Cross section width $b := 590$

Cross section height $h := 140$

Cross section steel bars $As := 300$ $A := b \cdot h$ $I := \frac{b \cdot h^3}{12}$

Centre steel bar from bottom $c := 5$

$d := h - c = 135$

$a := \frac{As}{b} = 0,5085$

$h1 := h - c - \frac{a}{2} = 134,7458$

$h2 := c - \frac{a}{2} = 4,7458$

$n1 := 10$ $n2 := 1$

$t1 := \frac{h1}{n1} = 13,4746$ $t2 := \frac{h2}{n2} = 4,7458$

Constutive laws

Concrete C20/25

$fcm := 28$ $fck := 20$ $\alpha c := 0,85$ $\gamma c := 1,5$

$Ecm := 30000$ $fctk := 1,5$ $Ec := 24900$

$\varepsilon c1 := 0,002$ $\varepsilon cu := 0,0035$ $fctd := \frac{fctk}{\gamma c} = 1$

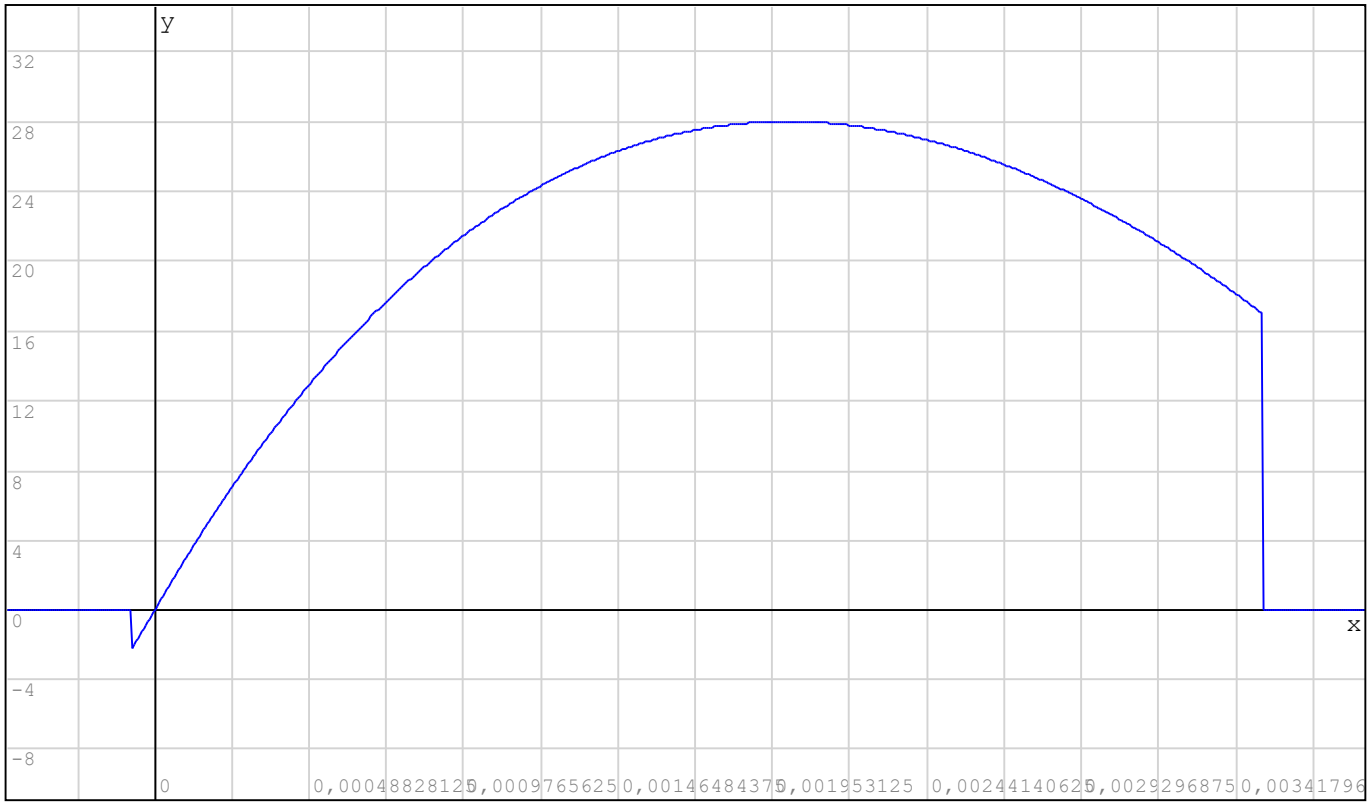
$fctm := 2,2$

$\varepsilon ctu := \frac{fctd}{Ec} = 4,0161 \cdot 10^{-5}$ $\varepsilon ctum := \frac{fctm}{Ecm} = 7,3333 \cdot 10^{-5}$

$k := 1,05 \cdot Ecm \cdot \frac{\varepsilon c1}{fcm} = 2,25$

$$\sigma c(\varepsilon c) := \begin{cases} \dfrac{\left(k \cdot \dfrac{\varepsilon c}{\varepsilon c1} - \left(\dfrac{\varepsilon c}{\varepsilon c1}\right)^2\right)}{\left(1 + (k-2) \cdot \dfrac{\varepsilon c}{\varepsilon c1}\right)} \cdot fcm & \text{if } (\varepsilon c \geq 0) \wedge (\varepsilon c < \varepsilon cu) \\ \dfrac{\varepsilon c}{\varepsilon ctum} \cdot fctm & \text{else if } (\varepsilon c < 0) \wedge (\varepsilon c > -\varepsilon ctum) \\ 0 & \text{else} \end{cases}$$

$fcd := \alpha c \cdot \frac{fck}{\gamma c} = 11,3333$



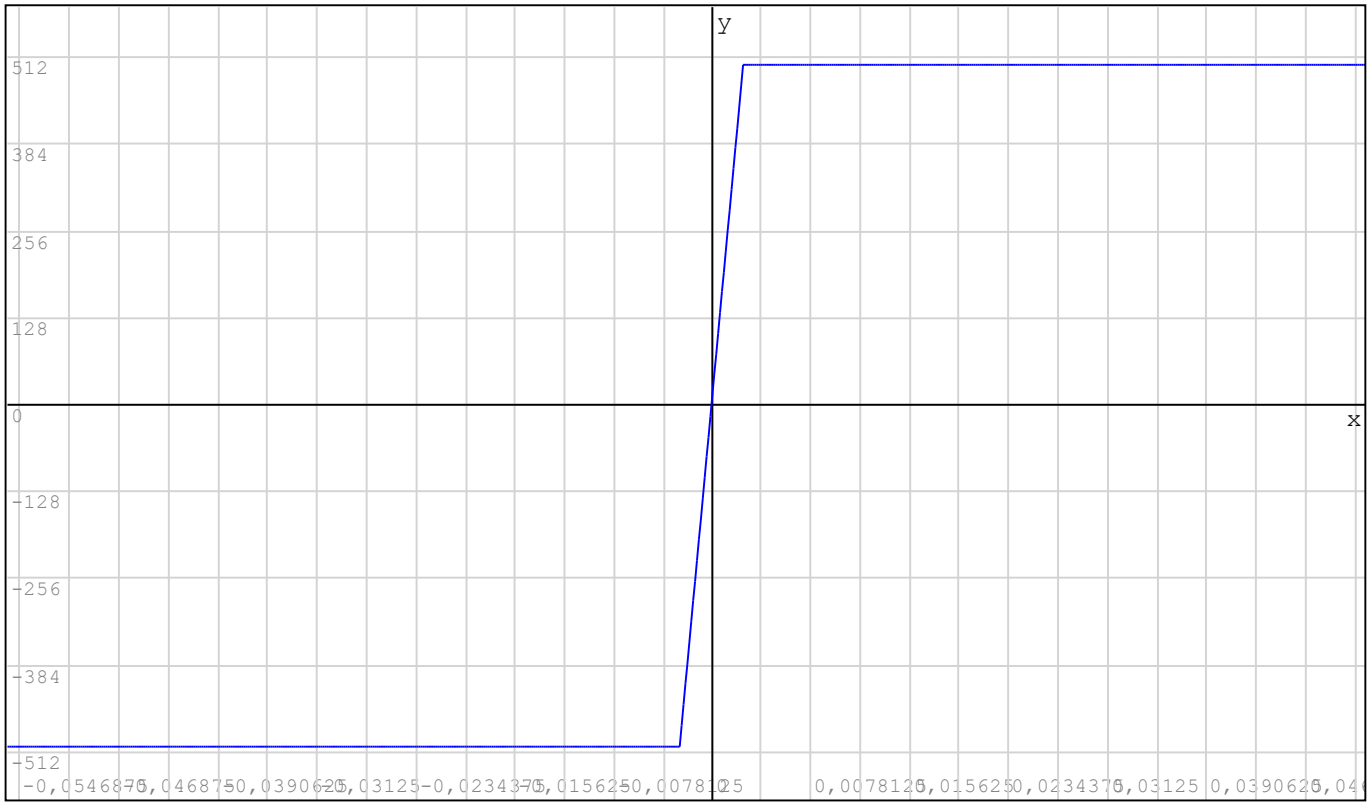
$\sigma c(x)$

Steel $fyk := 500$ $\gamma s := 1,15$ $Es := 200000$

$$fyd := \frac{fyk}{\gamma s} = 434,7826$$

$$\varepsilon e := \frac{fyk}{Es} = 0,0025 \qquad \varepsilon u := \frac{67,5}{1000}$$

$$\sigma s(\varepsilon s) := \begin{cases} \varepsilon s \cdot Es & \text{if } ((\varepsilon s > 0) \wedge (\varepsilon s < \varepsilon e)) \vee ((\varepsilon s < 0) \wedge (\varepsilon s > -\varepsilon e)) \\ fyk & \text{else if } \varepsilon s > \varepsilon e \\ -fyk & \text{else} \end{cases}$$



$\sigma s(x)$

Moment curvature

$N := 0$

$yn := \frac{h}{2}$

$\varepsilon e := \frac{fyk}{Es} = 0,0025$

$x1 := \frac{As \cdot fyk + N}{0,8 \cdot b \cdot fcm} = 11,3499$

$z := d - \frac{x1}{3} = 131,2167$

$M1 := \left(As \cdot fyk \cdot z + N \cdot \left(yn - \frac{x1}{3}\right)\right) = 1,9683 \cdot 10^{7}$

$\chi e := \frac{\varepsilon e}{d - x1} = 2,0218 \cdot 10^{-5}$

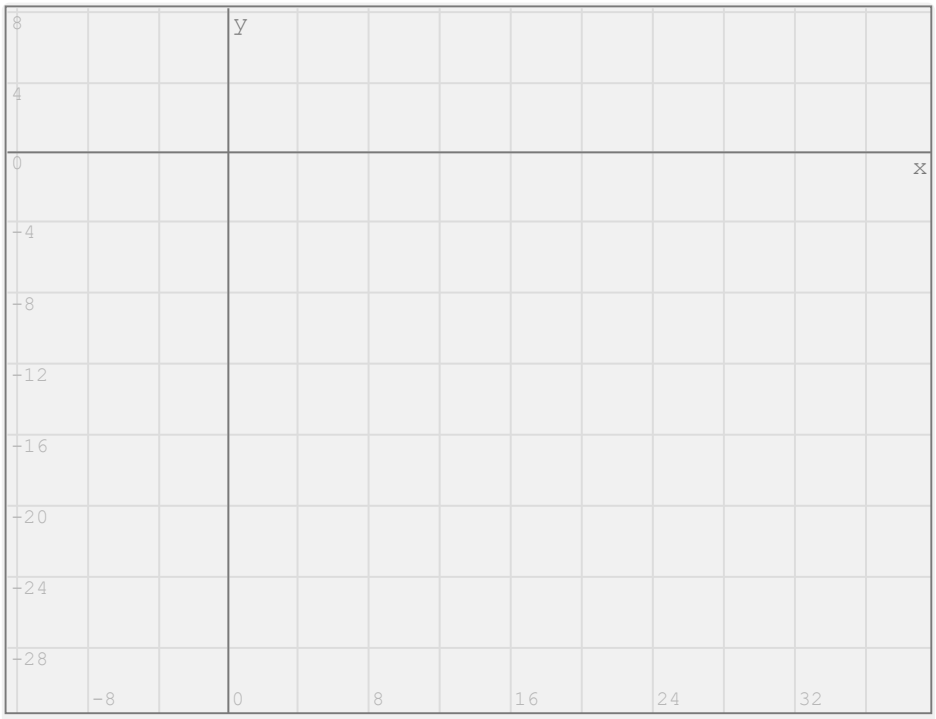
$\chi u := \frac{\varepsilon u}{d - x1} = 0,0005$

$Mcr := \left(fctm + \frac{N}{A}\right) \cdot \frac{I}{\frac{h}{2}} = 4,2401 \cdot 10^{6}$

$\chi cr := \frac{fctm + \frac{N}{A}}{Ec} \cdot \frac{1}{\frac{h}{2}} = 1,2622 \cdot 10^{-6}$

$$M(\chi; N) := \begin{vmatrix} x1 := \frac{As \cdot fyk + N}{0,8 \cdot b \cdot fcm} \\ z := d - \frac{x1}{3} \\ M1 := As \cdot fyk \cdot z + N \cdot \left(yn - \frac{x1}{3}\right) \\ \chi e := \frac{\varepsilon e}{d - x1} \\ \chi u := \frac{\varepsilon u}{d - x1} \\ Mcr := \left(fctm + \frac{N}{A}\right) \cdot \frac{I}{\frac{h}{2}} \\ \chi cr := \frac{fctm + \frac{N}{A}}{Ec} \cdot \frac{1}{\frac{h}{2}} \\ \text{if } ((\chi \geq 0) \wedge (\chi < \chi cr)) \\ \quad \frac{Mcr \cdot \chi}{\chi cr} \\ \text{else if } (\chi \geq \chi cr) \wedge (\chi \leq \chi e) \\ \quad Mcr \cdot \left(1 - \frac{\chi - \chi cr}{\chi e - \chi cr}\right) + M1 \cdot \frac{\chi - \chi cr}{\chi e - \chi cr} \\ \text{else if } \chi > \chi e \\ \quad M1 \\ \text{else} \\ \quad 0 \end{vmatrix}$$

$M(\chi e; N) = 1,9683 \cdot 10^{7}$



$$\begin{cases} M(x;0) \\ M(x;10000) \\ M(x;100000) \end{cases}$$

$$\chi cr := \frac{fctm}{Ec} \cdot \frac{1}{\frac{h}{2}} = 1,2622 \cdot 10^{-6}$$

$$\chi 0 := 2 \cdot \chi e = 4,0437 \cdot 10^{-5}$$

$$\varepsilon c0 := \chi 0 \cdot \frac{h}{2} = 0,0028$$

$$\varepsilon c(y) := \varepsilon c0 \cdot \left(1 - \frac{2 \cdot y}{h}\right)$$

$$kk := \frac{\chi cr \cdot \frac{h}{2}}{20} = 4,4177 \cdot 10^{-6}$$

$$tt := matrix(n1 + n2 + 1; 5)$$

$$hh1 := 0$$

for $i \in [1..(n1)]$

$$hh1 := hh1 + t1$$

$$tt_{i,1} := t1$$

$$tt_{i,2} := hh1 - \frac{t1}{2}$$

$$tt_{i,3} := "concr"$$

$$tt_{i,4} := \varepsilon c\left(hh1 - \frac{t1}{2}\right)$$

$$tt_{i,5} := \sigma c\left(tt_{i,4}\right)$$

$$tt_{n1+1\,1} := a$$

$$tt_{n1+1\,2} := hh1 + \frac{a}{2}$$

$$tt_{n1+1\,3} := \text{"steel"}$$

$$tt_{n1+1\,4} := \varepsilon c\left(hh1 + \frac{a}{2}\right)$$

$$tt_{n1+1\,5} := \sigma s\left(tt_{n1+1\,4}\right)$$

$$hh2 := hh1 + a$$

for $i \in [(n1+2)..(n1+n2+1)]$

$$hh2 := hh2 + t2$$

$$tt_{i\,1} := t2$$

$$tt_{i\,2} := hh2 - \frac{t2}{2}$$

$$tt_{i\,3} := \text{"concr"}$$

$$tt_{i\,4} := \varepsilon c\left(hh2 - \frac{t2}{2}\right)$$

$$tt_{i\,5} := \sigma c\left(tt_{i\,4}\right)$$

$$N1 := 10000 \qquad times := 0$$

while $(|N1| > 2000)$

$$N0 := N1$$

for $i \in [1..n1]$

$$tt_{i\,4} := tt_{i\,4} - kk$$

$$tt_{i\,5} := \sigma c\left(tt_{i\,4}\right)$$

$$tt_{n1+1\,4} := tt_{i\,4} - kk$$

$$tt_{n1+1\,5} := \sigma s\left(tt_{n1+1\,4}\right)$$

for $i \in [(n1+2)..(n1+n2+1)]$

$$tt_{i\,4} := tt_{i\,4} - kk$$

$$tt_{i\,5} := \sigma c\left(tt_{i\,4}\right)$$

$N1 :=$

$$NN := 0$$

for $i \in [1..rows(tt)]$

$$NN := NN + b \cdot tt_{i\,1} \cdot tt_{i\,5}$$

NN

if $N1 \geq 0$

$$kk := kk$$

else

$$kk := -kk$$

```
N1 := | NN := 0                                  = 1465,0841
      | for i ∈ [1..rows(tt)]
      |   NN := NN + b·tt_i1 ·tt_i5
      | NN
```

```
M := | MM := 0                                       = -1,9081·10^7
     | for i ∈ [1..rows(tt)]
     |   MM := MM + b·tt_i1 ·tt_i5 ·tt_i2
     | MM
```

$$tt = \begin{bmatrix}
6,7373 & 3,3686 & \text{"concr"} & 0,0008 & 18,605 \\
6,7373 & 10,1059 & \text{"concr"} & 0,0005 & 13,4648 \\
6,7373 & 16,8432 & \text{"concr"} & 0,0002 & 6,9761 \\
6,7373 & 23,5805 & \text{"concr"} & -3,1384\cdot10^{-5} & -0,9415 \\
6,7373 & 30,3178 & \text{"concr"} & -0,0003 & 0 \\
6,7373 & 37,0551 & \text{"concr"} & -0,0006 & 0 \\
6,7373 & 43,7924 & \text{"concr"} & -0,0008 & 0 \\
6,7373 & 50,5297 & \text{"concr"} & -0,0011 & 0 \\
6,7373 & 57,2669 & \text{"concr"} & -0,0014 & 0 \\
6,7373 & 64,0042 & \text{"concr"} & -0,0017 & 0 \\
6,7373 & 70,7415 & \text{"concr"} & -0,0019 & 0 \\
6,7373 & 77,4788 & \text{"concr"} & -0,0022 & 0 \\
6,7373 & 84,2161 & \text{"concr"} & -0,0025 & 0 \\
6,7373 & 90,9534 & \text{"concr"} & -0,0028 & 0 \\
6,7373 & 97,6907 & \text{"concr"} & -0,003 & 0 \\
6,7373 & 104,428 & \text{"concr"} & -0,0033 & 0 \\
6,7373 & 111,1653 & \text{"concr"} & -0,0036 & 0 \\
6,7373 & 117,9025 & \text{"concr"} & -0,0038 & 0 \\
6,7373 & 124,6398 & \text{"concr"} & -0,0041 & 0 \\
6,7373 & 131,3771 & \text{"concr"} & -0,0044 & 0 \\
0,5085 & 135 & \text{"steel"} & -0,0044 & -500 \\
4,7458 & 137,6271 & \text{"concr"} & -0,0046 & 0
\end{bmatrix}$$

$N := 0$ $\qquad$ $yn := \frac{h}{2}$ $\qquad$ $\varepsilon e := \frac{fyk}{Es} = 0,0025$

$$x1 := \frac{As \cdot fyk + N}{0,8 \cdot b \cdot fcm} = 11,3499$$

$$z := d - \frac{x1}{3} = 131,2167$$

$$M1 := \left(As \cdot fyk \cdot z + N \cdot \left(yn - \frac{x1}{3}\right)\right) = 1,9683 \cdot 10^{7}$$

$\chi e := \frac{\varepsilon e}{d - x1} = 2,0218 \cdot 10^{-5}$ $\chi u := \frac{\varepsilon u}{d - x1} = 0,0005$

$Mcr := \left(fctm + \frac{N}{A} \right) \cdot \frac{I}{\frac{h}{2}} = 4,2401 \cdot 10^{6}$

$\chi cr := \frac{fctm + \frac{N}{A}}{Ec} \cdot \frac{1}{\frac{h}{2}} = 1,2622 \cdot 10^{-6}$

$tt := \mathrm{matrix}(n1 + n2 + 1;\ 5)$

$\varepsilon c(y;\ \varepsilon c) := \varepsilon c \cdot \left(1 - \frac{2 \cdot y}{h} \right)$

$\chi cr := \frac{fctm}{Ec} \cdot \frac{1}{\frac{h}{2}}$

$Mom(\chi 1) :=$

$\varepsilon c1 := \chi 1 \cdot \frac{h}{2}$

$\varepsilon c(y) := \varepsilon c1 \cdot \left(1 - \frac{2 \cdot y}{h} \right)$

$\chi cr := \frac{fctm}{Ec} \cdot \frac{1}{\frac{h}{2}}$

$kk := \frac{\chi 1}{1000} \cdot \frac{h}{2}$

$hh1 := 0$

for $i \in [1..(n1)]$

$hh1 := hh1 + t1$

$tt_{i,1} := t1$

$tt_{i,2} := hh1 - \frac{t1}{2}$

$tt_{i,3} := \text{"concr"}$

$tt_{i,4} := \varepsilon c \left(hh1 - \frac{t1}{2} \right)$

$tt_{i,5} := \sigma c \left(\varepsilon c \left(hh1 - \frac{t1}{2} \right) \right)$

$tt_{n1+1,1} := a$

$tt_{n1+1,2} := hh1 + \frac{a}{2}$

$tt_{n1+1,3} := \text{"steel"}$

$tt_{n1+1,4} := \varepsilon c \left(hh1 + \frac{a}{2} \right)$

$tt_{n1+1,5} := \sigma s \left(\varepsilon c \left(hh1 + \frac{a}{2} \right) \right)$

$hh2 := hh1 + a$

for $i \in [(n1+2)..(n1+n2+1)]$

$hh2 := hh2 + t2$

$tt_{i,1} := t2$

$tt_{i,2} := hh2 - \frac{t2}{2}$

$tt_{i,3} := \text{"concr"}$

$$tt_{i\,4} := \varepsilon c\left(hh2 - \frac{t2}{2}\right)$$

$$tt_{i\,5} := \sigma c\left(\varepsilon c\left(hh2 - \frac{t2}{2}\right)\right)$$

$N1 := 10000$

$times := 0$

while $(|N1| > 1000)$

$N0 := N1$

for $i \in [1..n1]$

$tt_{i\,4} := tt_{i\,4} - kk$

$tt_{i\,5} := \sigma c\left(tt_{i\,4}\right)$

$tt_{n1+1\,4} := tt_{i\,4} - kk$

$tt_{n1+1\,5} := \sigma s\left(tt_{n1+1\,4}\right)$

for $i \in [(n1+2)..(n1+n2+1)]$

$tt_{i\,4} := tt_{i\,4} - kk$

$tt_{i\,5} := \sigma c\left(tt_{i\,4}\right)$

$N1 :=$ $NN := 0$; for $i \in [1..\mathrm{rows}(tt)]$ $NN := NN + b \cdot tt_{i\,1} \cdot tt_{i\,5}$; NN

$MM := 0$

for $i \in [1..\mathrm{rows}(tt)]$

$MM := MM + b \cdot tt_{i\,1} \cdot tt_{i\,5} \cdot tt_{i\,2}$

MM

$MomCurv := \mathrm{matrix}(9; 2)$

$MomCurv_{1\,1} := 0$

$MomCurv_{1\,2} := 0$

$MomCurv_{2\,1} := \chi cr$

$MomCurv_{2\,2} := |Mom(\chi cr)|$

$MomCurv_{3\,1} := 2 \cdot \chi cr$

$MomCurv_{3\,2} := |Mom(2 \cdot \chi cr)|$

$MomCurv_{4\,1} := 2,2 \cdot \chi cr$

$$MomCurv_{4,2} := |Mom(2,2 \cdot \chi cr)|$$

$$MomCurv_{5,1} := 0,8 \cdot \chi e$$

$$MomCurv_{5,2} := |Mom(0,8 \cdot \chi e)|$$

$$MomCurv_{6,1} := 1 \cdot \chi e$$

$$MomCurv_{6,2} := |Mom(1 \cdot \chi e)|$$

$$MomCurv_{7,1} := 1,2 \cdot \chi e$$

$$MomCurv_{7,2} := |Mom(1,2 \cdot \chi e)|$$

$$MomCurv_{8,1} := 1,5 \cdot \chi e$$

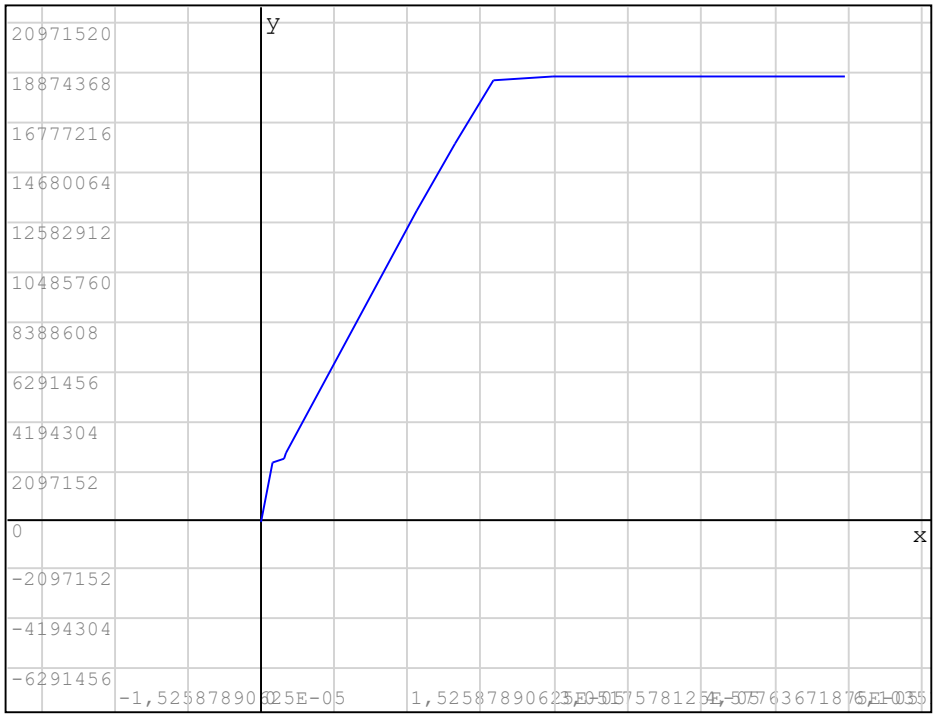
$$MomCurv_{8,2} := |Mom(1,5 \cdot \chi e)|$$

$$MomCurv_{9,1} := 3 \cdot \chi e$$

$$MomCurv_{9,2} := |Mom(3 \cdot \chi e)|$$

⊞—Moment curvture - Step

$$MomCurv = \begin{bmatrix} 0 & 0 \\ 1,2622 \cdot 10^{-6} & 2,4991 \cdot 10^{6} \\ 2,5244 \cdot 10^{-6} & 2,662 \cdot 10^{6} \\ 2,7768 \cdot 10^{-6} & 2,9102 \cdot 10^{6} \\ 1,6175 \cdot 10^{-5} & 1,3084 \cdot 10^{7} \\ 2,0218 \cdot 10^{-5} & 1,5886 \cdot 10^{7} \\ 2,4262 \cdot 10^{-5} & 1,8594 \cdot 10^{7} \\ 3,0328 \cdot 10^{-5} & 1,8725 \cdot 10^{7} \\ 6,0655 \cdot 10^{-5} & 1,8725 \cdot 10^{7} \end{bmatrix}$$



MomCurv