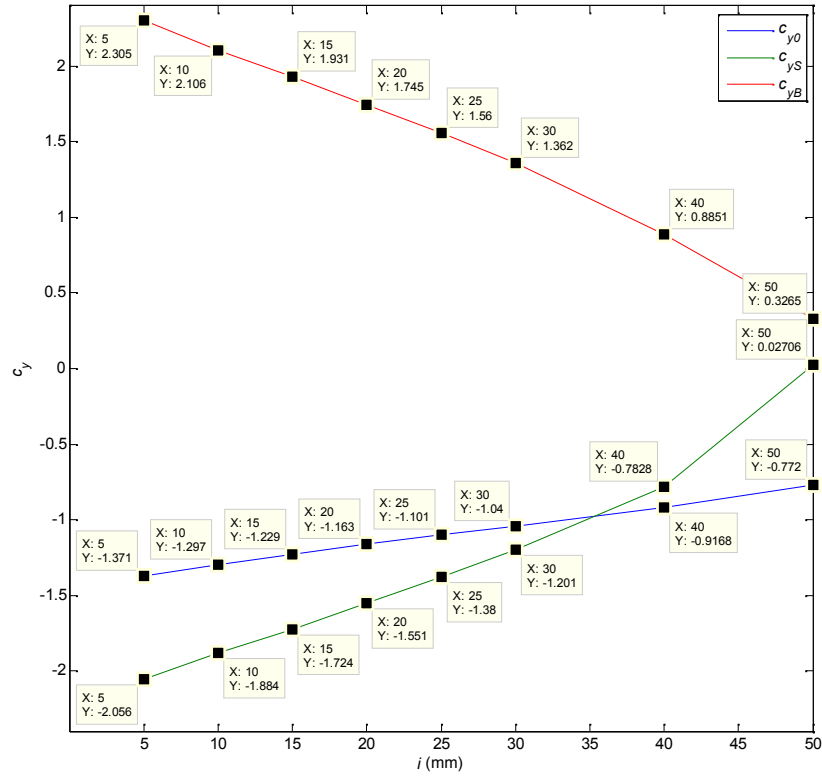
()

5.10: IPE 300 -

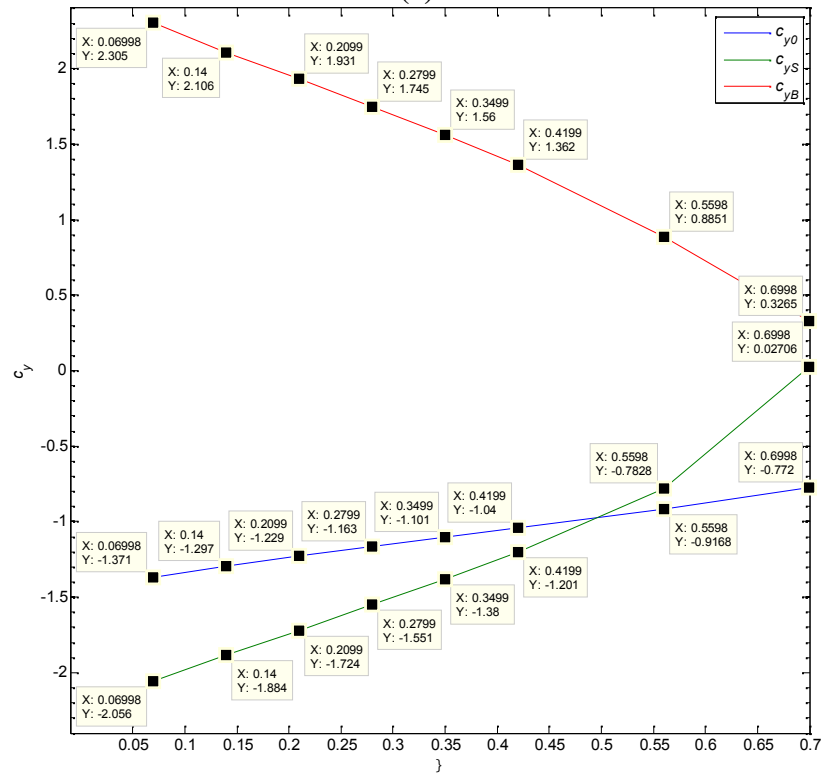
c_x

()

()



()



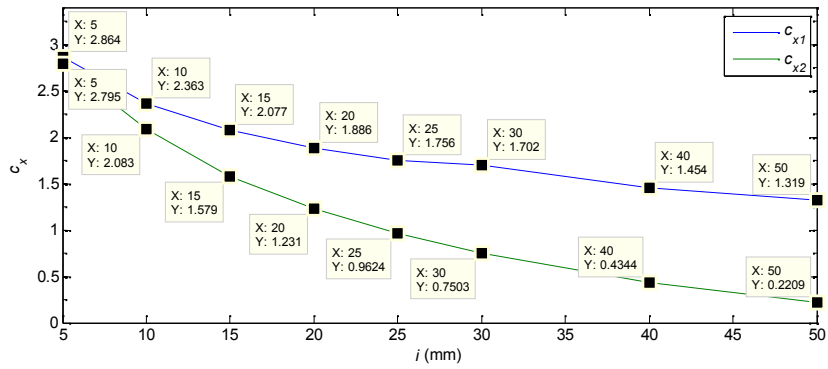
()

5.11: IPE 300 -

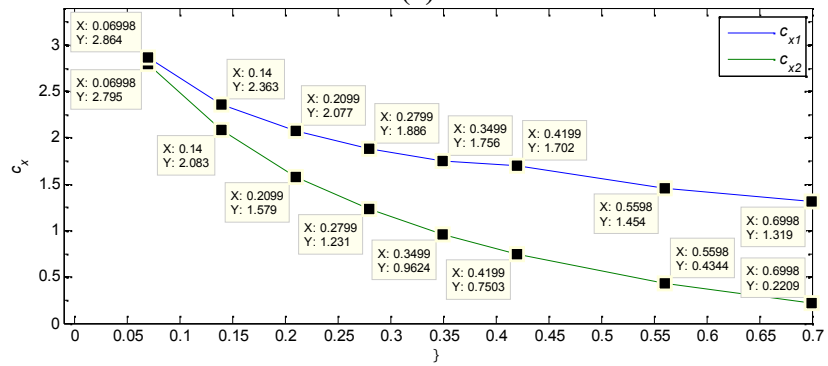
cy

()

()



()



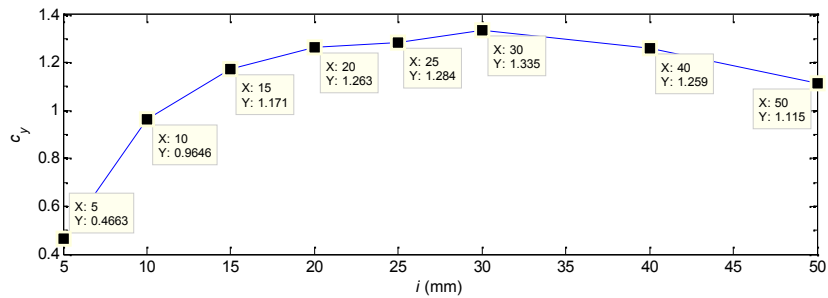
()

5.12: IPE 300 -

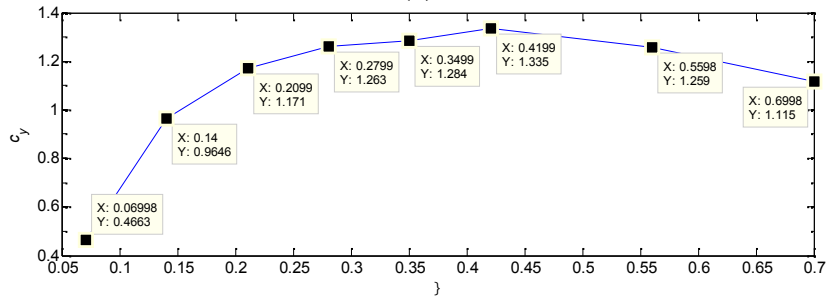
1 2

()

()



()



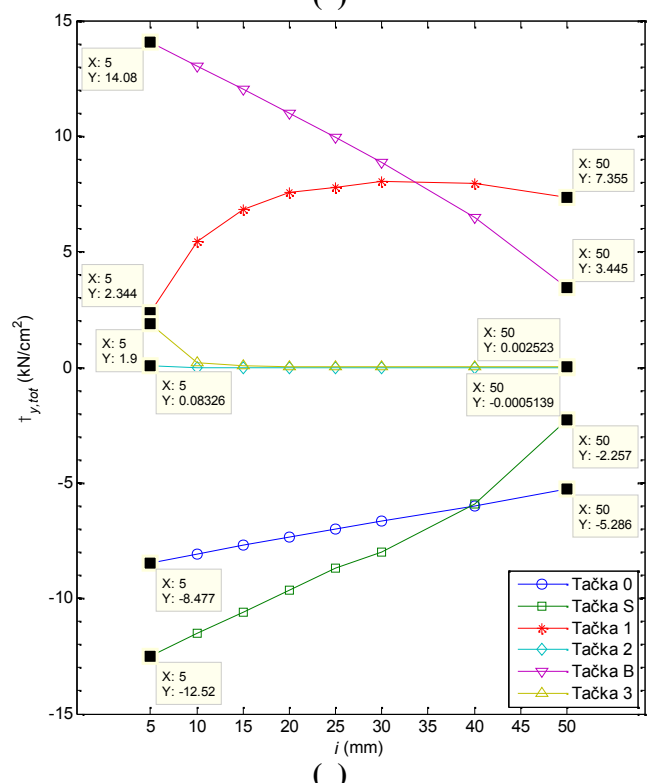
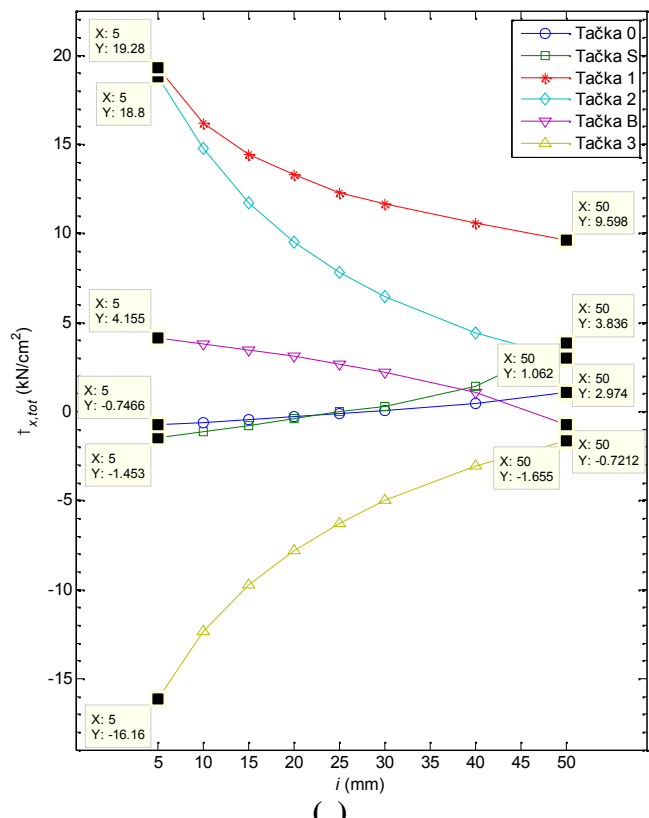
()

5.13: IPE 300 -

c_y 1

()

()

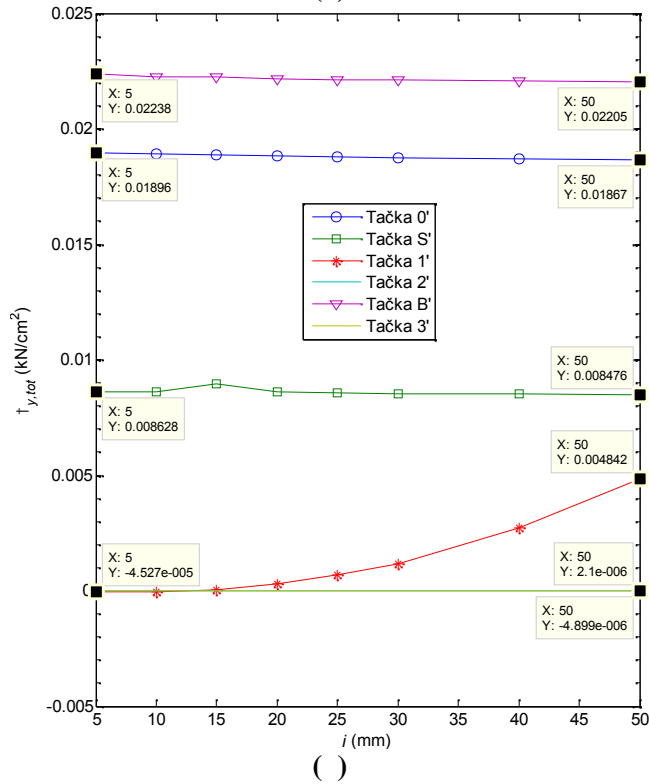
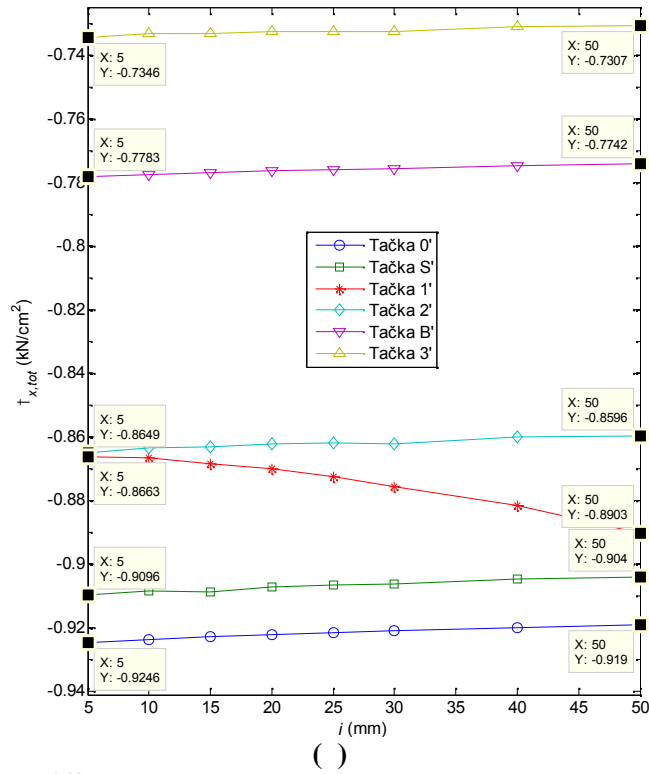


5.14: IPE 360 -

()

; ()

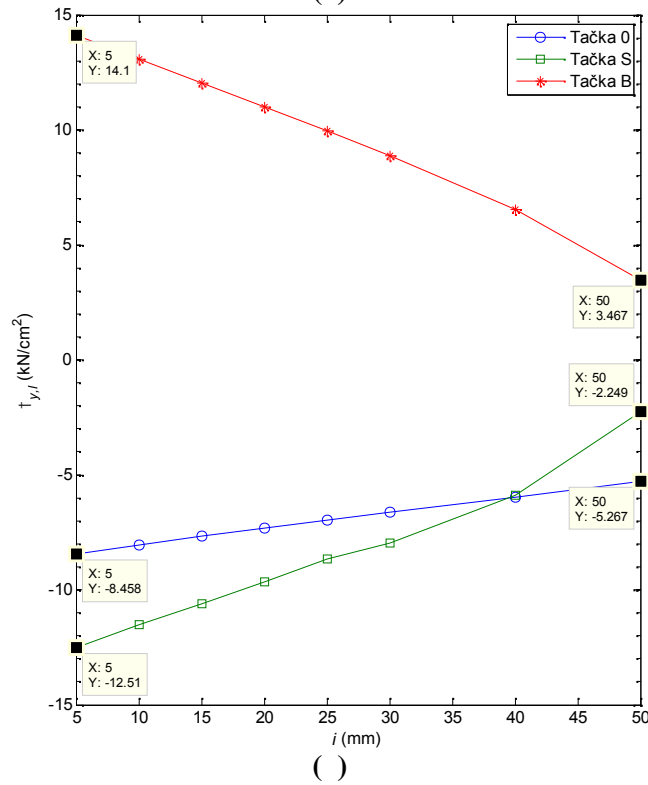
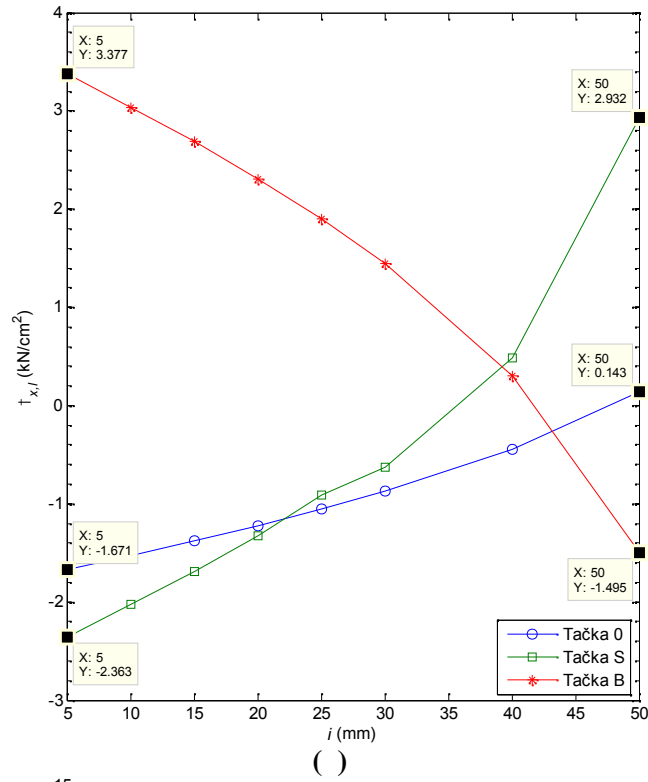
:



5.15: IPE 360 -

() ; ()

:

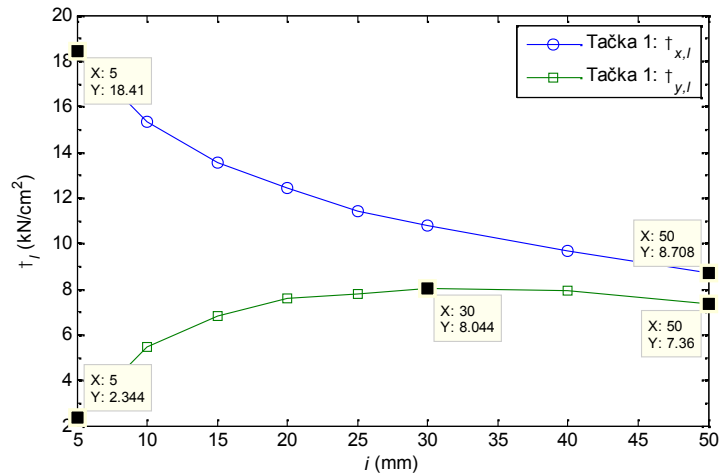


5.16: IPE 360 -

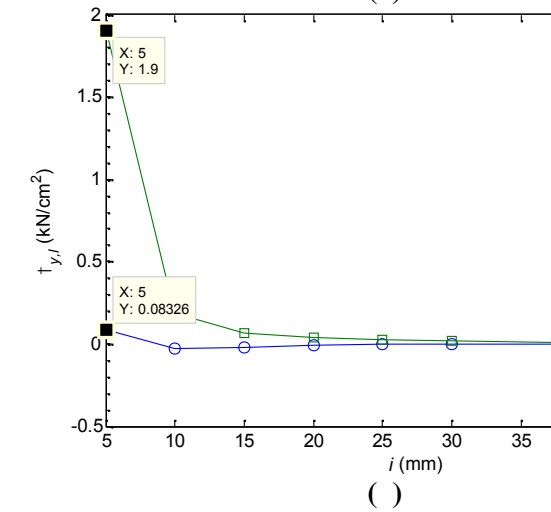
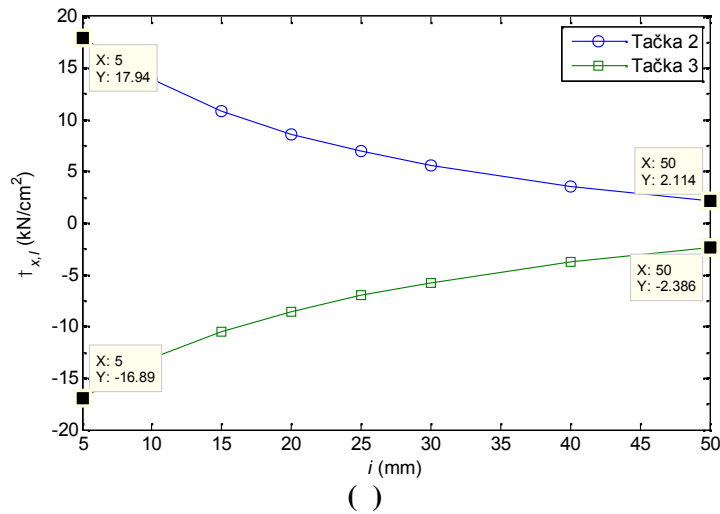
()

; ()

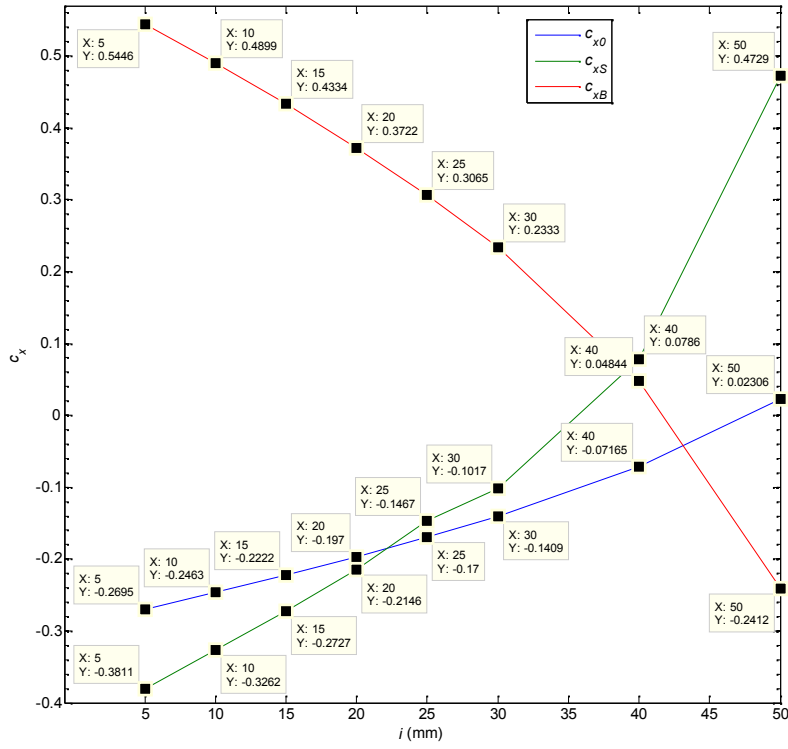
/ :



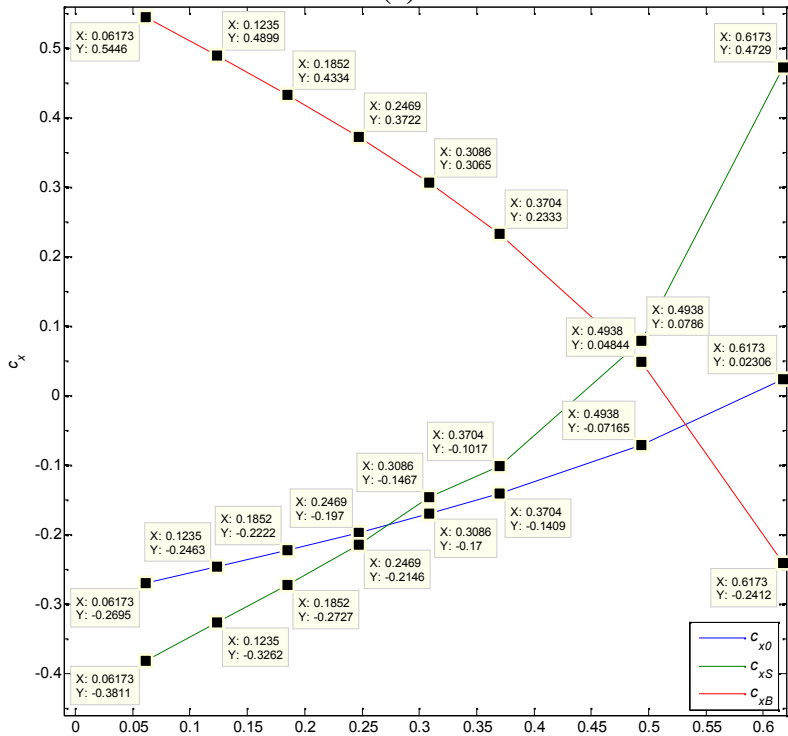
5.17: IPE 360 - () 1: () ;



5.18: IPE 360 - () ; () :



()



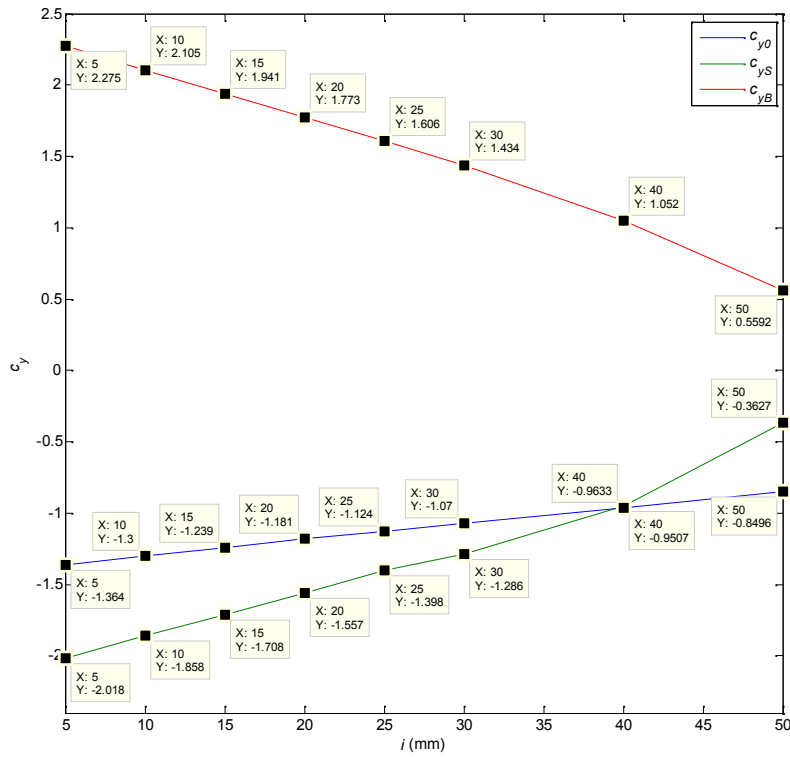
()

5.19: IPE 360 -

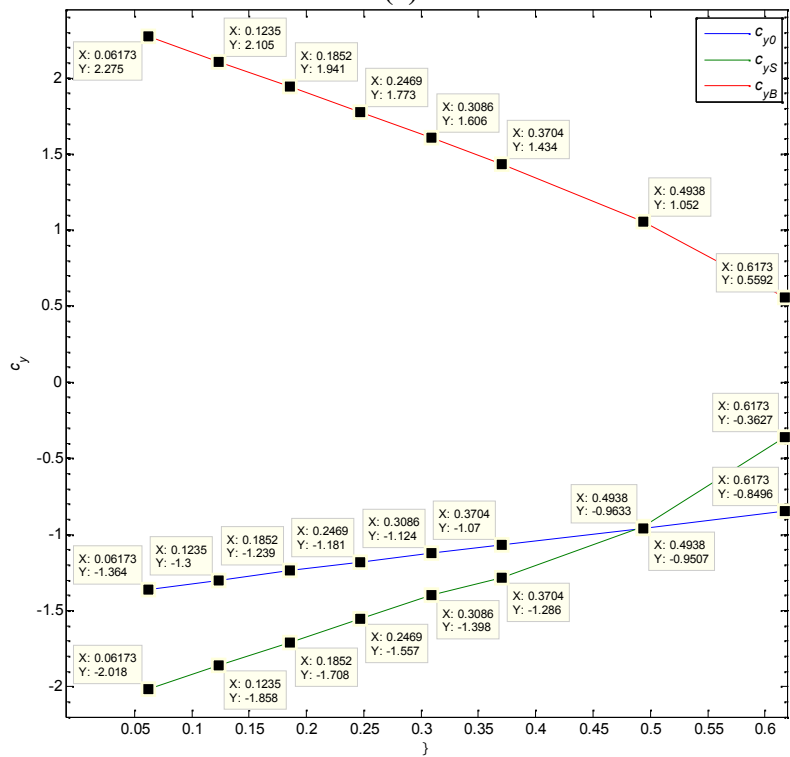
C_x

()

()



()



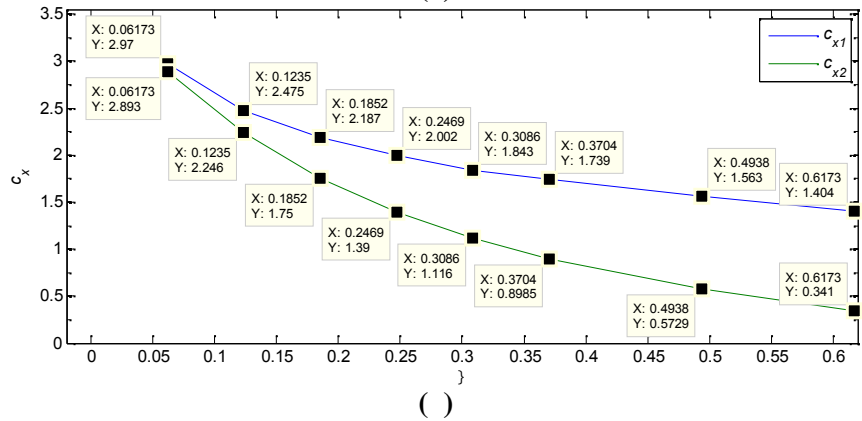
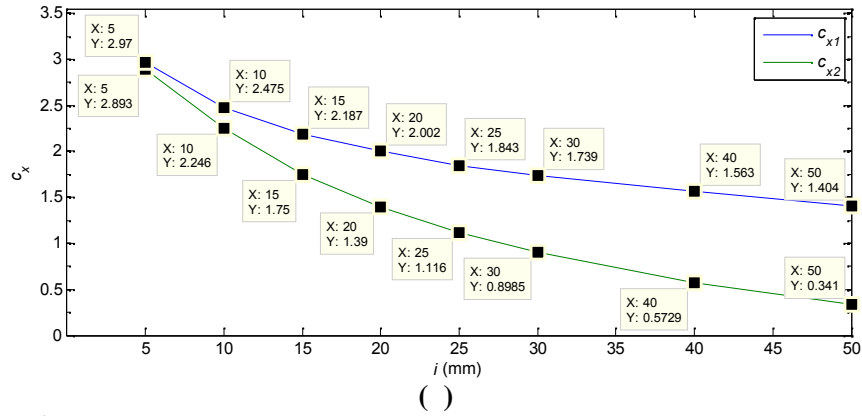
()

5.20: IPE 360 -

c_y

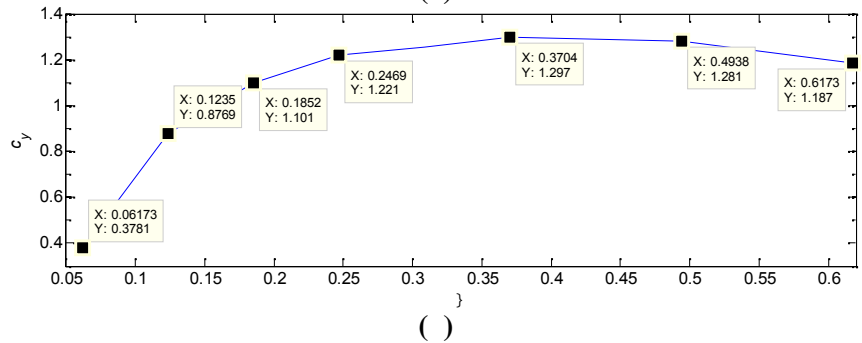
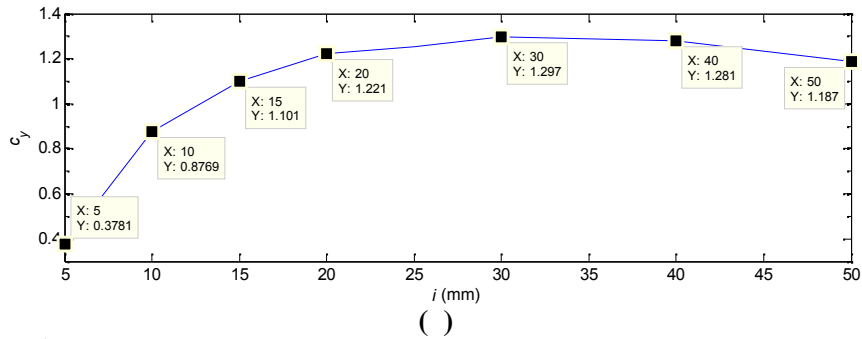
()

()



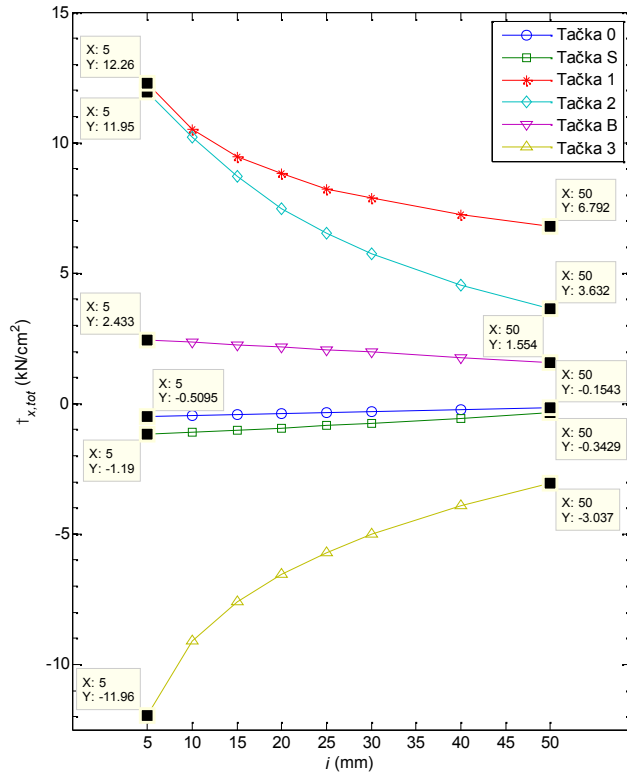
5.21: IPE 360 -

1 2
()

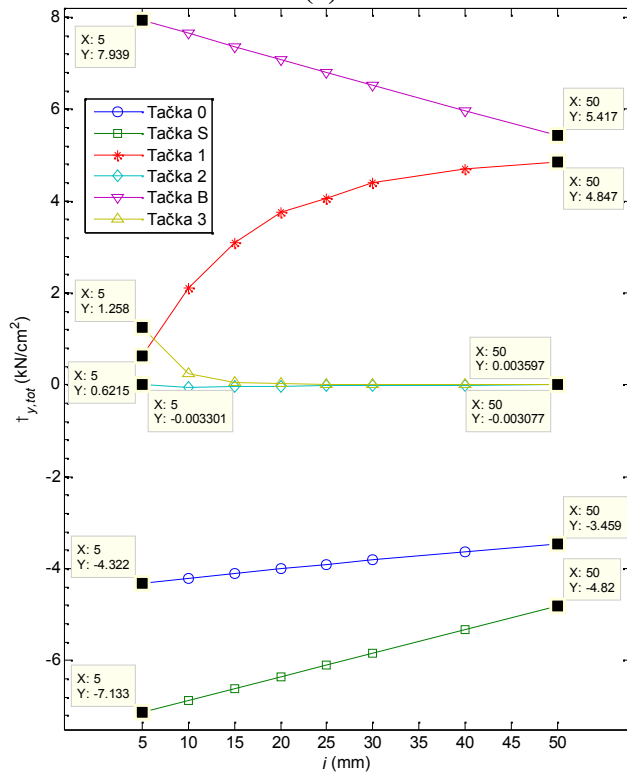


5.22: IPE 360 -

c_y 1
()



()



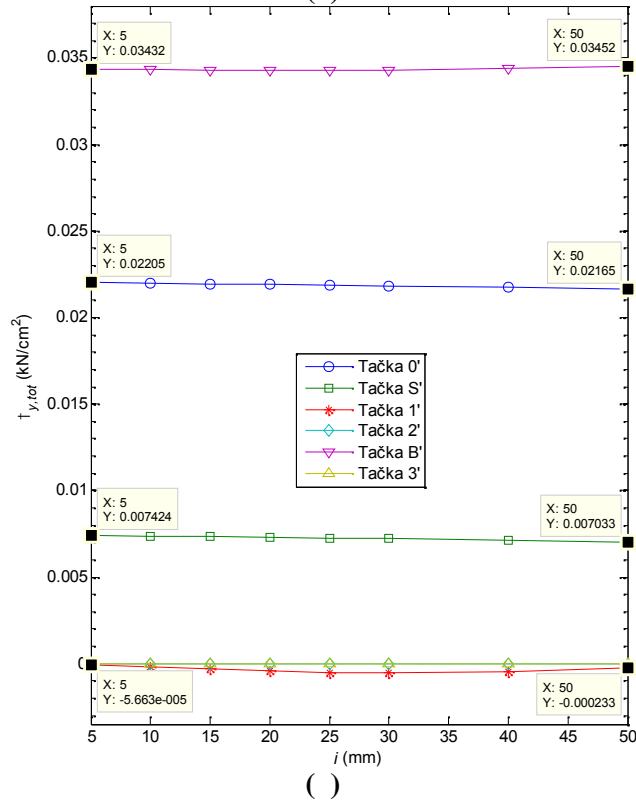
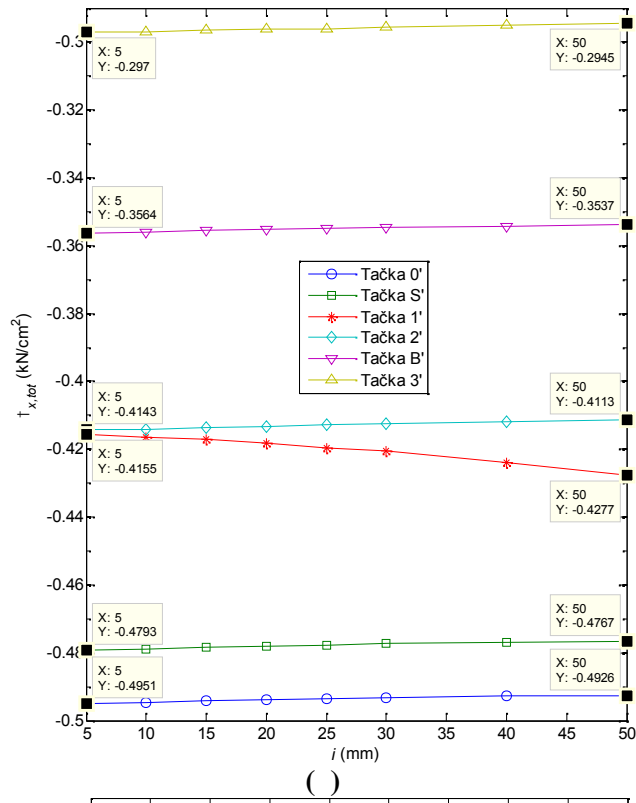
()

5.23: HEA 360 -

()

; ()

:

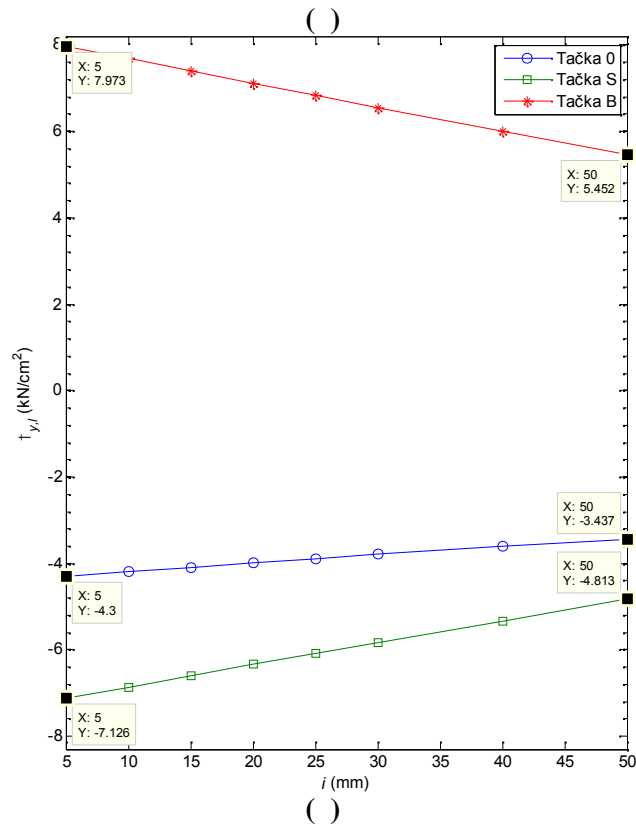
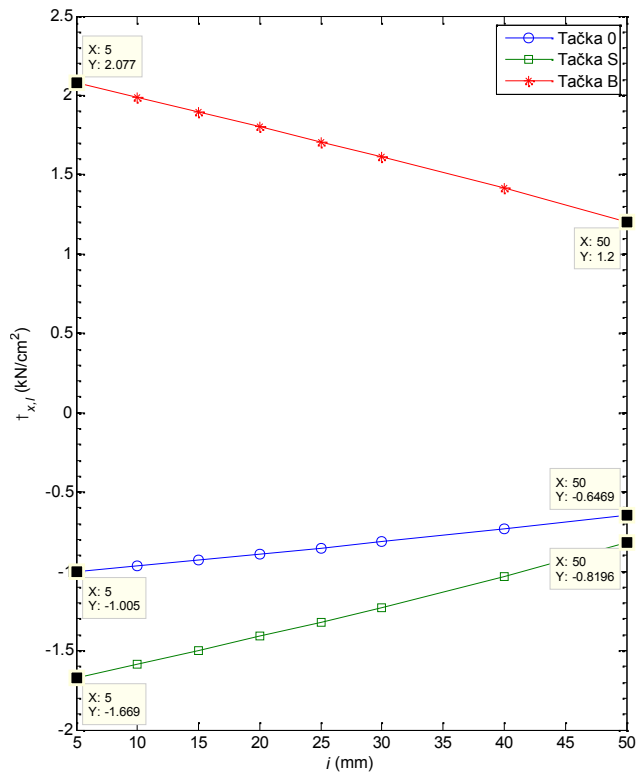


5.24: HEA 360 -

()

; ()

:

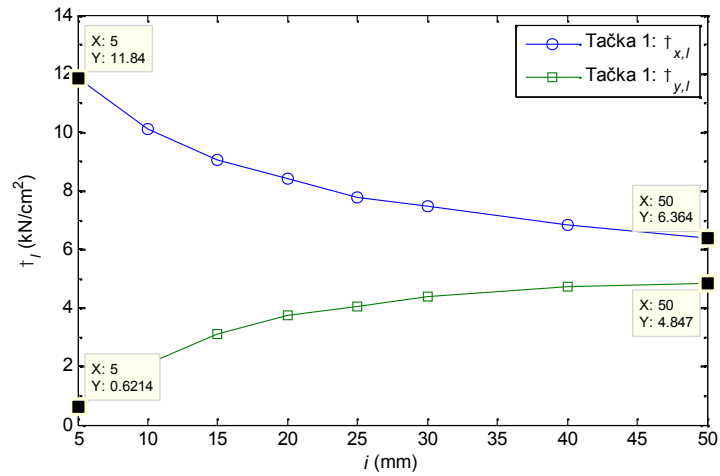


5.25: HEA 360 -

()

; ()

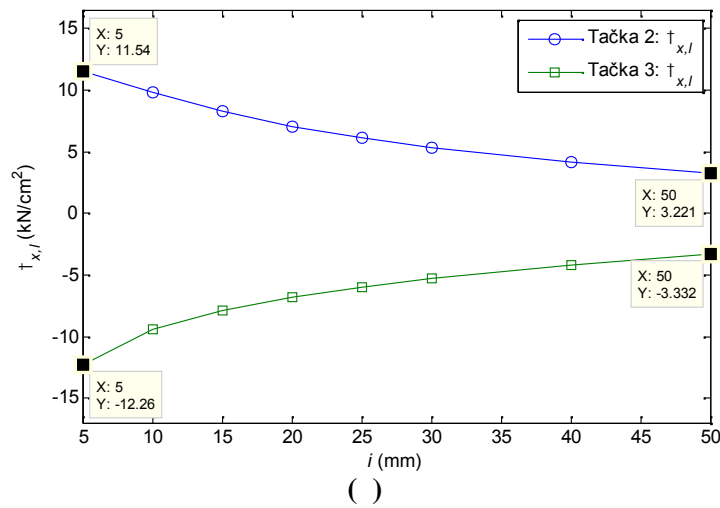
/ :



5.26: HEA 360 -
()

1: ()

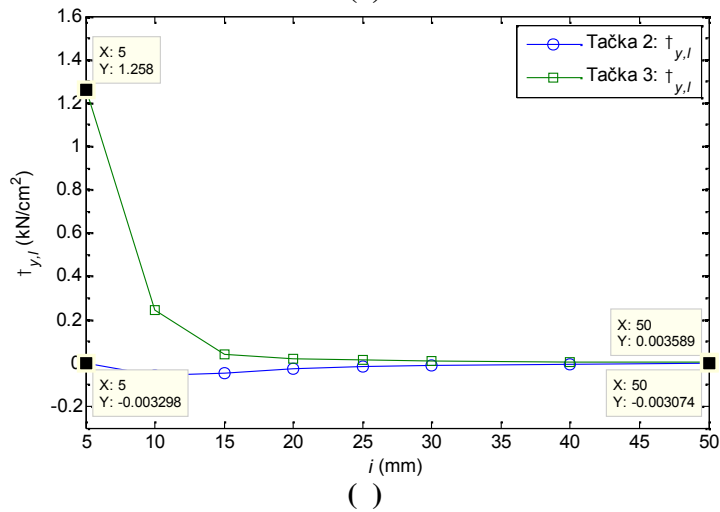
;

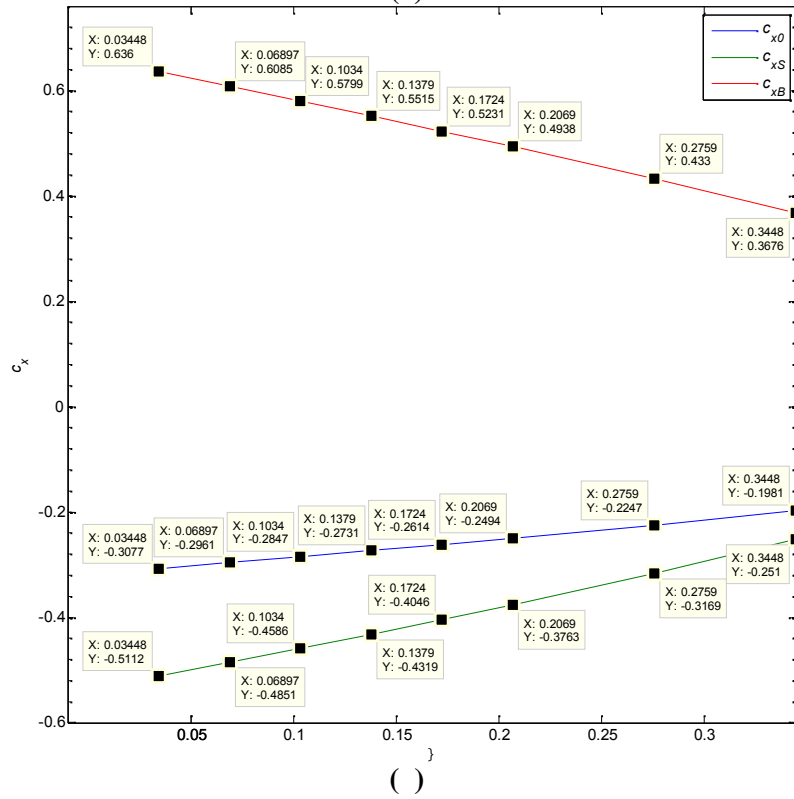
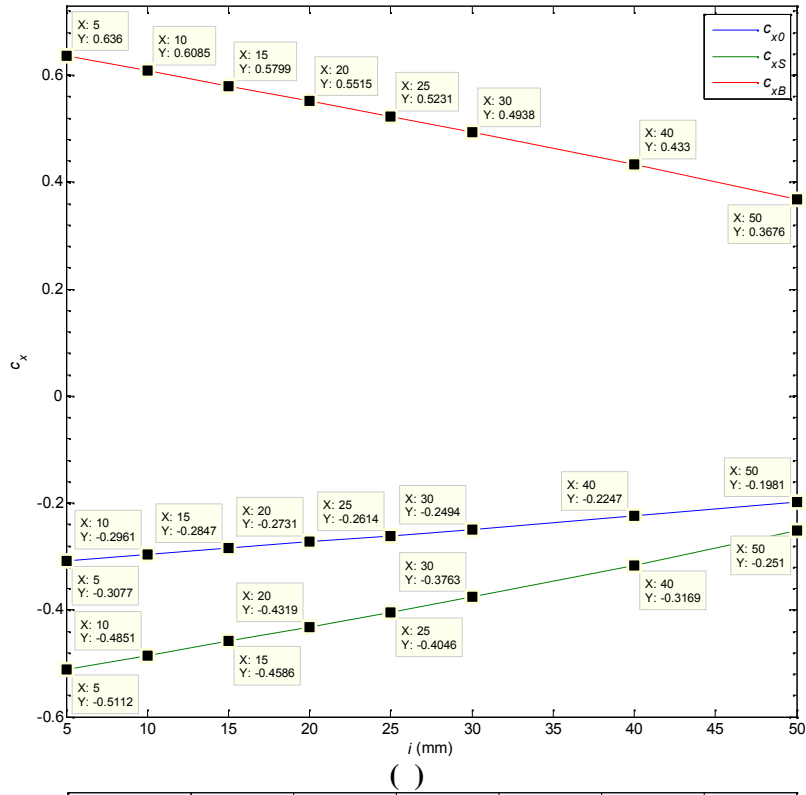


5.27: HEA 360 -
()

; ()

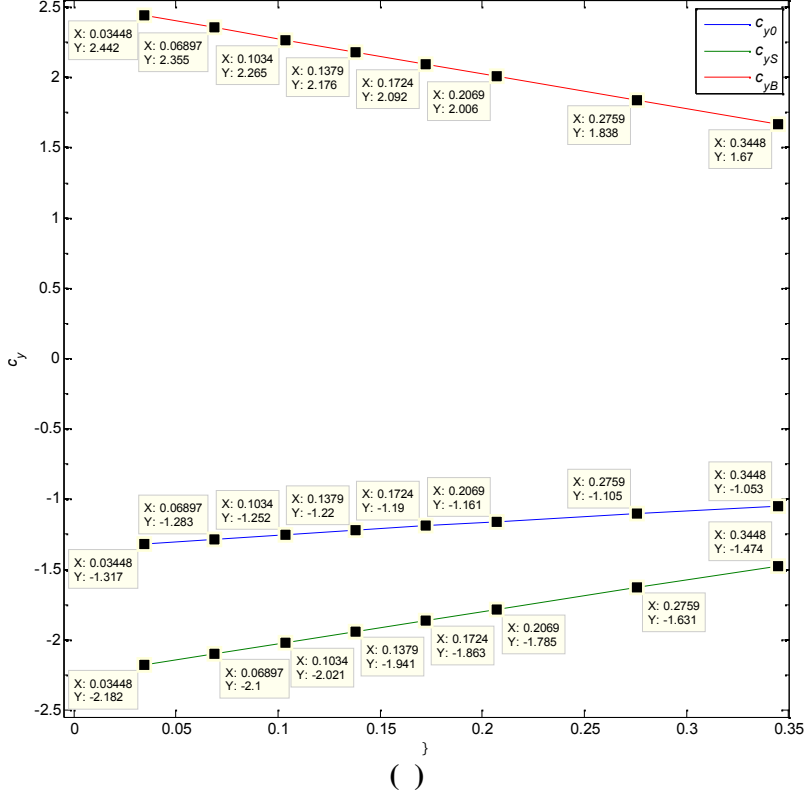
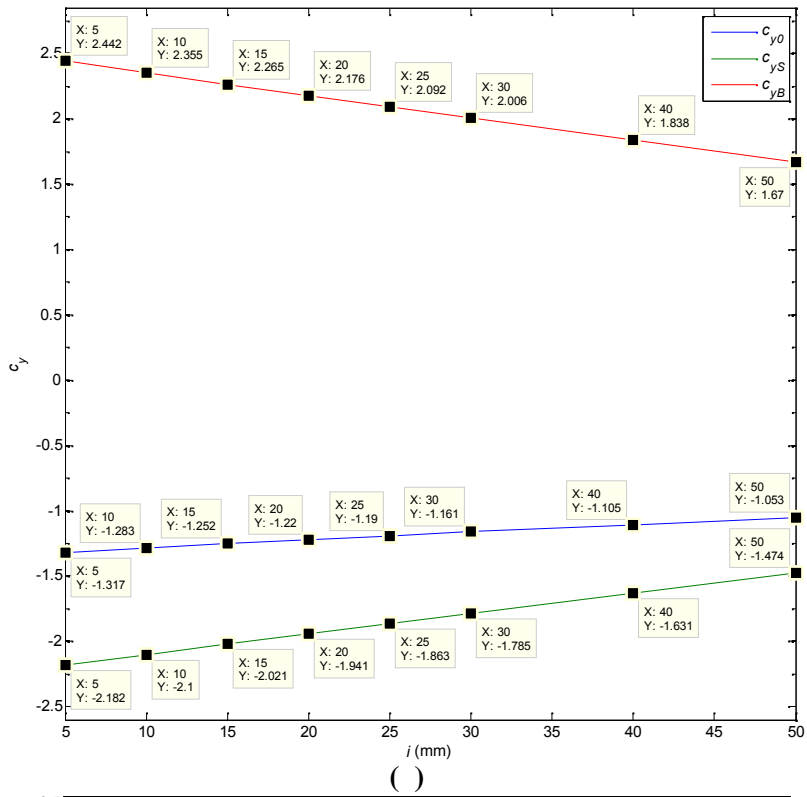
:





5.28: HEA 360 -

C_x

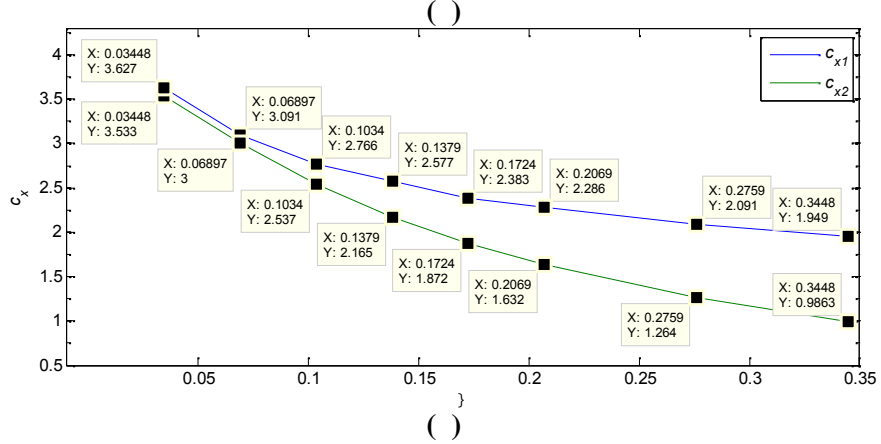
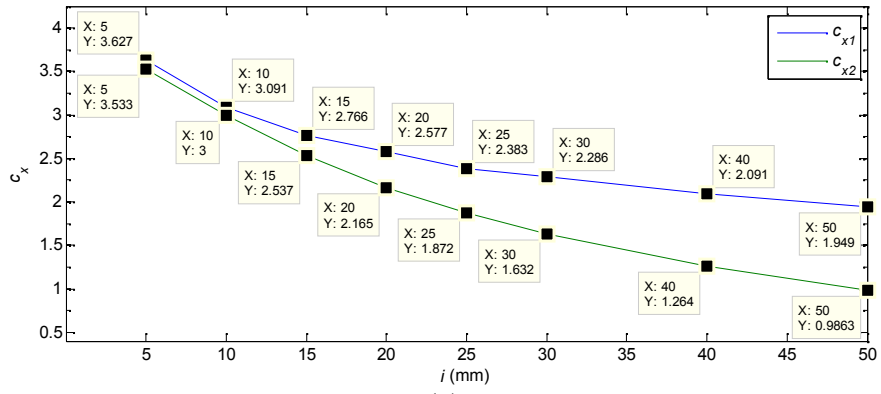


5.29: HEA 360 -

()

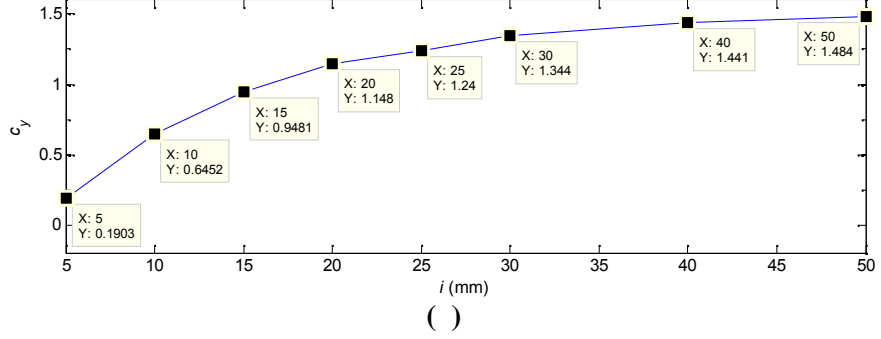
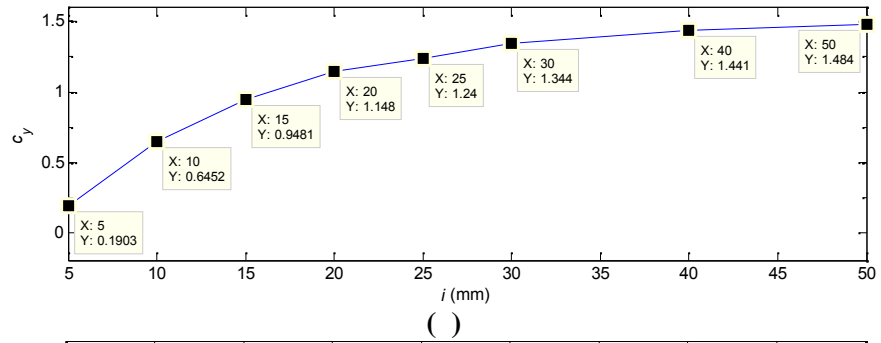
cy

()



5.30: HEA 360 -

1 2



5.31: HEA 360 -

cy 1

5.1

/ (0
S),
(x) , **5.32.**

IPE 300, IPE 360,
HEA 360. HEA 360
0 S
IPE 300 IPE 360 0 S
, **5.32.**

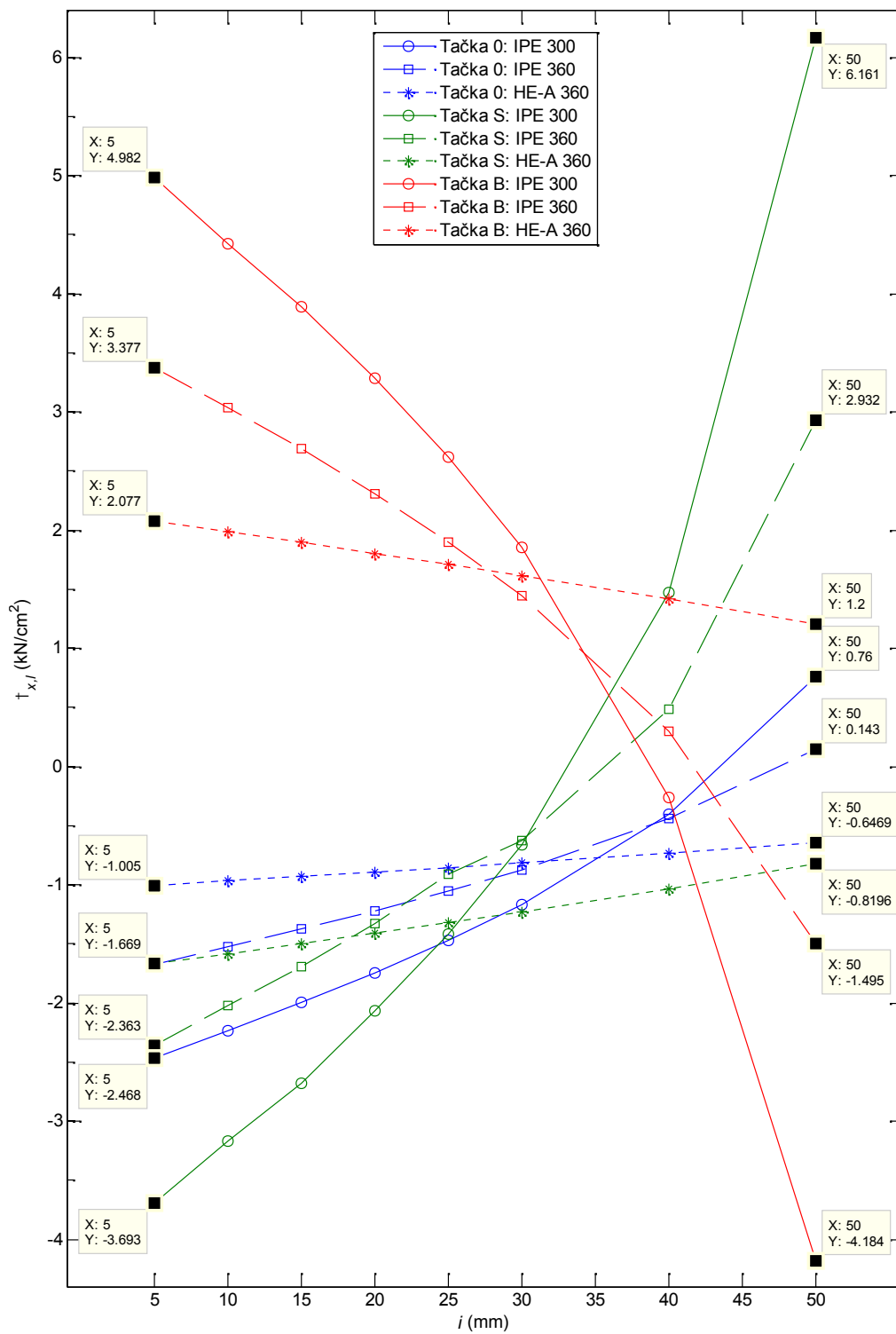
0 $i > 43,5$ mm IPE 300,
 $i > 47,6$ mm IPE 360. S

5.32. IPE 300 $i > 33,6$ mm,
IPE 360 $i > 35,6$ mm. ,
S IPE 300
(B),

(x) , **5.32.**
HEA 360

IPE 300. (IPE 300 IPE 360)
B
IPE 300 $i > 38,8$ mm, IPE 360
 $i > 41,6$ mm.

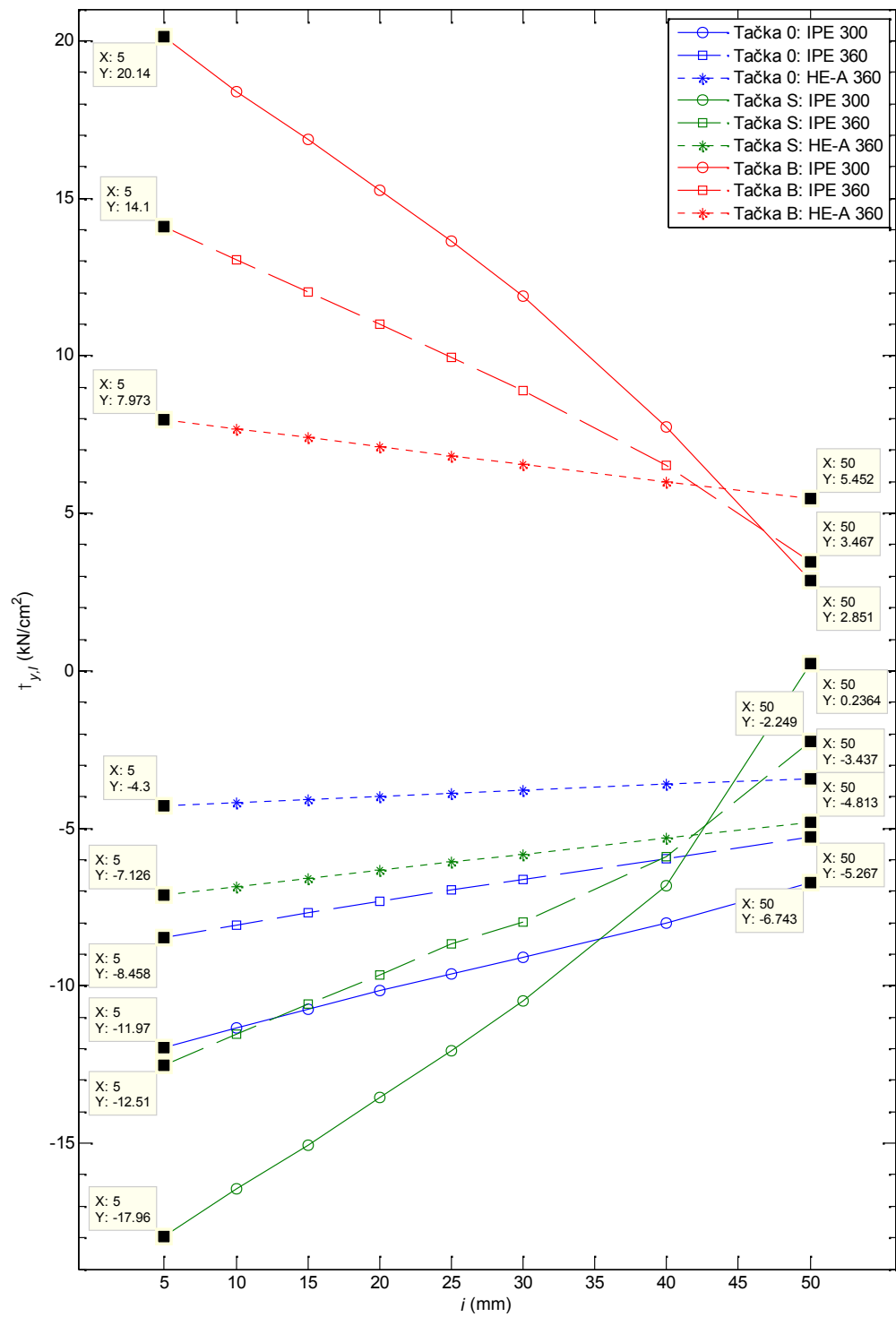
0 S
(y) ,
5.33.



5.32:

(x,i)

/



5.33:

(y,i)

/

IPE 360 HEA 360

0 S,

5.33. 0 IPE 300

S

i 49,7 mm

5.33.

IPE 300

0 S,

B,

5.33.

HEA 360,

IPE 300.

HEA 360 0

S B,

5.34 **5.35.**

$|x_{S,l}|/|x_{0,l}|$ 1,66 *i*=5 mm, 1,27 *i*=50 mm,

$|x_{B,l}|/|x_{0,l}|$

2,07 1,86,

$|y_{S,l}|/|y_{0,l}|$ 1,66 1,4, $|y_{B,l}|/|y_{0,l}|$

1,85 1,57. HEA 360

B.

IPE 300 IPE 360

HEA 360, **5.34**

5.35. IPE 300 $|x_{S,l}|/|x_{0,l}|$ 1,50

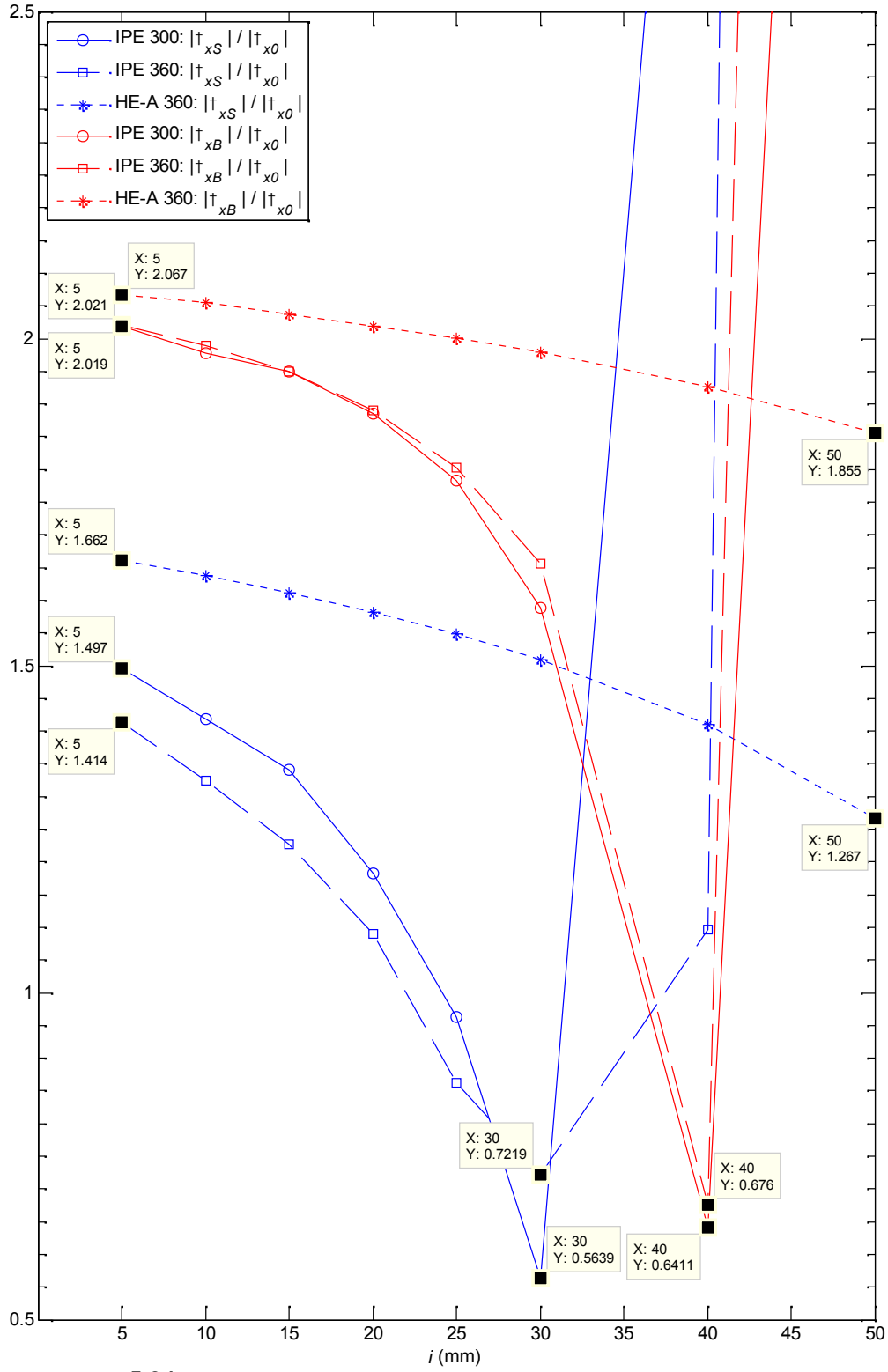
i=5 mm, (0,56) *i*=30 mm,

8,11 *i*=50 mm.

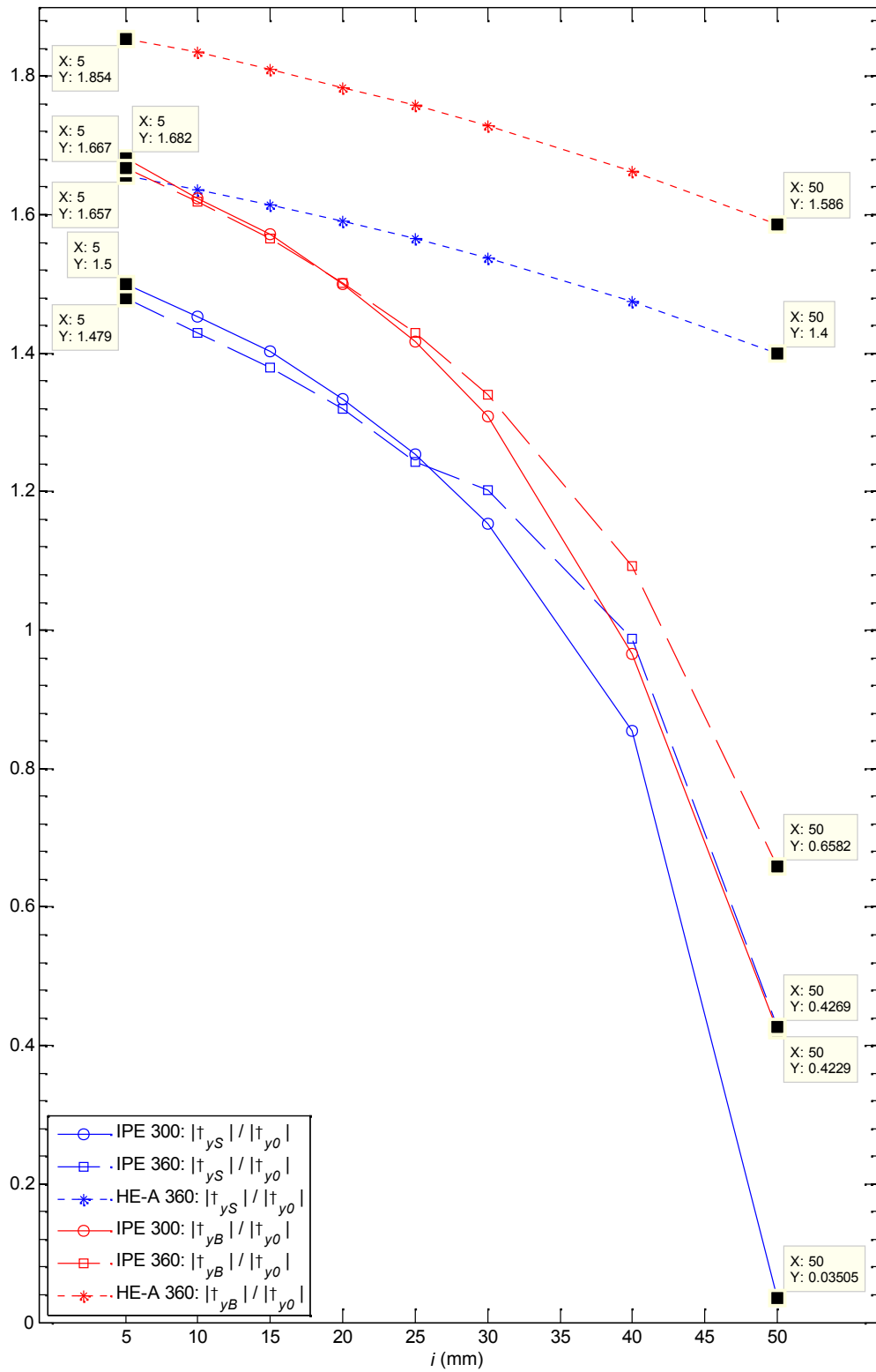
IPE 360 $|x_{S,l}|/|x_{0,l}|$ 1,41 *i*=5 mm,

(0,72) *i*=30 mm,

20,5 *i*=50 mm, **5.34.**



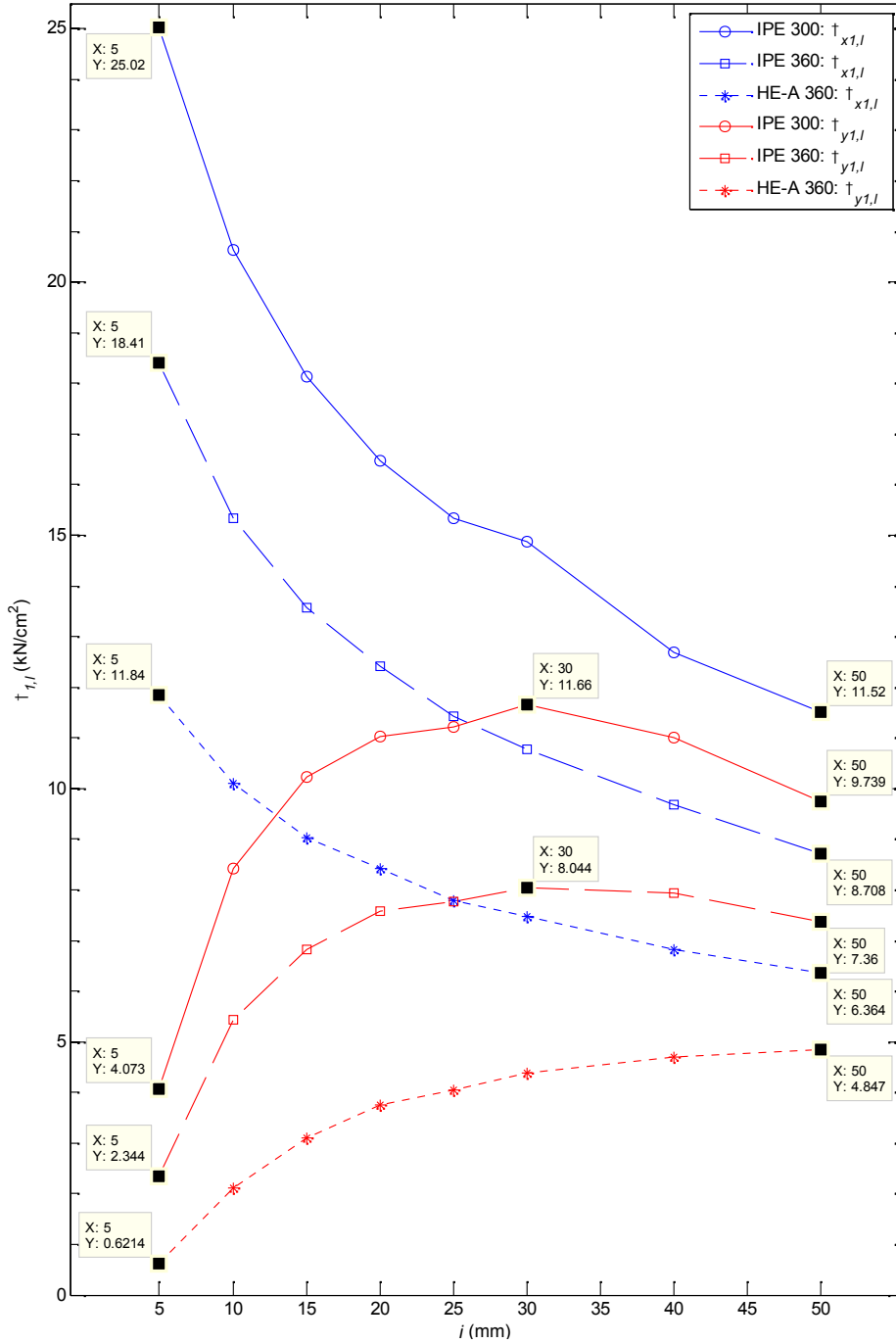
5.34:



5.35:

B 0
 S 0,
5.34. 10 mm
 $|x_{B,l}/x_{0,l}|$ IPE 300 2,02
 $i=5$ mm, 0,64 $i=40$ mm,
 5,51 $i=50$ mm. IPE 360
 2,02 $i=5$ mm, 0,68 ($i=40$ mm),
 , 10,46 ($i=50$ mm).
 IPE 300 IPE 360
5.35. HEA 360.
 $|y_{S,l}/y_{0,l}|$ IPE 300 1,5 $i=5$ mm,
 0,04 $i=50$ mm, IPE 360
 1,48 0,43.
 $|y_{B,l}/y_{0,l}|$ 1,68 0,42 IPE 300,
 IPE 360 1,67 0,66, **5.35.**
5.36.
 HEA 360,
 IPE 300,
 HEA 360 , IPE 300 .
 IPE
 300 25,0 kN/cm²
 $i=5$ mm, 11,5 kN/cm² $i=50$ mm,
 IPE 360
 18,4 kN/cm² 8,7 kN/cm². HEA 360
 11,8 kN/cm², 6,4 kN/cm².
 HEA 360
 0,6 kN/cm² 4,9 kN/cm².

IPE 300 IPE 360
 2,3 kN/cm² (IPE 300), 4,1 kN/cm² (IPE 360),
 i=30 mm 11,7 kN/cm² 8,0 kN/cm²,
 9,8 kN/cm² IPE 300,
 7,4 kN/cm² IPE 360.



5.36:

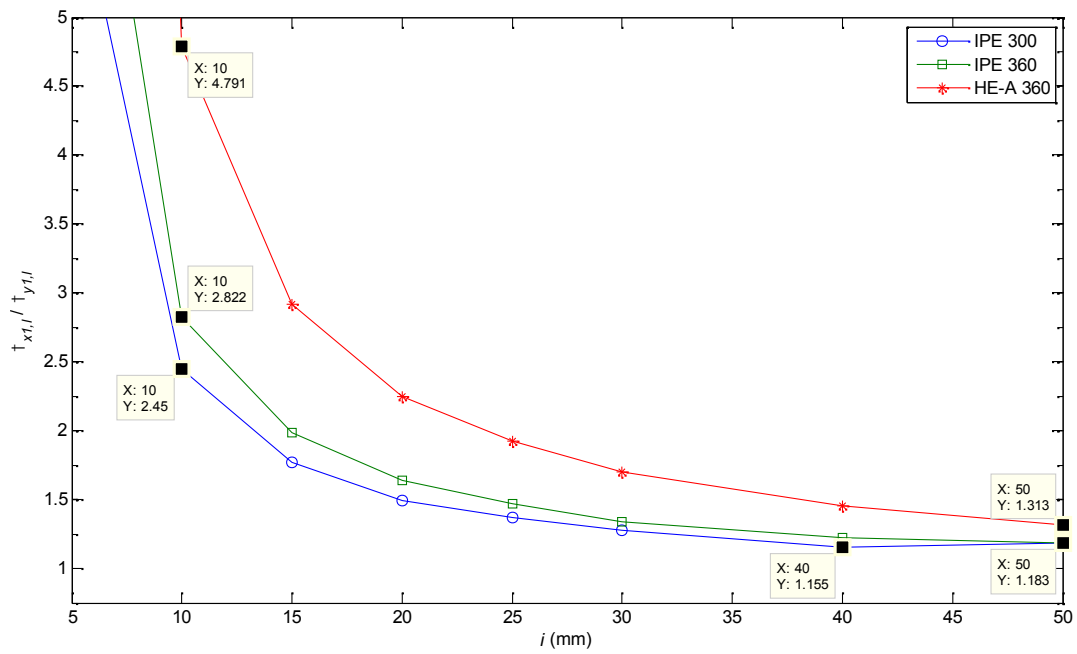
1,

5.37.

HEA 360 19,1, IPE 360
 IPE 300, 7,9 6,1,

1,2,

(HEA 360) 1,3, 5.37.



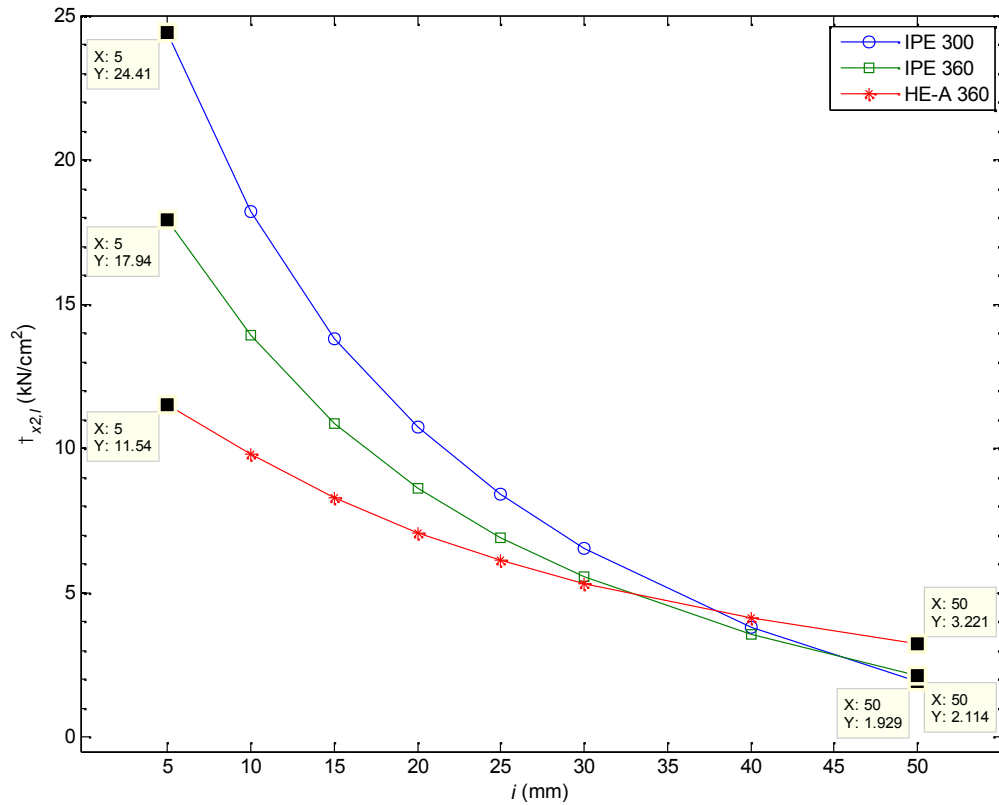
5.37:

1

2,

5.38.

IPE 300
 25,4 kN/cm² 1,9 kN/cm²,
 17,9 kN/cm² 2,1 kN/cm².
 HEA 360, 11,5
 kN/cm² 3,2 kN/cm².



5.38:

2

2,

5.9(), 5.18() 5.27().

[5].

HEA 360

B S

5.39. $i=5$ mm

() 24,4%

S (), $i=50$ mm 46,5%.

, $i=5$ mm

11,9%

S, $i=50$ mm

IPE 300 IPE 360

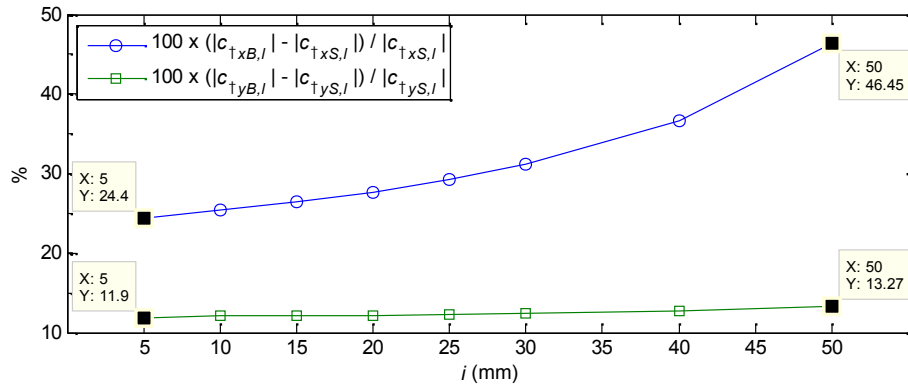
B S,

IPE 300

$i=50$ mm, 1,34 5.40. IPE 360 2,82 $i=30$ mm, 0,18 $i=40$ mm 0,68

B S

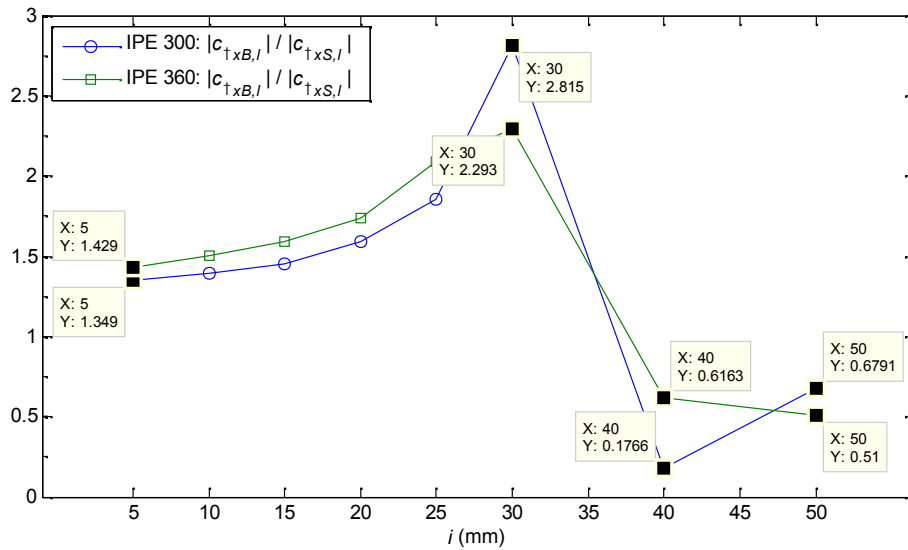
1,42 2,29 $i=30$ mm, 0,51 $i=50$ mm, 5.40.



5.39:

B S

HEA 360



5.40:

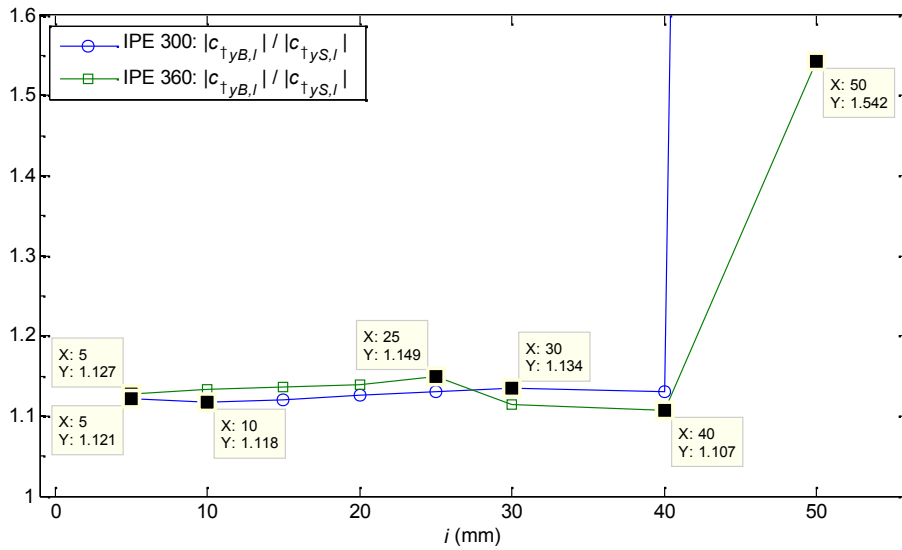
B S

IPE 300 IPE 360

, o

IPE 300 1,11 1,15. IPE 360 1,12 1,13, $i=40$ mm: 0,68

$i=50$ mm 12,1 IPE 300, 1,54
 IPE 360, **5.41.**



5.41:

B S IPE 300 IPE 360

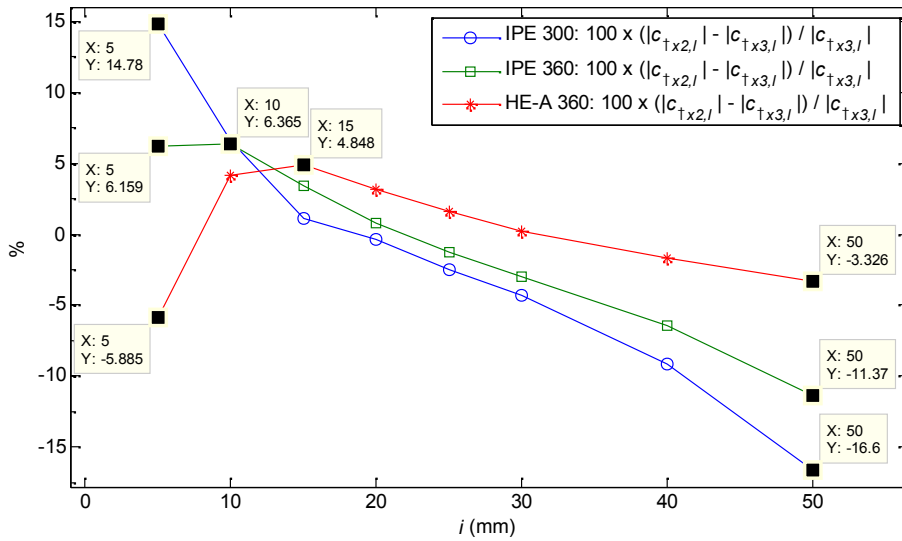
2 3 () HEA 360
 , -5,9% 4,9%, **5.42.**
 IPE 300 14,8%

-16,6%,

6,4% ($i=10$ mm),

6,2%

-11,4%, **5.42.**



5.42:

2 3

(), **5.10 - 5.13, 5.19 -**
5.22 5.28 - 5.31,

0 0,8.

5.1.1

, **5.43, 5.44 5.45,**
 EN 15011 [5],

$$c_{i,j} = a_{i,j} + b_{i,j} + d_{i,j} e^{f_{i,j}}, \quad i = x, y, j = 1, 2, S, B \quad \dots(5.1)$$

$a_{i,j}, b_{i,j}, d_{i,j} f_{i,j}$ **5.1.**

HEA 360

(:

„ HEA 360 “), **5.2.**

HEA 360

DIN 1025 (Blatt 3/1963), **2.1.**

5.1:

() IPE 300

	<i>a</i>		<i>b</i>		<i>d</i>		<i>f</i>	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
S	-0,46880	-2,18470	0,49659	2,18965	0,02133	0,00272	5,28285	8,04079
1	2,14797	2,33341	-1,22890	-1,71790	1,76664	-2,34880	-10,9440	-4,78660
2	0,86699	0,00000	-1,00730	0,00000	2,93115	0,00000	-5,42650	0,00000
B	0,64408	2,51271	-0,90210	-2,55900	-0,00120	-0,00450	8,78072	6,38460

() IPE 360

	<i>a</i>		<i>b</i>		<i>d</i>		<i>f</i>	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
S	-0,44630	-2,17910	0,78496	2,43625	0,00484	2,8 10 ⁻⁴	7,12888	11,06361
1	2,17049	1,86224	-1,26670	-1,06410	1,70926	-1,86250	-10,76100	-6,10092
2	0,97422	0,00000	-1,16920	0,00000	2,83089	0,00000	-5,60970	0,00000
B	0,60684	2,45211	-0,87540	-2,71280	-0,00230	-4 10 ⁻⁵	8,06732	14,16868

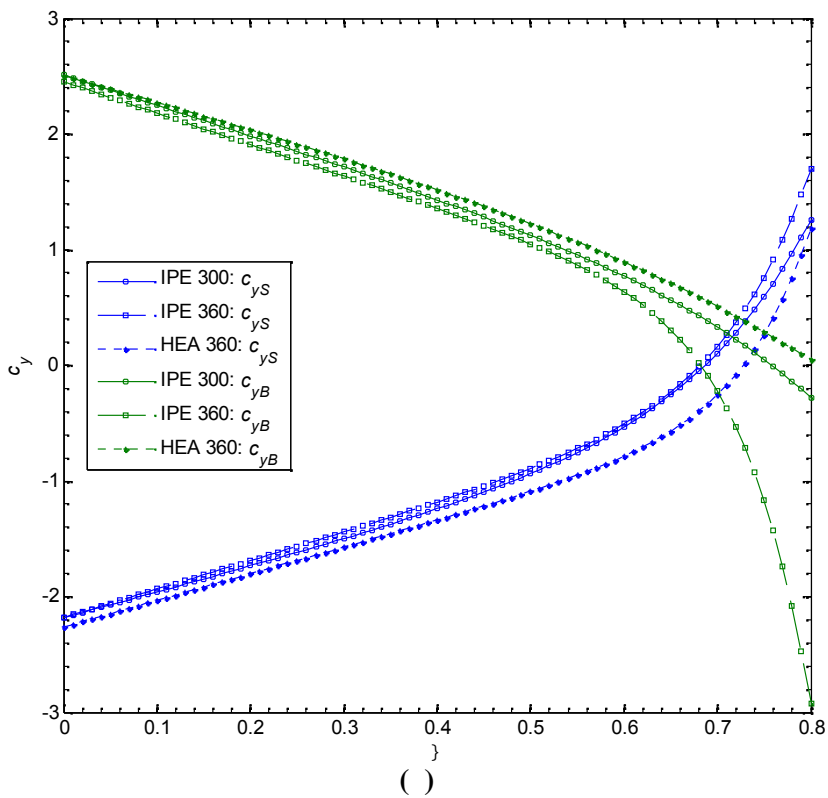
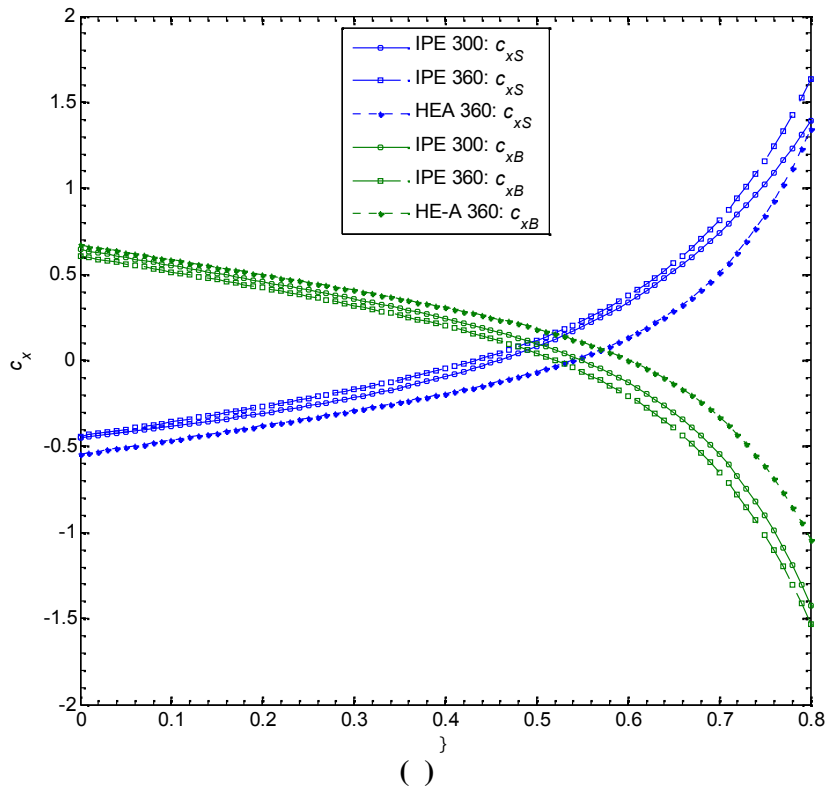
() HEA 360

	<i>a</i>		<i>b</i>		<i>d</i>		<i>f</i>	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
S	-0,54550	-2,26090	0,81010	2,29330	0,00070	0,00003	9,35340	13,83424
1	2,44832	1,95553	-1,49600	-0,98870	1,93150	-2,27060	-13,34900	-8,46172
2	1,11505	0,00000	-1,34500	0,00000	3,08718	0,00000	-6,54520	0,00000
B	0,67006	2,54408	-0,84380	-2,11350	-0,00060	-0,04080	9,33120	3,72974

5.2:

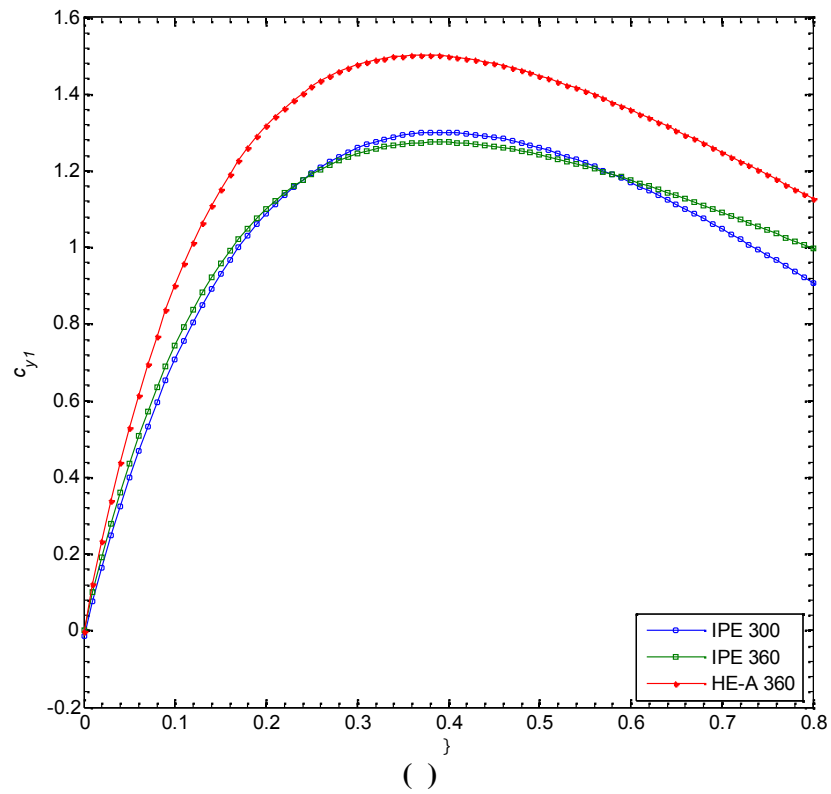
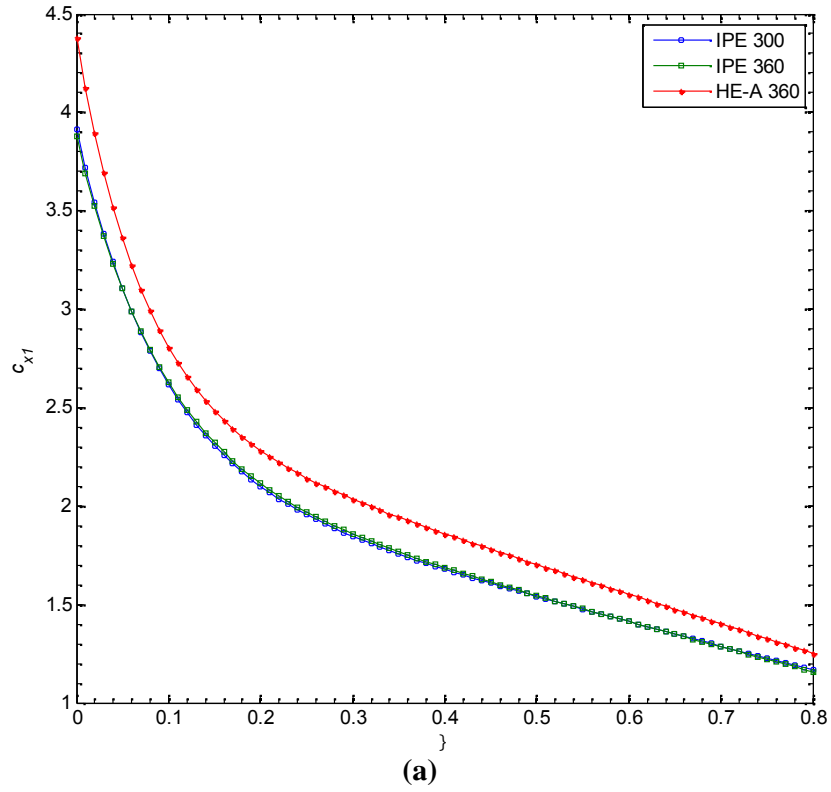
HEA 360

	<i>a</i>		<i>b</i>		<i>d</i>		<i>f</i>	
	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>	<i>x</i>	<i>y</i>
S	-0,5590	-2,2847	0,7430	2,1725	0,0011	4,9 10 ⁻⁵	8,5337	12,5426
1	2,4831	2,3800	-1,5358	-1,6000	1,9508	-2,3800	-13,156	-5,8000
2	1,0834	0,0000	-1,2615	0,0000	3,1561	0,0000	-6,3824	0,0000
B	0,7295	2,5836	-0,9865	-2,1436	-2 10 ⁻⁶	-0,0175	16,4190	4,5823



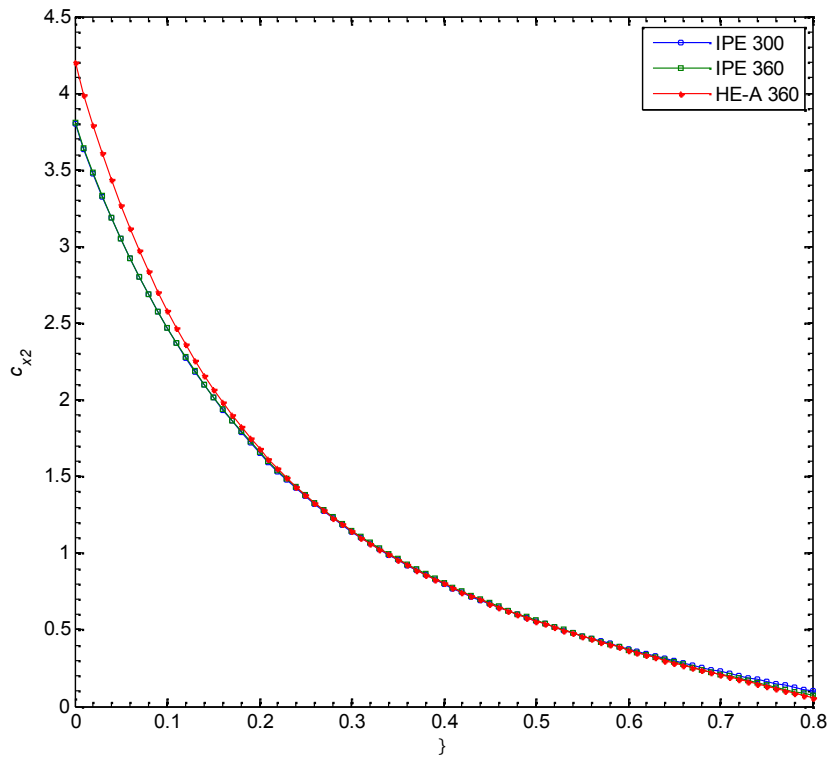
5.43:

: () c_x ; () c_y



5.44:

1: () c_x ; () c_y



5.45:

c_x

2

(IPE 300 IPE 360)

HEA 360

, 5.43, 5.44 5.45.

IPE 300,

IPE 360

HEA 360

,

5.46 - 5.49¹.

IPE 360

,

5.46.

c_x

S

-1,4% -21,4%,

B, -6,0% -10,7%.

,

c_y S

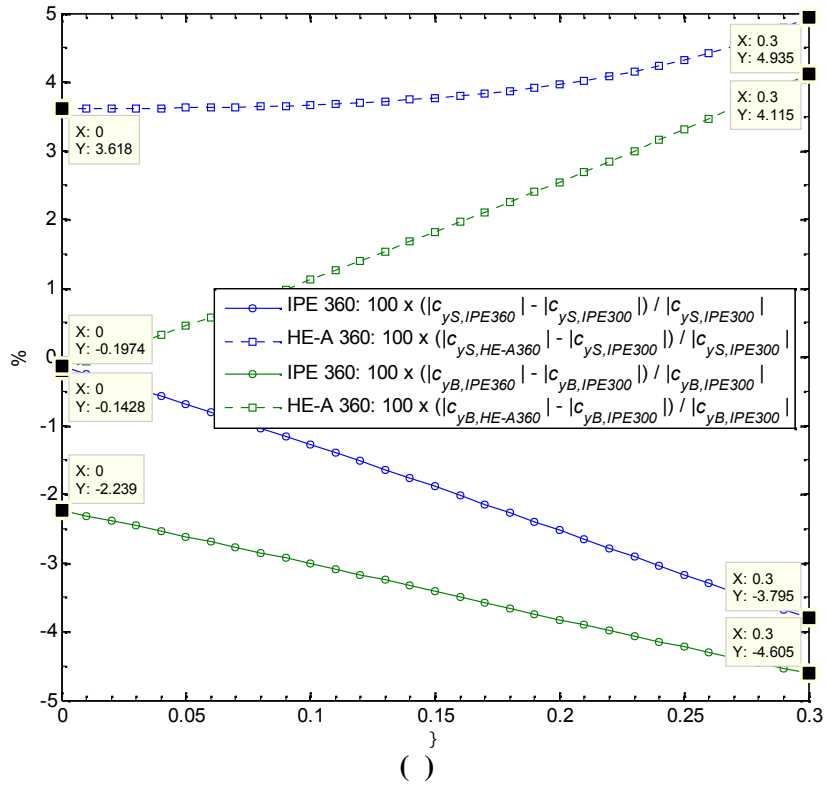
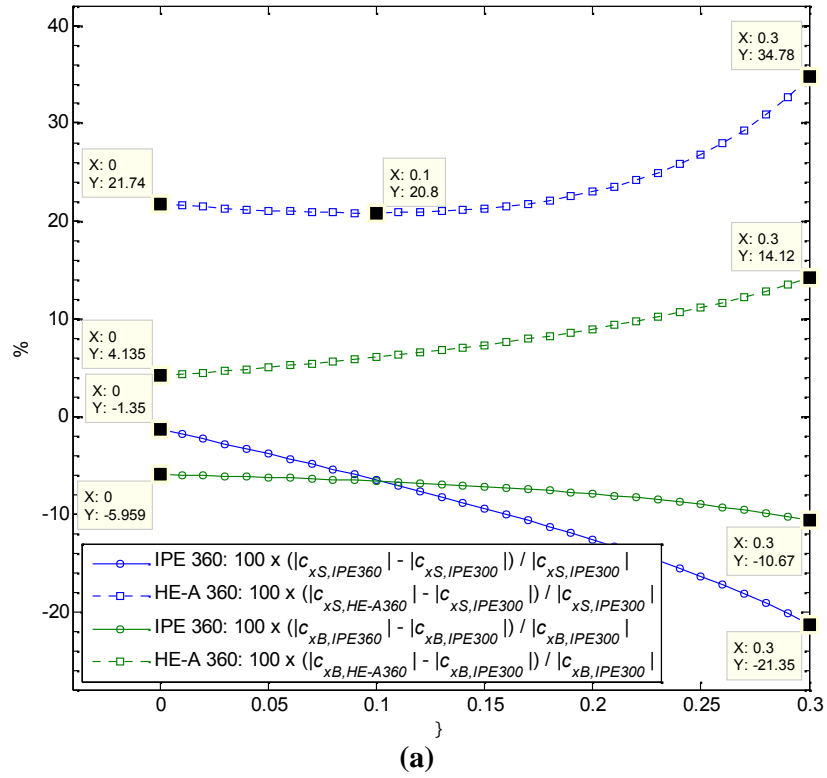
-0,1% -3,8%,

B, -2,2%

-4,6%.

1

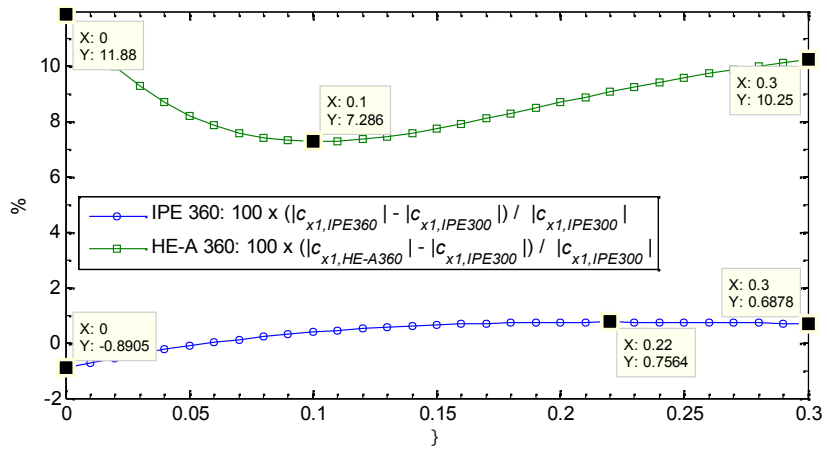
0 0,3,



5.46:

: () c_x ; () c_y

c_x S HEA 360 21,7%
 20,8% (=0,1), 34,8%, **5.46** (). B
 4,1% 14,1%.
 c_y S
 3,6% 4,9%, B, -0,2% 4,1%, **5.46** ().
 IPE 360
 c_x 1 (-0,9%
 0,7%), **5.47**, .
 HEA 360, 11,9% =0,
 7,3% =0,1, 10,3%
 =0,3, **5.47**.

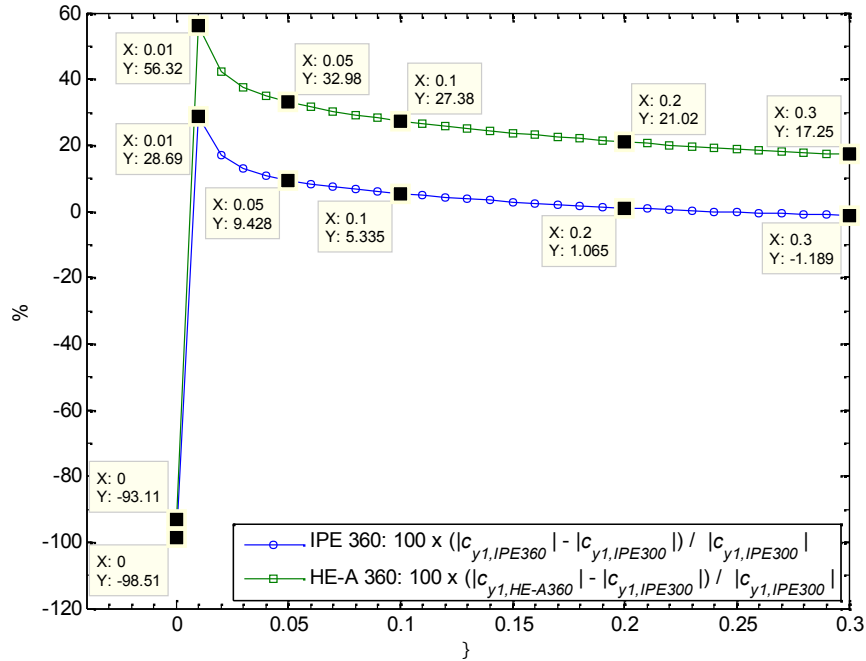


5.47:

c_x 1
 ()
 c_y 1 , **5.44** (),

5.48. 0,05 0,1 IPE 360

c_y 1 9,4%
 5,4%, 5%,
5.48. HEA 360 :
 =0,05 - 33,0%, =0,1 - 27,4%, =0,3 - 17,3%, **5.48.**



5.48:

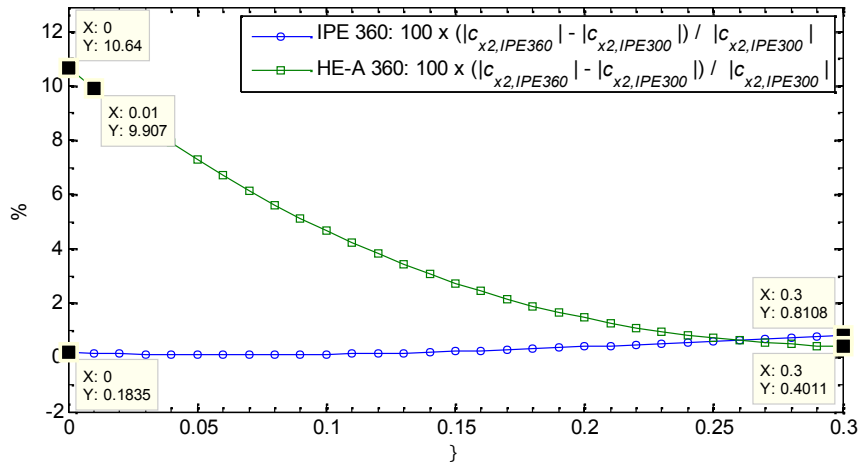
c_y 1

c_x 2 IPE 360

5.49.

0,2% 0,8%. HEA 360
10,6% 0,4%,

5.49.



5.49:

c_x 2

5.3,

- IPE 300, c_x
- IPE 360, c_x S (21,4%);
- HEA 360, IPE 300, c_x 10%. S B 34,8% 14,1%, c_y 4,9% 4,1%, c_y 1 33,0%.

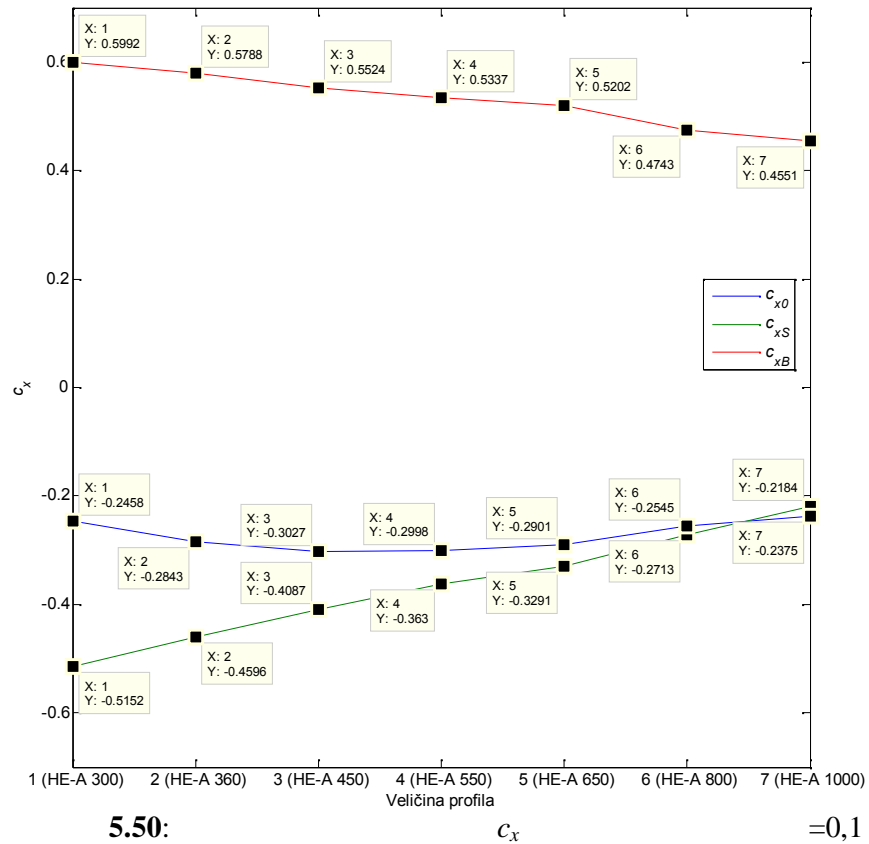
5.3:

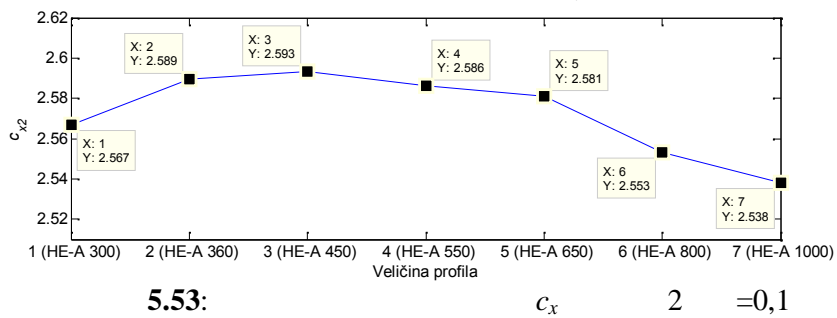
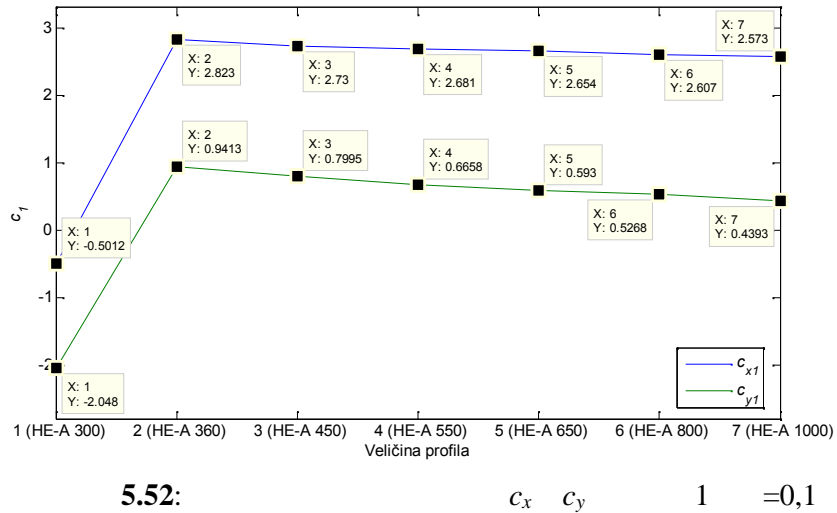
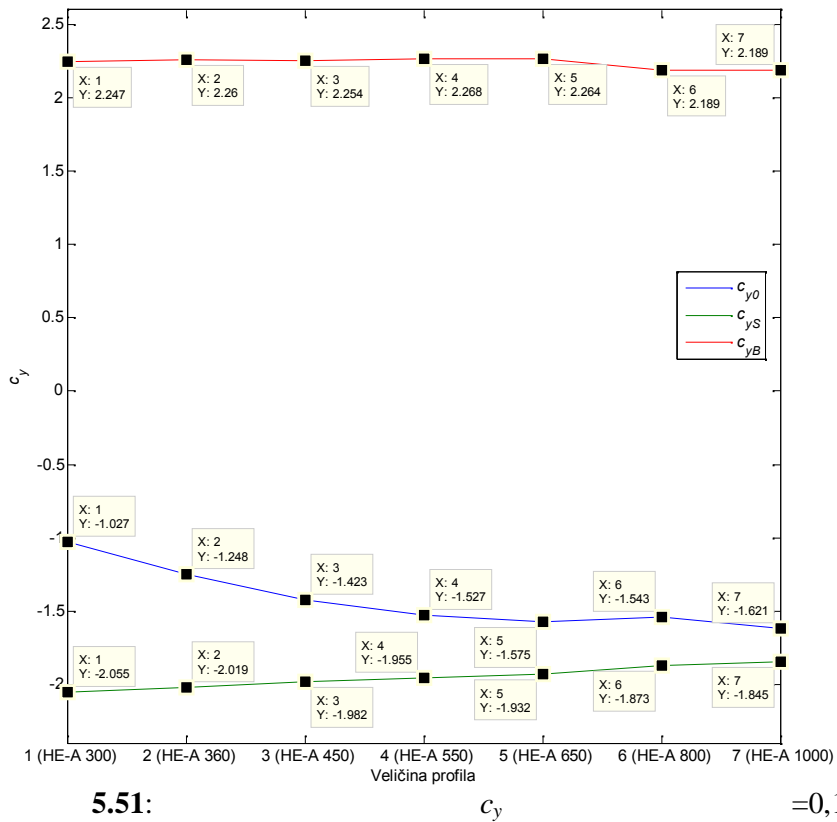
		c_x	c_y
IPE 360	S	21,4%	3,8%
	B	10,7%	4,6%
	1	0,9%	9,4%*
	2	0,8%	—
HEA 360	S	34,8%	4,9%
	B	14,1%	4,1%
	1	11,9%	33,0%*
	2	10,6%	—

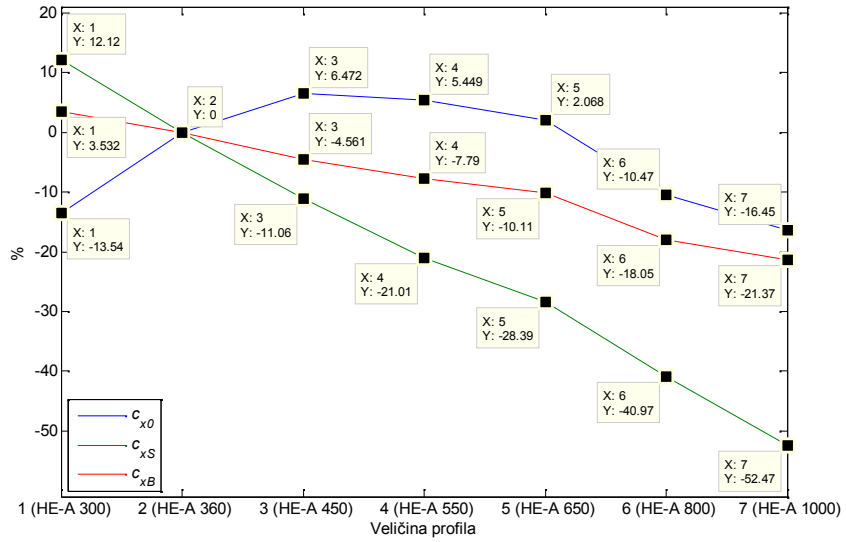
* c_y 1 = 0,05

5.1.2

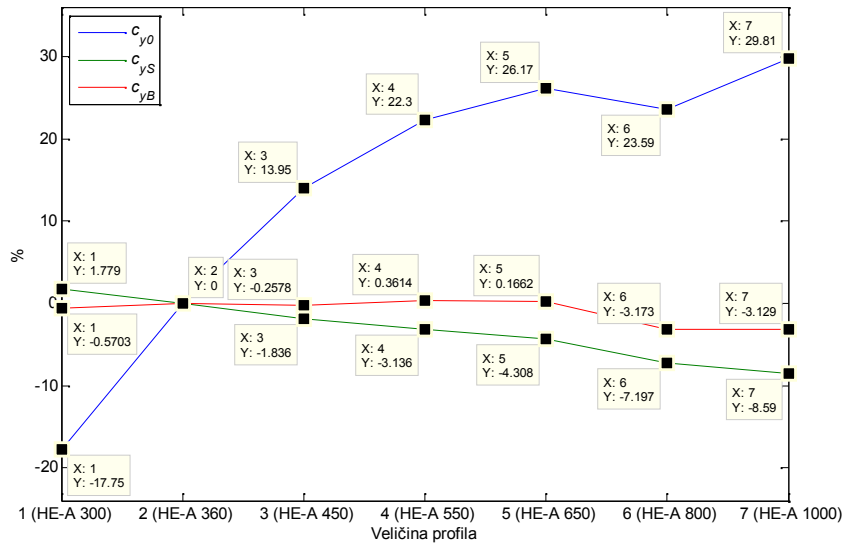
IPE 360
IPE 300
HEA [DIN
1025 (Blatt 3/1963)]
HEA 300, HEA 360, HEA 450, HEA 550, HEA 650, HEA 800
HEA 1000, **5.50 - 5.53,** =0,1.
5.54 - 5.56, **5.4,**
HEA 360







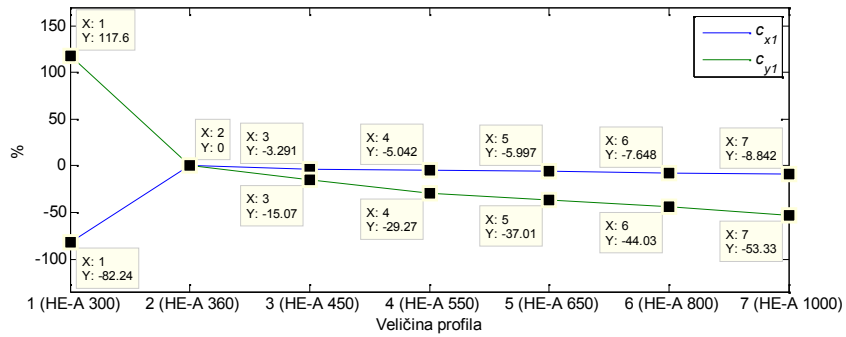
()



()

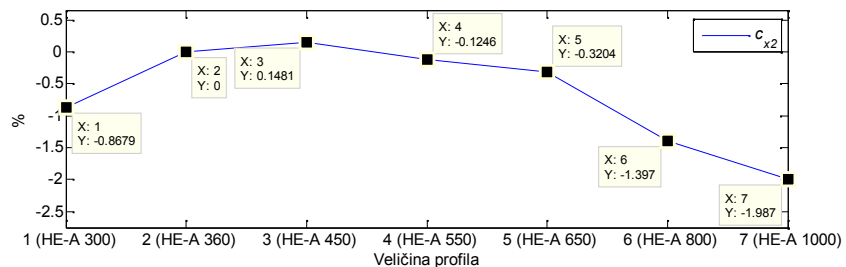
5.54:

=0,1: () c_x ; () c_y



5.55:

1 =0,1



5.56:

$$2 = 0,1$$

c_x

5.4:

$$= 0,1$$

	c_x		c_y	
	min.	max.	min.	max.
0	-16,5%	6,5%	-17,8%	29,8%
S	-52,7%	12,1%	-8,6%	1,8%
1	-82,2%	-3,3%	-53,3%	117,6%
2	-2,0%	0,2%	-	-
B	-21,4%	3,5%	-3,2%	0,4%

5.54 - 5.56,

5.4,

:

•

c_x

;

0, S B -16,5%, -52,7% -21,4%,

;

•

c_x

0, S B

6,5%, 12,1,7% 3,5%,

;

,

,

(10%);

•

c_y

0 (-17,8% 29,8%),

(

10%);

S B

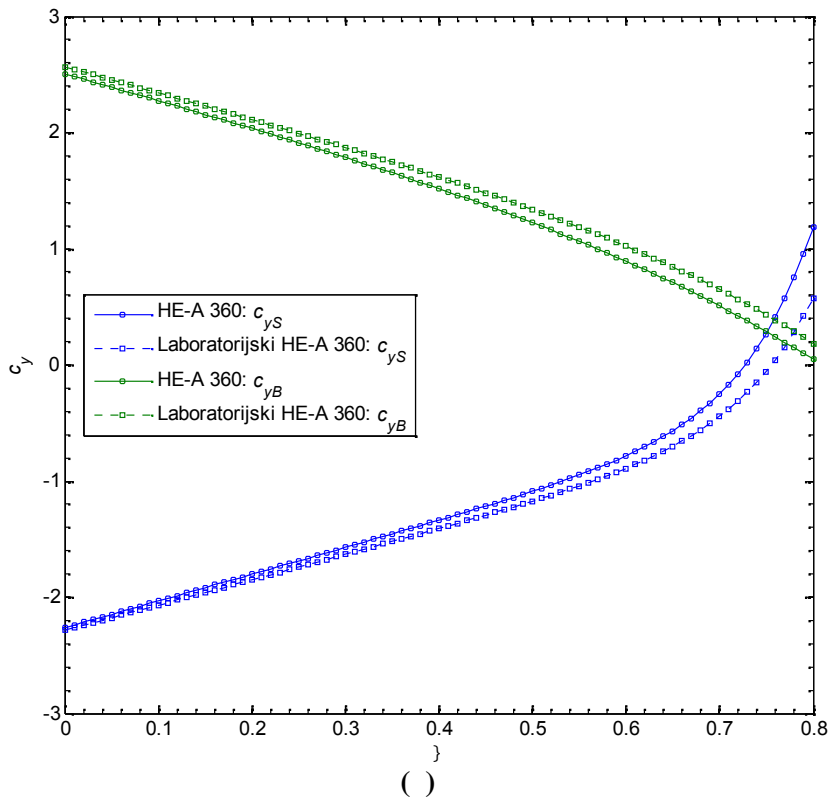
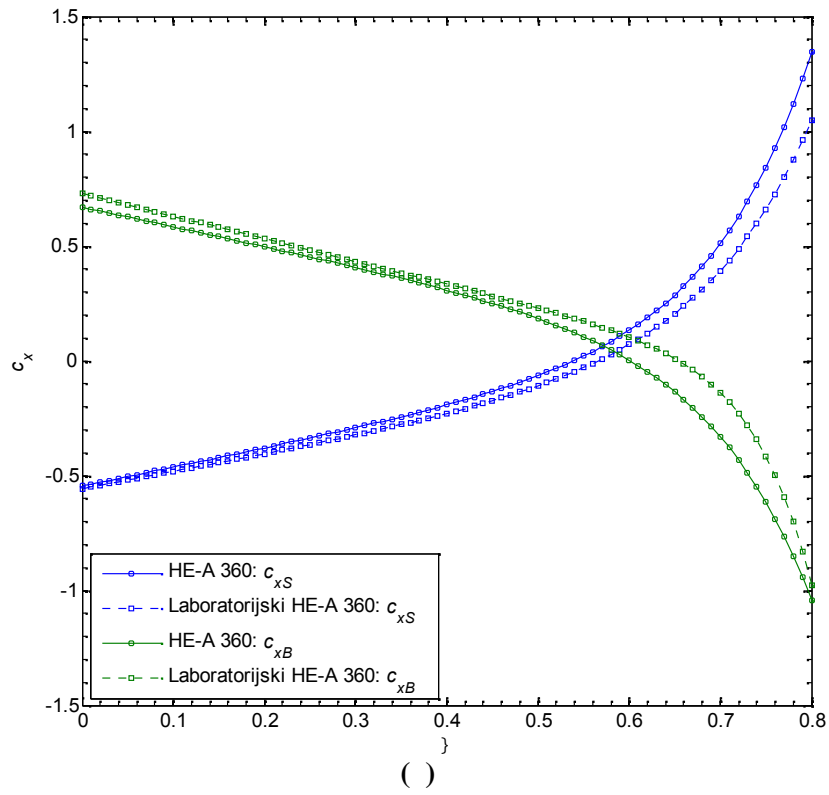
- 10%;
1, c_x -82,7% HEA 300;
,
10%, 5.55,
;
- 1 117,6% -53,3%, 5.55;
,
10%
- 2 ; , c_x 2
.

5.1.3

HEA 360
, 2.1,
,
5.57 - 5.63, 5.5.

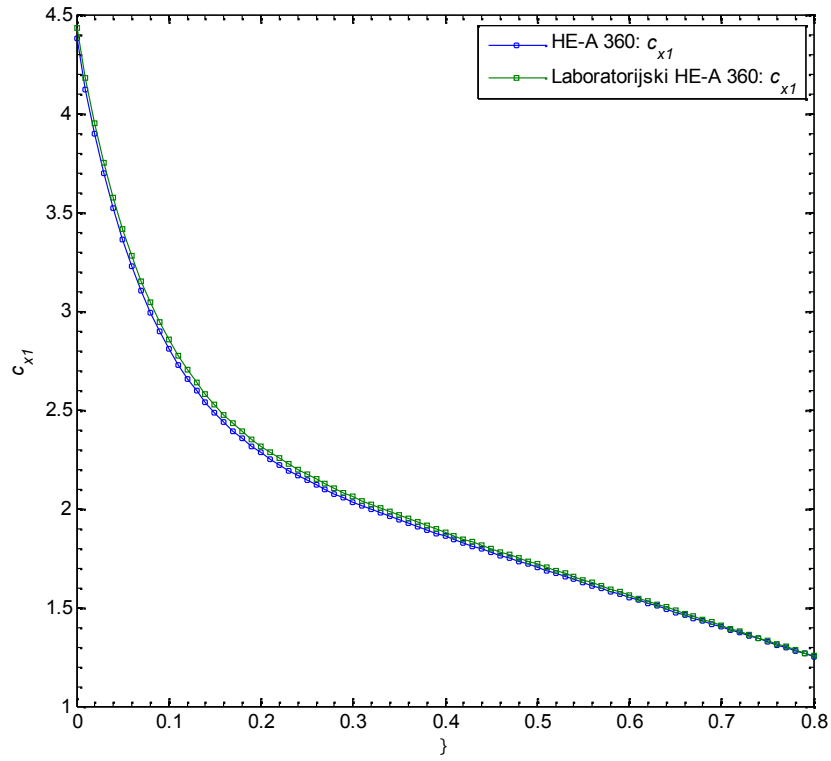
5.5:

	HEA 360		HEA 360	
	min.	c_x max.	min.	c_y max.
S	2,4%	10,7%	1,1%	3,8%
1	1,2%	1,6%	-2,4%	0,4%
2	0,9%	2,2%	-	-
B	6,4%	9,0%	2,5%	4,8%

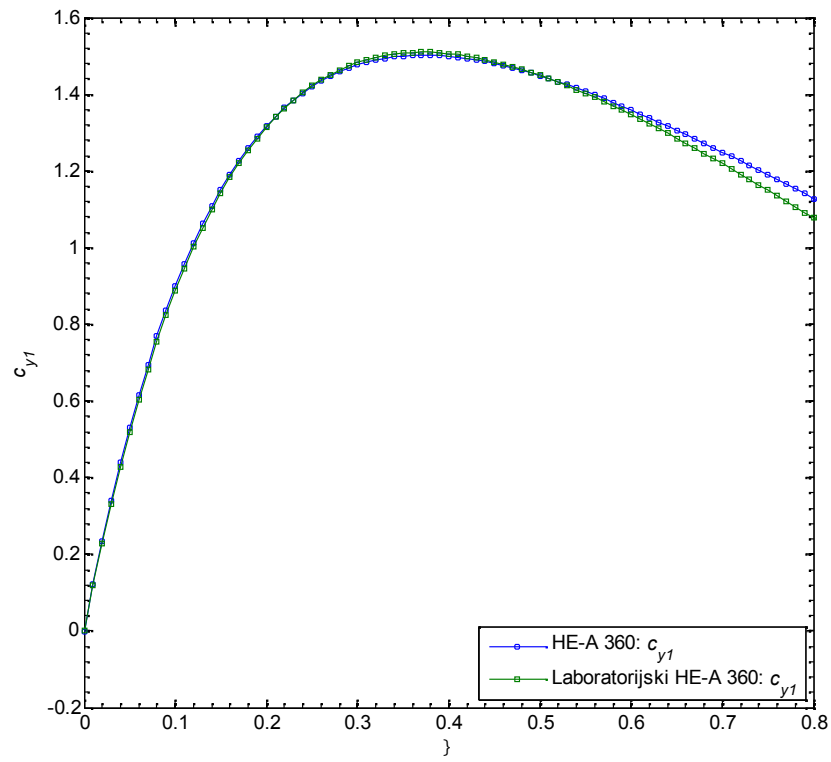


5.57:

: () c_x ; () c_y



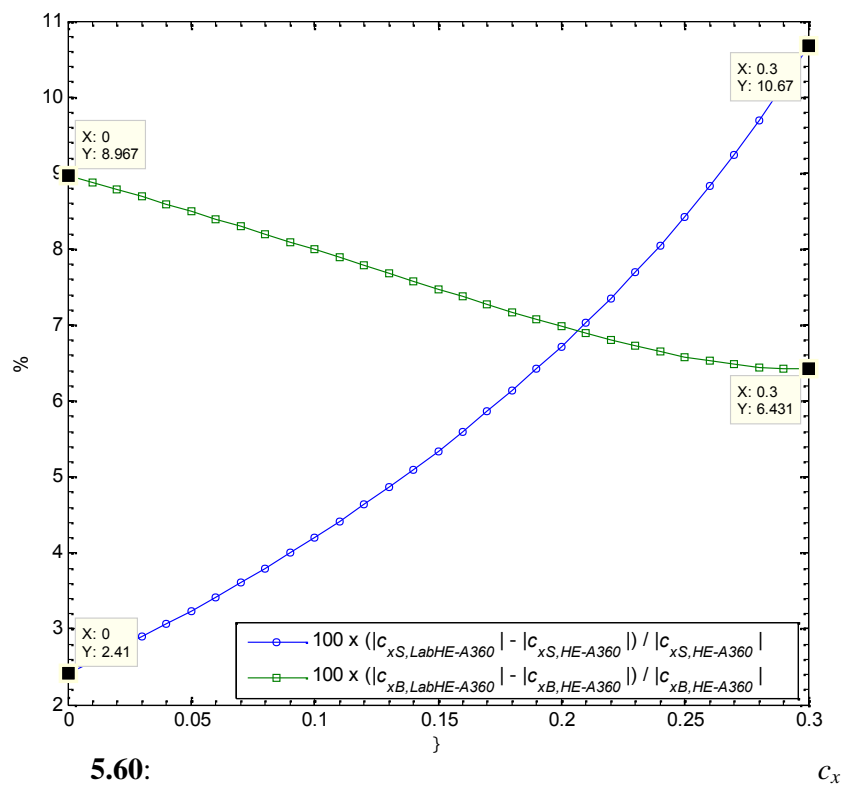
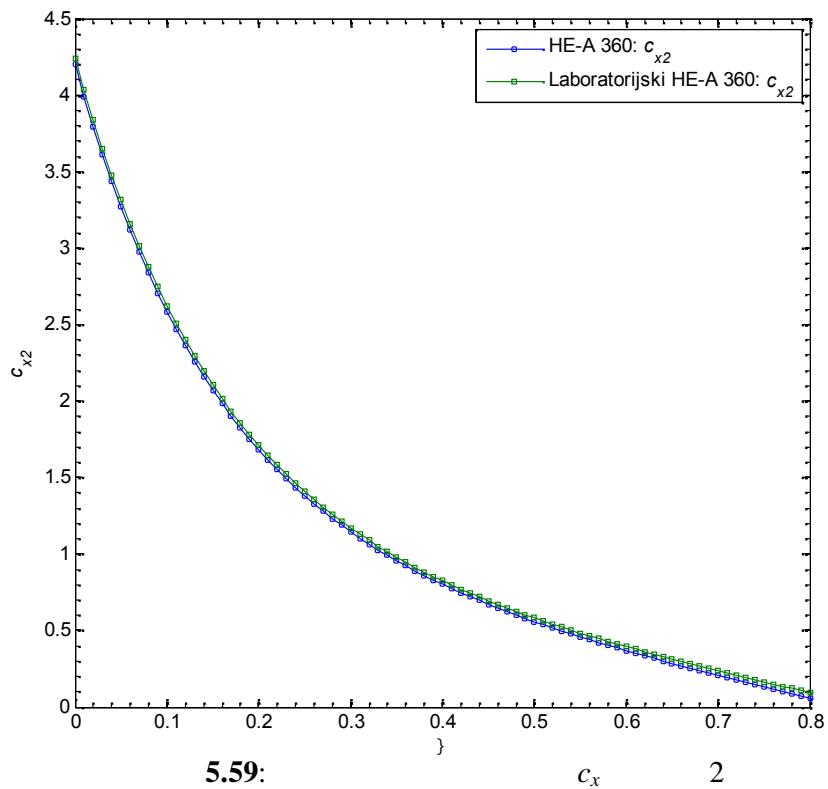
(a)

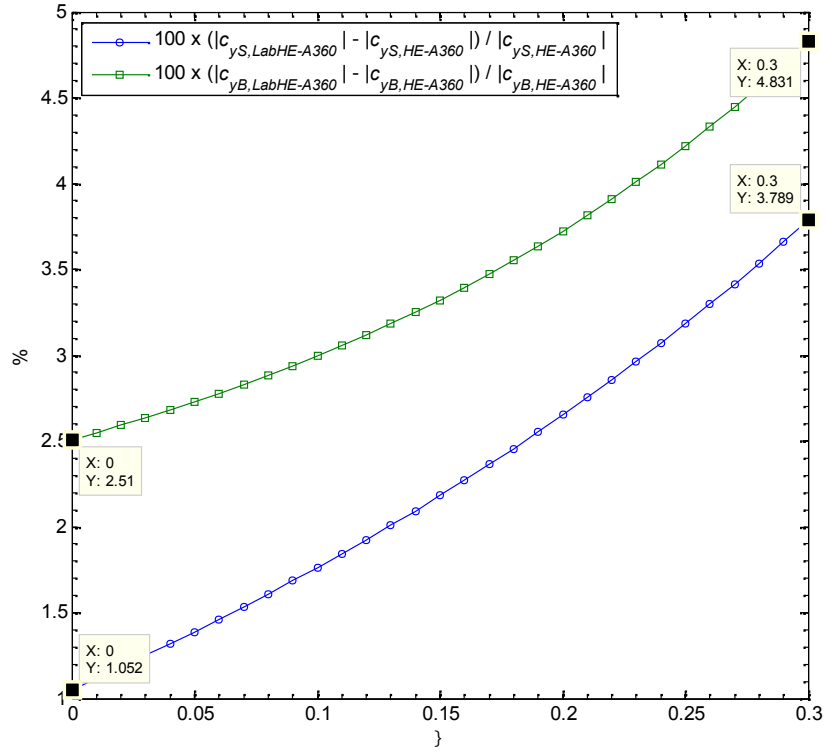


()

5.58:

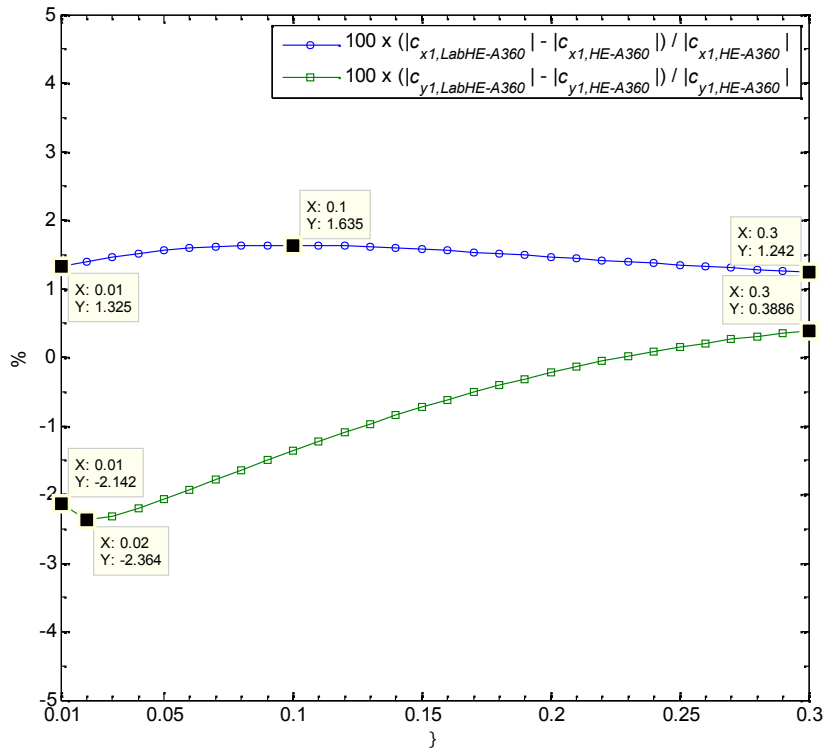
1: () c_x ; () c_y





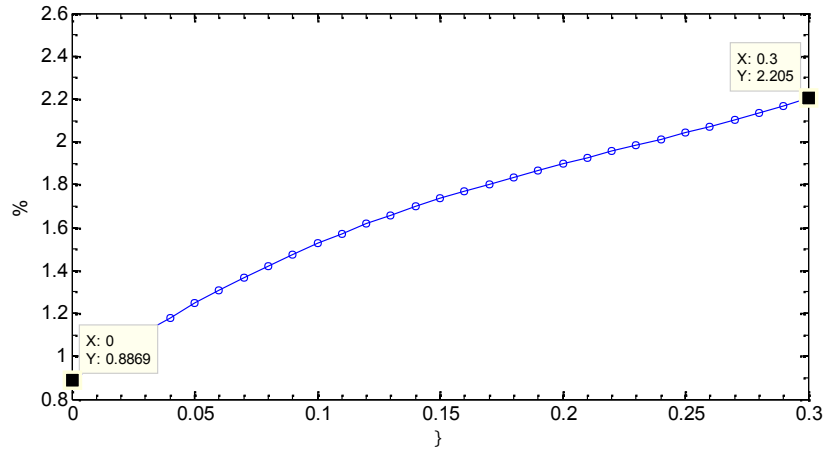
5.61:

Cy



5.62:

1



5.63: c_x 2

, 5.57 - 5.63, 5.5,
0 0,3, :

•

HEA 360 HEA 360,

c_y 1;

•

S, , 9,0% B; : 10,7%
5%.

5.2

•

EN 15011 [5]

•

0 0,3 (,

)

c_x

,

[5]

;

•

,

,

;

()

,

[5],

,

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•

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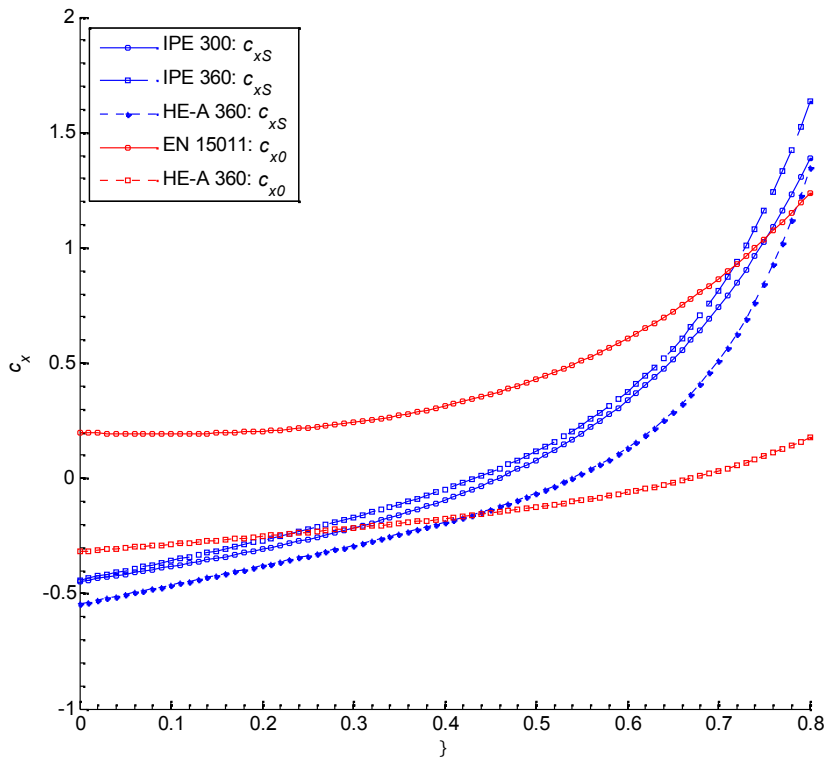
,

.

[5].

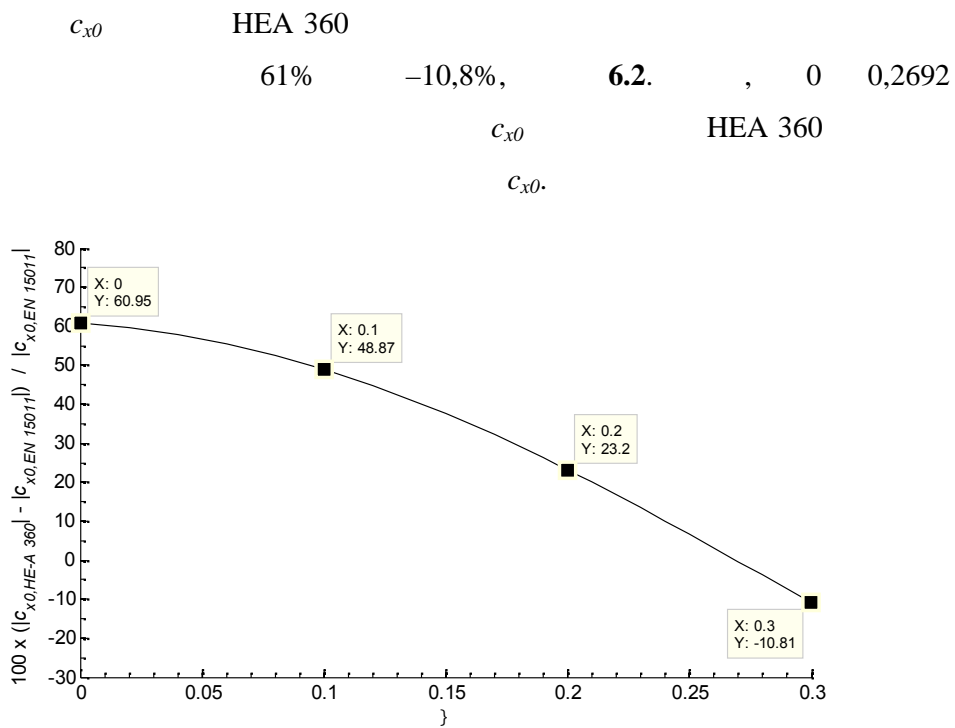
6.

c_x / ,
 (0 S, 2.1), , 6.1.
 0 (c_{x0})
 EN 15011 (: c_{x0})
 HEA 360, , c_x 0
 >0,67, 6.1,
 (0,3).



6.1:

0 S (c_x) /



6.2:

c_{x0} HEA 360

c_{x0}

S (c_{xS}),

c_{x0} , 0 0,3

6.3.

HEA 360

0 0,3

175,1% 20,4%,

6.3.

IPE 300

126,0%

=0,283,

-10,7%

=0,3,

6.3.

IPE 360

123,0%

=0,251

-29,8%

=0,3,

6.3.

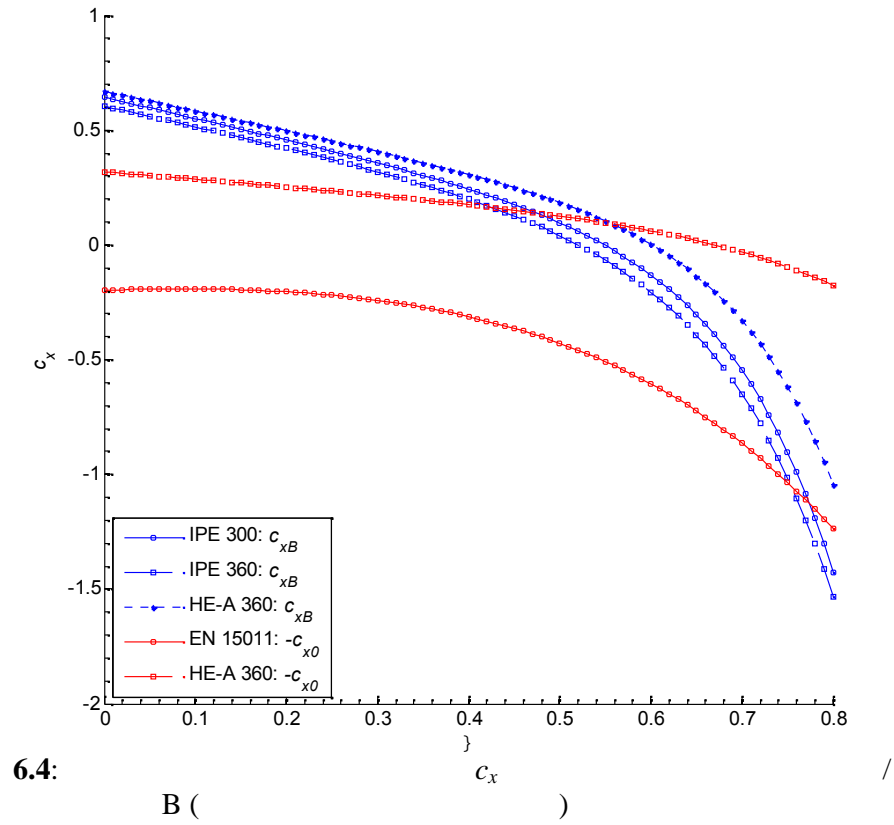
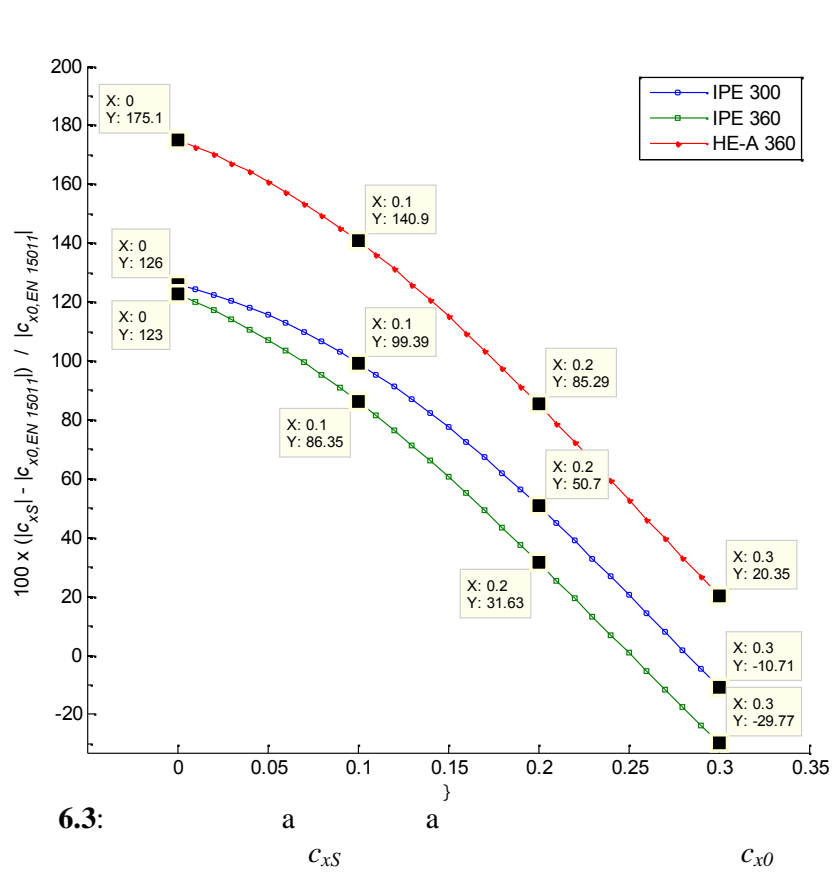
0

EN 15011 [5]

6.4,

B ()

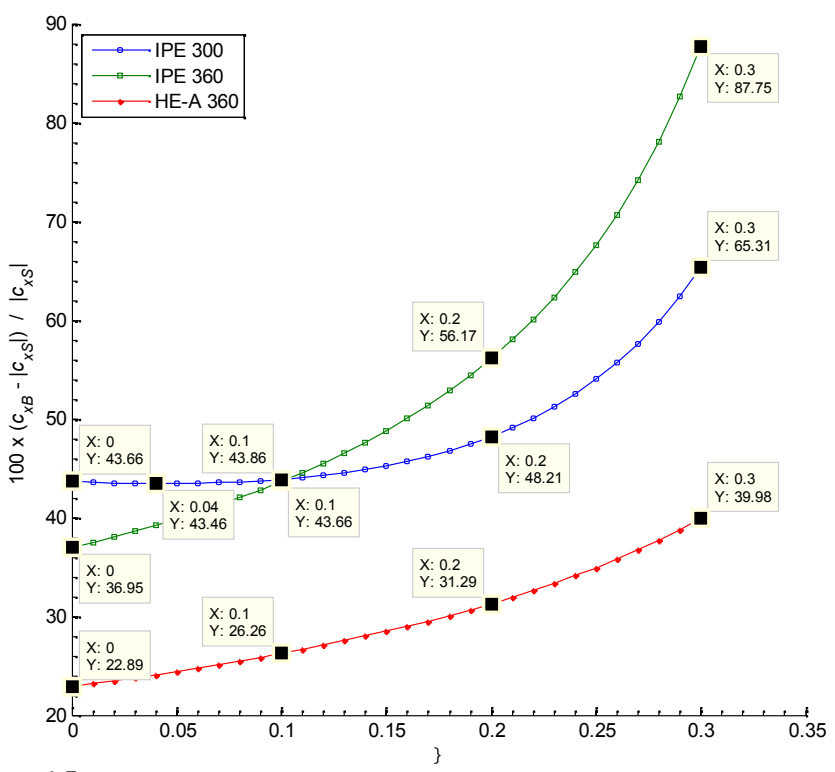
0,



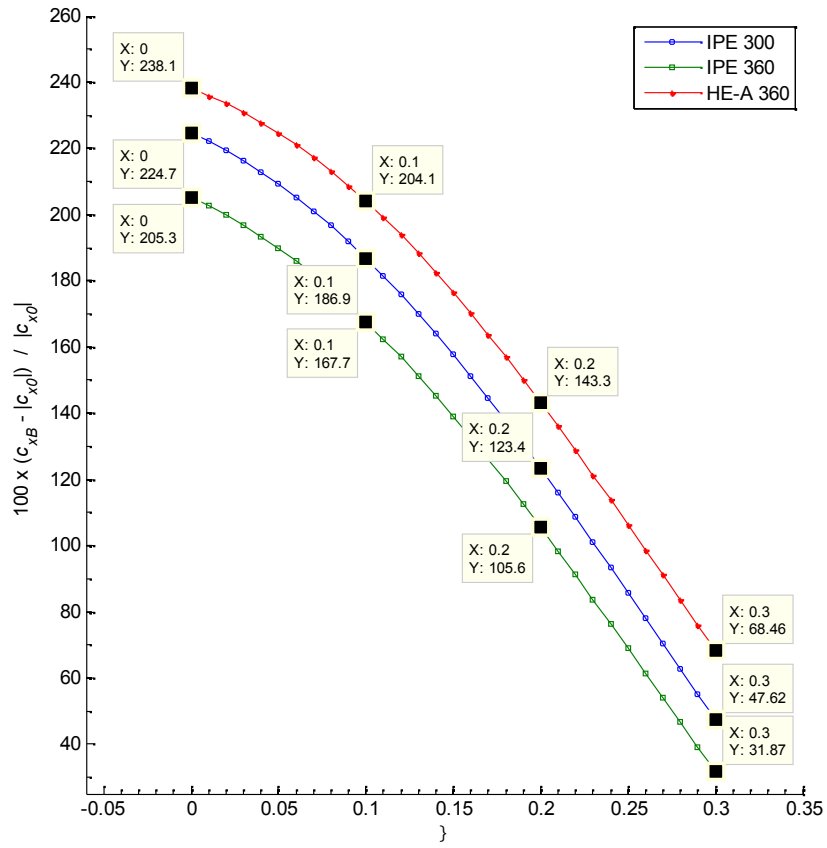
c_x B (c_{xB}) , 0 0,3
6.4,
 S (c_{xS})
6.5. IPE 300
 43,7% 43,5% =0,04,
 65,3% =0,3, **6.5.** IPE 360 ,
 37,0% 87,8%.
 HEA 360,
 22,9% 40,0%, **6.5.** ,
 c_{xB}
 c_{x0} ,

6.6.

HEA 360 (238,1% =0, 68,5% =0,3), IPE 360
 (205,3% =0, 31,9% =0,3), **6.6.**



6.5: a } c_x
 (B S)



6.6:

a

c_{xB}

c_{x0}

c_y

/

,

(0 S),

,

6.7.

c_y

S,

c_y

0.

HEA 360,

6.7.

HEA 360

c_{y0}

c_{y0}

36,5%

=0,

,

25,4%

=0,3,

6.8.

c_{yS}

c_{y0}

(IPE 300

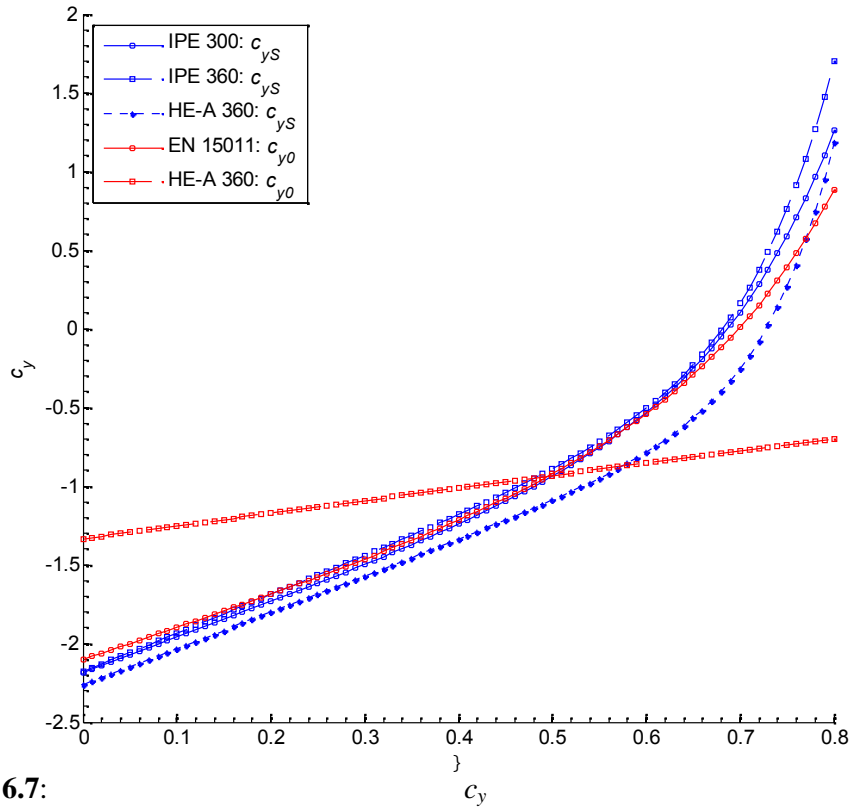
IPE 360)

3,8%,

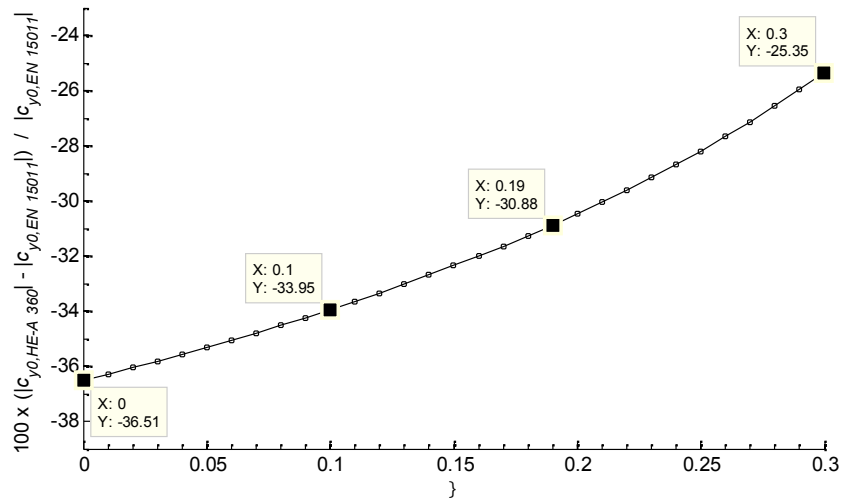
6.9.

HEA 360

7,6%, 6.9.

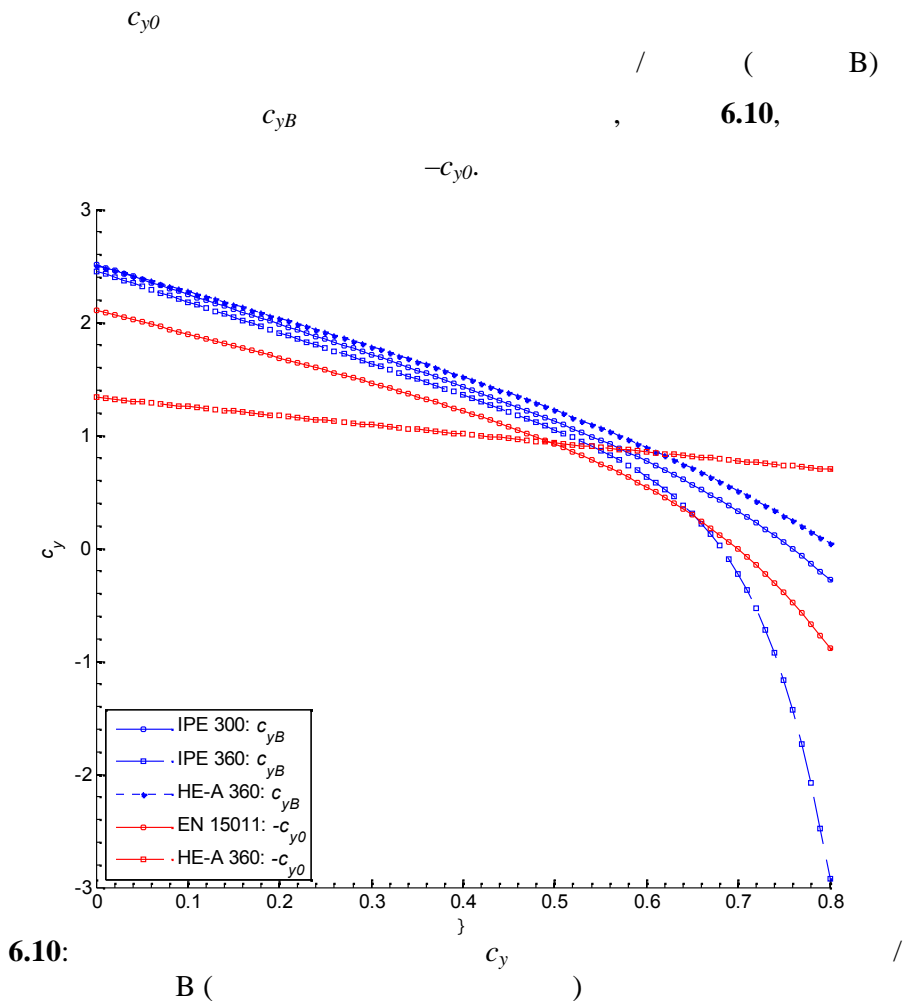
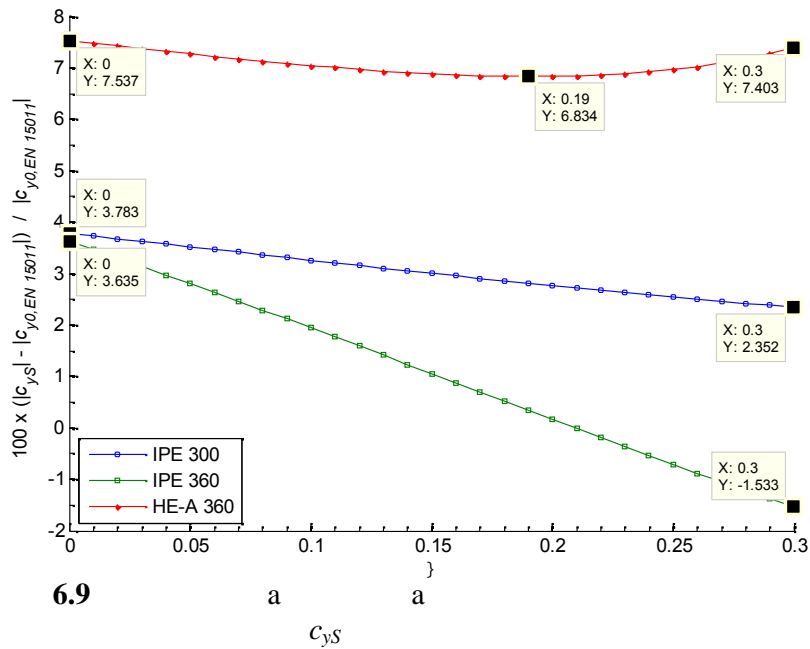


6.7:



6.8:

HEA 360
 c_{y0}



0 0,3

c_{yB}

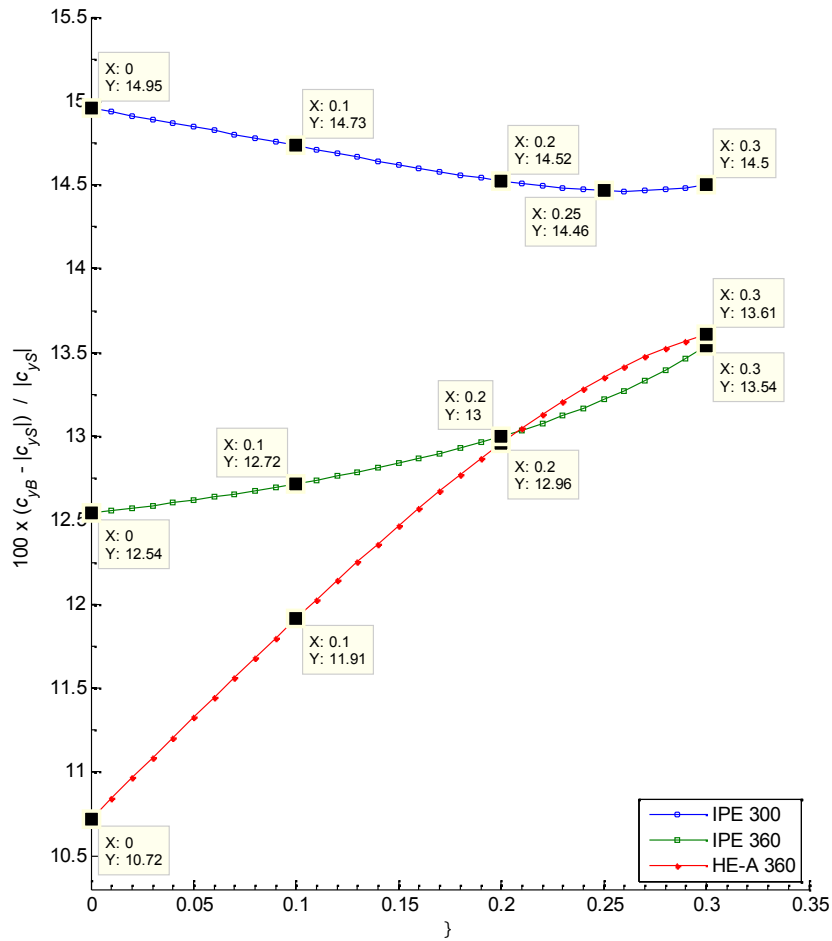
c_{yS}

6.11.

IPE 300.

14,5% 15,0%, 6.11. IPE 360,
HEA 360,

IPE 360 12,5% 13,5%,
HEA 360 10,7% 13,6%, 6.11.



6.11:

a

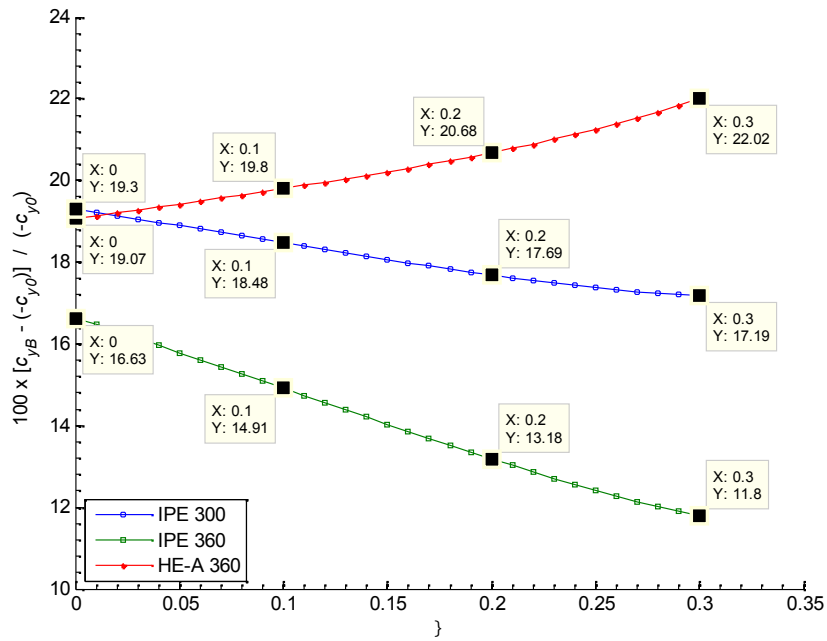
(B S)

c_y

c_{yB}

$-c_{y0}$

0 0,3, 6.12. K HEA 360
 19,1% 22,0%, 6.12.,
 , 6.12,
 IPE 300 19,3% 17,2%, IPE 360,
 16,6% 11,8%.



6.12: a c_x $-c_{y0}$ c_{yB}

c_x 1 (c_{x1})

6.13.

c_{x1} .

c_{x1}

c_{x1} , 6.14.

HEA 360. 21,0%

=0,05 24,1%,

13,8%, 6.14.

IPE 300

8,1%

14,9% (=0,06),

3,2%.

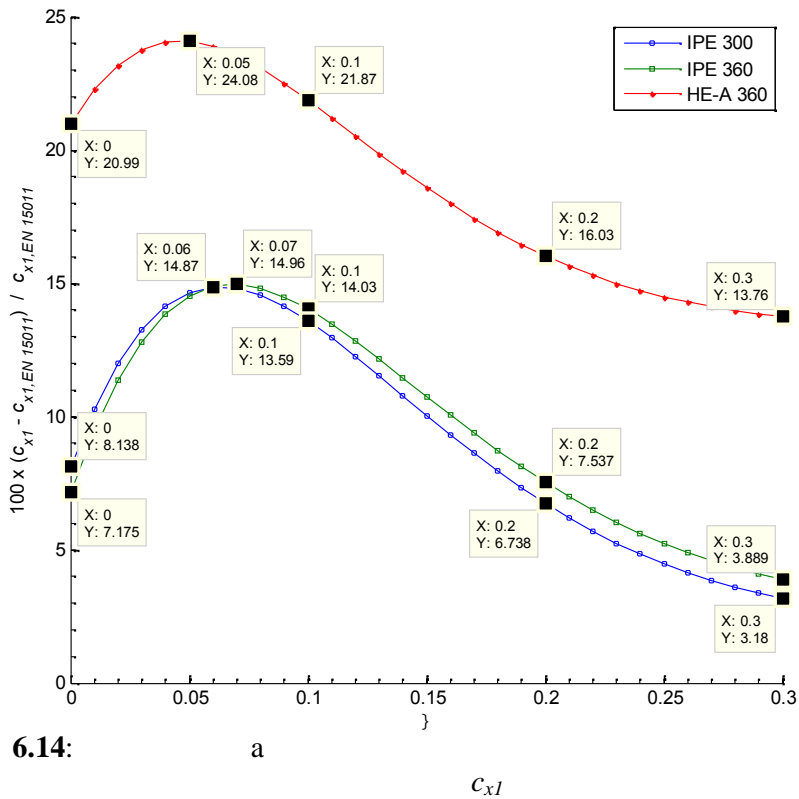
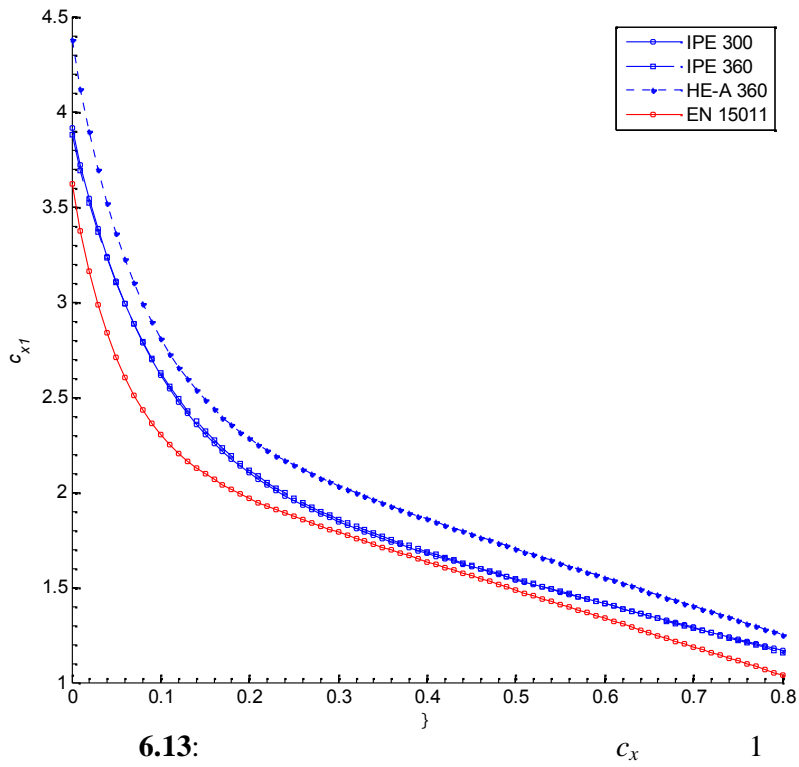
IPE 360

7,2%

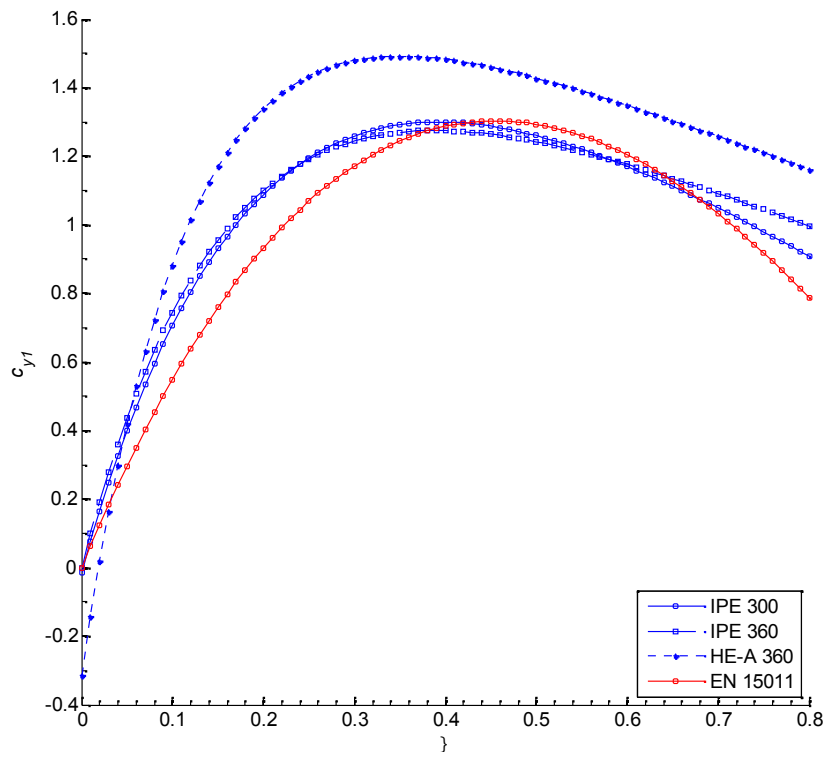
15,0%
3,9%

=0,07,

6.14.



6.15. $0,05$ $0,3^2$ c_{y1} c_{y1}
 HEA 360 $41,5\%$
 $=0,1$ $61,0\%$
 $26,2\%$ **6.16.**
 c_{y1}
 IPE 300 $34,7\%$
 $7,5\%$ IPE 360 $47,4\%$ $6,2\%$ **6.16.**



6.15:

c_y 1

c_x 2 (c_{x2})

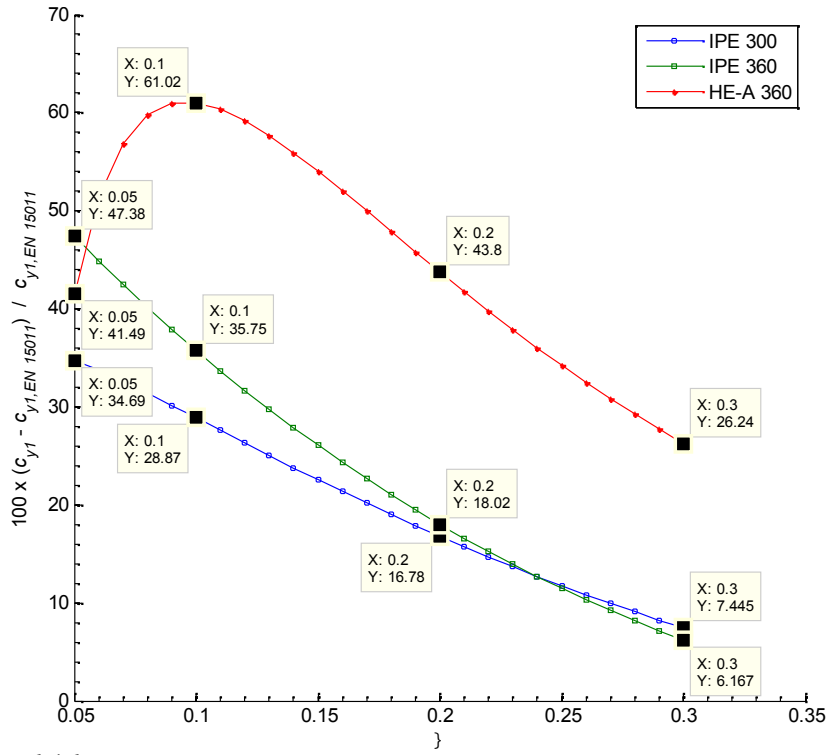
(IPE 300 IPE 360)

6.17.

(HEA 360),

c_{x2} .

² <0,05

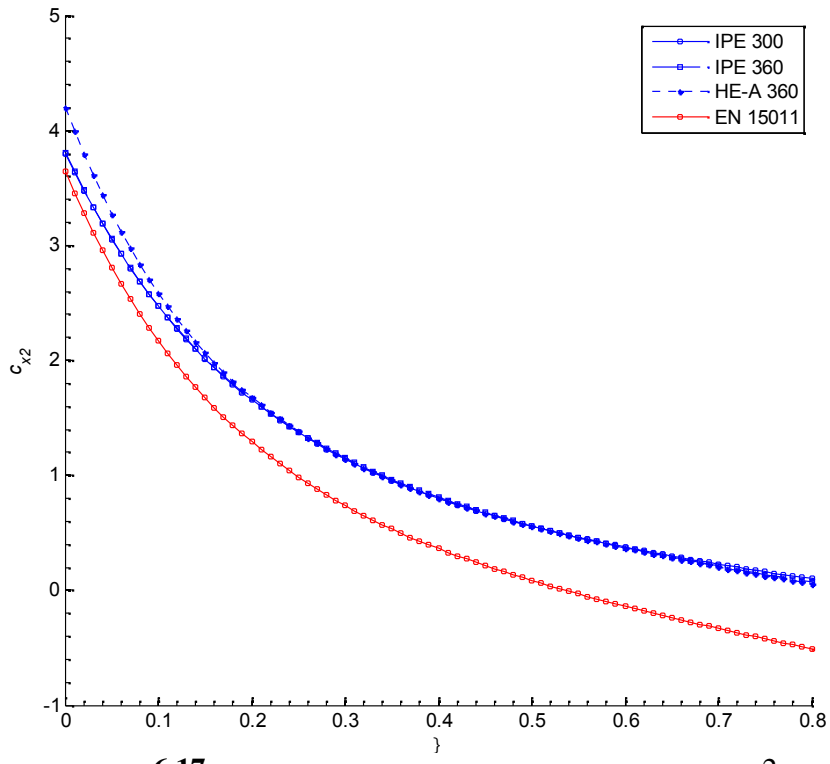


6.16:

a

c_{y1}

c_{y1}

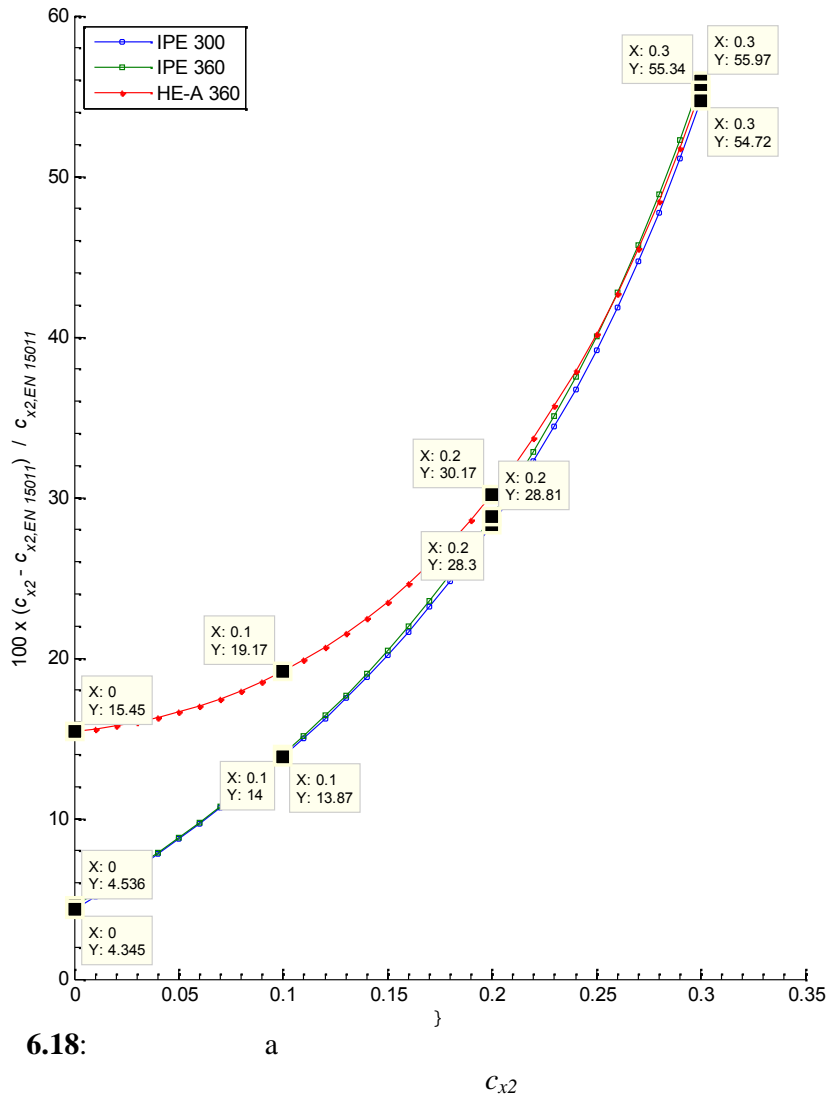


6.17:

c_x

2

HEA 360
 4,4% 54,7%,
 15,5% 55,3%,
 IPE 360
 4,5% 56,0%,
 IPE 300



6.1

IPE 300 IPE 360

HEA 360)
 EN 15011 [5],

(0,3),

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(0);

c_{x0}

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c_{x0}

HEA 360

(

-10,8% 61,0%)

c_{x0} ;

•

HEA 360

S

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B

(

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),

c_x

0,

, $|c_{xS}| > |c_{x0}|$;

•

,

c_{xS}

c_{x0} ,

:

HEA 360

20,4%

175,1%,

IPE 300

-10,7%

126,0%,

IPE 360

-29,8%

123,0%;

•

c_x

B (c_{xB})

(c_{xS}),

: IPE 300 65,3% 43,5%,
 IPE 360 37,0% 87,8%, HEA 360 22,9%
 40,0%; c_{x0} ,

c_{xB} ,

, :
 HEA 360 31,9% 205,3%, IPE 300 47,6%
 224,7%, IPE 360 205,3% 31,9%;

- c_y 0 (c_{y0})
 HEA 360
 c_{y0} , -36,5%
 -25,4%;

- c_y
 S (c_{yS}) c_{y0}
 ;
 (IPE)
 3,8%, HEA 360
 7,8%;

- c_y B (c_{yB})
 c_{yS} ,
 : IPE 300 14,5% 15,0%,
 IPE 360 12,5% 13,5%, HEA 360 10,7%
 13,6%;

- c_{yB}
 $-c_{y0}$,
 19,1% 22,0%
 HEA 360, IPE 300 17,2% 19,3%,
 IPE 360 11,8% 16,6%;

- | | | | | | | |
|---------|--------|---------|-------|--------|----------------|---------|
| | | | c_x | | 1 (c_{x1}) | |
| | | | | | c_{x1} , | |
| HEA 360 | | | | | | 13,8% |
| 24,1%, | | IPE 300 | 3,2% | 14,9%, | | IPE 360 |
| 3,9% | 15,0%; | | | | | |

- | | | | | | | |
|---------|--------|---------|-------|--------|----------------|---------|
| | | | c_y | | 1 (c_{y1}) | |
| | | | | | c_{y1} , | |
| HEA 360 | | | | | | 26,2% |
| 61,0%, | | IPE 300 | 7,5% | 34,7%, | | IPE 360 |
| 6,2% | 47,4%; | | | | | |

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|--------------|--------|----------|------|--------|------------|---------|
| | | | | | c_x | 2 |
| (c_{x2}) | | | | | c_{x2} , | |
| 15,5% | 55,3% | HEA 360, | | | | IPE 300 |
| 4,4% | 54,7%, | IPE 360 | 4,5% | 56,0%. | | |

7. |

7.1

7.2

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