# Lineare Finite-Elemente Analyse einer Balkenstruktur



## Probemstellung: Lineare Statik-Analyse

Definition von Lagerungen (Einspannung im Knoten 1) und Lasten (Erdbeschleunigung g in negativer 2-Richtung sowie Kraft F in 1 am Knoten 4).
Berechnung der reduzierten Bewegungsgleichungen, ohne geometrische Steifigkeiten KF0
Loesen der linearen Statik KFy . yF = hFy und Auswertung der Lagerkraefte, Normalspannungen und Biegespannungen
fuer F = 0, -200, 200 N.
Die Abschnitte 1 und 2 muessen bereits durchgerechnet sein!

**Aufgaben**:
3.1 Bestimmung der Minimalkoordinaten yF
Bilden des Lastvektors hF infolge Knotenlasten
Bilden von hF infolge der Referenzbewegung
Reduzierung auf Minimalform der lin. DGL: MFy . ddyF + DFy . dyF + KFy . yF = hFy
3.2 Berechne die Knotenverschiebungen zFstat
Berechne die Auflagerkraeft fbar
Berechne die Schnittgroessen f1e und m3e je Element
Berechne die Normalspannung und Biegespannung je Element
Stelle die Ergebnisse grafisch dar.

```
FEName
```

```
Elast. Winkel mit 3 Elementen
```

## Festlegung der Parameter

- **Setzen von Lagerbedingungen: `Lager = {{`Nr. Knoten mit Lager`, Key-u1, Key-u2, Key-theta3}},`
  Key: 0=frei, 1=fest der drei Bewegungen u1, u2, theta3**

```
Lager = {{1, 1,1,1}}
```

```
{{1, 1, 1, 1}}
```

- **Setzen von Knotenlasten: `LastKnot = {{`Nr. Knoten mit Last`, F1, F2, M3}},`
  Werte fuer Kraefte F1, F2, Moment M3**

```
LastKnot = {{4, F,0,0}}
```

```
{{4, F, 0, 0}}
```

- **Setzen einer Referenzbewegung: `LastRef = {a1, a2, domega3, omega3}},`**
  **Werte fuer Linearbeschleunigung a1, a2, Winkelbeschleunigung domega3, Winkelgeschwindigkeit omega3**
  **Beachte: Fuer Erdbeschleungigung gilt a == - g!**
  **domega3 und omega3 sind nicht implementiert!**

```
LastRef = {0, 9.81,0,0}
```

```
{0, 9.81, 0, 0}
```

- **Setzen von Berechnungsschluesseln**

```
keyPrint = 1;         (* 0 = kein Print von System-Matrizen, 1 = Print                    *)
```

# Loesung: 3 Lineare Statik Analyse

## 3.1 Bestimmung der Minimalkoordinaten yF und der Mininal-Systemmatrizen

```
nKLager = Length[Lager];
nIndr   = Sum[Delete[Transpose[Lager],1][[j,i]],{i,nKLager},{j,nfk}];
Indr    = Table[0,{nIndr}];
nR=0;
If[Lager[[1,1]]===0,IndM = Table[n,{n,1,nF}]; nM   = nF;,   (* keine Randbedingungen *)
                                                            (* mit Randbedingungen   *)
                    Do[If[Lager[[k,2]]===1,nR=nR+1;Indr[[nR]]=(Lager[[k,1]]-1)*nfk+1];
                       If[Lager[[k,3]]===1,nR=nR+1;Indr[[nR]]=(Lager[[k,1]]-1)*nfk+2];
                       If[Lager[[k,4]]===1,nR=nR+1;Indr[[nR]]=(Lager[[k,1]]-1)*nfk+3];
                      ,{k,1, nKLager}];];
nR                                                          (* Zahl der gebundenen Koorditen *)
Indr                                                        (* gebundene Koordinaten         *)
```

```
3

{1, 2, 3}
```

```
If[nR===0, IndM = Table[n,{n,1,nF}],
           IndM = Delete[Table[n,{n,1,nF}],Partition[Indr,1]]];
nM = nF - nR                                                (* Zahl der (freien) Minimal-Koordinaten
*)
IndM                                                        (* Liste der Minimal-Koordinaten
*)
```

```
9

{4, 5, 6, 7, 8, 9, 10, 11, 12}
```

## Bilden des Lastvektors hF infolge Knotenlasten

```
nKLast = Length[LastKnot];
hF = Table[0, {nF}];
Do[Do[ hF[[LastKnot[[kk,1]]*nfk-nfk+k]] = hF[[LastKnot[[kk,1]]*nfk-nfk+k]] + LastKnot[[kk,1+k]]
    ,{k,nfk}];
,{kk,nKLast}];
hF
```

```
{0, 0, 0, 0, 0, 0, 0, 0, 0, F, 0, 0}
```

## Bilden von hF infolge der Referenzbewegung

a-Anteil in hFref = - CFt . a

```
Beschl = Delete[ReplacePart[LastRef,0,3],4]
```

```
{0, 9.81, 0}
```

```
hFref = - CFt . Beschl
```

{0., -26.487, -4.4145, 0., -52.974, 0., 0., -55.918, 4.4145, 0., -29.431, 0.}

## ■ Reduzierung auf Minimalform der lin. DGL.: MFy . ddyF + DFy . dyF + KFy . yF = hFy

```
hFsum = Chop[hF + hFref]
```

{0, -26.487, -4.4145, 0, -52.974, 0, 0, -55.918, 4.4145, F, -29.431, 0}

```
hFy = Table[0,{nM}];
Do [ hFy[[i]] = hFsum[[IndM[[i]]]], {i,1,nM}]; hFy
```

{0, -52.974, 0, 0, -55.918, 4.4145, F, -29.431, 0}

```
KFy = Table[0,{nM},{nM}];
Do [ Do [KFy[[i,j]] = KF[[IndM[[i]],IndM[[j]]]], {j,1,nM}], {i,1,nM}];
If[keyPrint == 1, KFy//MatrixForm]
```

$$\begin{pmatrix} 2.52\times10^{8} & 0 & 0 & -1.26\times10^{8} & 0 & 0 & 0 & 0 & 0 \\ 0 & 20412. & 0. & 0 & -10206. & 5103. & 0 & 0 & 0 \\ 0 & 0. & 6804. & 0 & -5103. & 1701. & 0 & 0 & 0 \\ -1.26\times10^{8} & 0 & 0 & 1.26563\times10^{8} & 0 & -112534. & -562669. & 0 & -112534. \\ 0 & -10206. & -5103. & 0 & 9.9751\times10^{8} & -5103. & 0 & -9.975\times10^{8} & 0 \\ 0 & 5103. & 1701. & -112534. & -5103. & 33411. & 112534. & 0 & 15004.5 \\ 0 & 0 & 0 & -562669. & 0 & 112534. & 562669. & 0 & 112534. \\ 0 & 0 & 0 & 0 & -9.975\times10^{8} & 0 & 0 & 9.975\times10^{8} & 0 \\ 0 & 0 & 0 & -112534. & 0 & 15004.5 & 112534. & 0 & 30009. \end{pmatrix}$$

```
MFy = Table[0,{nM},{nM}];
Do [ Do [MFy[[i,j]] = MF[[IndM[[i]],IndM[[j]]]], {j,1,nM}], {i,1,nM}];
If[keyPrint == 1, MFy//MatrixForm]
```

$$\begin{pmatrix} 3.6 & 0 & 0 & 0.9 & 0 & 0 & 0 & 0 & 0 \\ 0 & 4.01143 & 0. & 0 & 0.694286 & -0.167143 & 0 & 0 & 0 \\ 0 & 0. & 0.102857 & 0 & 0.167143 & -0.0385714 & 0 & 0 & 0 \\ 0.9 & 0 & 0 & 4.02865 & 0 & -0.125718 & 0.771454 & 0 & 0.0742882 \\ 0 & 0.694286 & 0.167143 & 0 & 4.00578 & -0.282857 & 0 & 1.00003 & 0 \\ 0 & -0.167143 & -0.0385714 & -0.125718 & -0.282857 & 0.0605717 & -0.0742882 & 0 & -0.00685737 \\ 0 & 0 & 0 & 0.771454 & 0 & -0.0742882 & 2.22865 & 0 & 0.125718 \\ 0 & 0 & 0 & 0 & 1.00003 & 0 & 0 & 2.00007 & 0 \\ 0 & 0 & 0 & 0.0742882 & 0 & -0.00685737 & 0.125718 & 0 & 0.00914316 \end{pmatrix}$$

## ■ 3.2 Berechnung der Statikloesung F = 0

```
F1 = 0
```

0

## ■ Knotenverschiebungen zFstat = Jy . yF, yF = KFy^-1 . hFy,

```
nfk
```

3

```
yF    = Inverse[KFy] . hFy/.F->F1;
zFstat = Chop[yF];
If[nR>0, Do [zFstat = Insert[zFstat,0,Indr[[j]] ], {j,nR}]];
zFstat
```

{0, 0, 0, 0, -0.101793, -0.17648, 0, -0.309128, -0.221465, 0.088586, -0.309128, -0.221465}

```
Print["Knoten k |  u1 (m) |  u2 (m)  | theta3 (rad) "];
Do[Print[k, "         | ", zFstat[[(k - 1) * nfk + 1]],
    "   | ", zFstat[[(k - 1) * nfk + 2]], "  |    ", zFstat[[(k - 1) * nfk + 3]]];
  ,
  {k,
   nK}];
```

```
Knoten k |  u1 (m) |  u2 (m)  | theta3 (rad)

1         | 0   | 0  |   0

2         | 0   | -0.101793  |   -0.17648

3         | 0   | -0.309128  |   -0.221465

4         | 0.088586   | -0.309128  |   -0.221465
```

- **Auflagerkraefte in der Bedeutung der Koordinaten nach Indr: fbar = JFbar^T ( KF . zFstat - hF )**

```
fbar = KF . zFstat -  hFsum;
fbar = Chop[Expand[Delete[fbar,Partition[IndM,1]]]];MatrixForm[fbar]
```

$$\begin{pmatrix} 0 \\ 164.81 \\ 223.672 \end{pmatrix}$$

- **Schnittgröoessen  je Element: sigmae = He . epse = He .  Be . Te . zF**

```
sigmae = Table[0, {nE}, {2}];
Print["Element e |  f1e (N) |    m3e (Nm)          |   me3(0)   |    me3(1)  "]
Do[
 sigmae[[e]] = Chop[Expand[ He.Be.Transpose[TeT[[e]]].zFstat /.
     {le → Edata⟦e, 5⟧, Ae → Edata⟦e, 2⟧, I33e → Edata⟦e, 3⟧, Ee →  Edata⟦e, 1⟧}]];
 Print[e, "         | ", sigmae[[e, 1]], "   | ", sigmae[[e, 2]], "   | ",
  sigmae[[e, 2]] /. xi → 0, "   | ", Chop[sigmae[[e, 2]] /. xi → 1] ];
 ,
 {e,
  nE}]
```

```
Element e |  f1e (N) |    m3e (Nm)          |   me3(0)   |    me3(1)

1         | 0   | -219.257 + 138.323 xi   | -219.257   | -80.9345

2         | 0   | -80.9345 + 85.349 xi   | -80.9345   | 4.4145

3         | -29.431   | 0   | 0   | 0
```

- **Normalspannung = sigmae[[1]]/Ae   und Biegespannung =  sigmae[[2]] / I33e * he**

```
spannung = Table[0, {nE}, {2}];
Print["Element e |  Normalspg (N/m^2) |    Biegespg (N/m^2)           "]
Do[
 spannung[[e, 1]] =
  Chop[sigmae[[e, 1]]] / Ae /. {le → Edata⟦e, 5⟧, Ae → Edata⟦e, 2⟧, I33e → Edata⟦e, 3⟧, Ee →  Edata⟦e, 1⟧};
 spannung[[e, 2]] = Expand[sigmae[[e, 2]] / I33e * h1 /.
    {le → Edata⟦e, 5⟧, Ae → Edata⟦e, 2⟧, I33e → Edata⟦e, 3⟧, h1 →  Edata⟦e, 7⟧}];
 Print[e, "         | ", spannung[[e, 1]], "   | ", spannung[[e, 2]]];
 , {e, nE}]
```

Element e |  Normalspg (N/m^2) |    Biegespg (N/m^2)

1         | 0   | $-1.62413\times10^{8} + 1.02461\times10^{8}$ xi

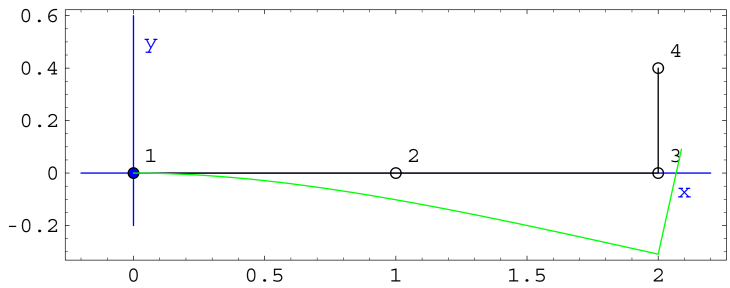
2         | 0   | $-5.99515\times10^{7} + 6.32215\times10^{7}$ xi

3         | -15490.   | 0

## ■ Grafiken für Verschiebung und Biegemoment

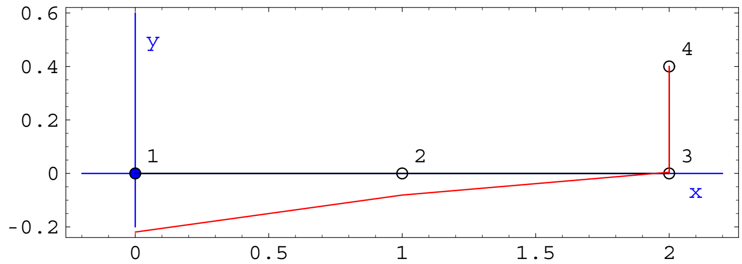
```
m3eSka = 1000;
f1eSka = 500;
Ne3 = Join[Ne, {Table[0, {nFe}]}];  (*  Nullzeile anhaengen *)
Ue = Table[0, {nE}, {3}];
plotUe = Table[0, {nE}];
plotf1 = Table[0, {nE}];
plotMe = Table[0, {nE}];
Do[Ue[[e]] = Transpose[Gammae[[e]]].Ne3.Transpose[TeT[[e]]].(zFstat + ZF) /. {le → Edata[[e, 5]], F → F1};
  plotUe[[e]] = ParametricPlot[{Ue[[e, 1]], Ue[[e, 2]]}, {xi, 0, 1},
    DisplayFunction → Identity, PlotStyle → {{RGBColor[0, 1, 0]}}];
  Res = Transpose[Gammae[[e]]].{xi le, sigmae[[e, 2]]/m3eSka, 0} + RK[[e]] /. {le → Edata[[e, 5]], F → F1};
  plotMe[[e]] = ParametricPlot[{Res[[1]], Res[[2]]}, {xi, 0, 1},
    DisplayFunction → Identity, PlotStyle → {{RGBColor[1, 0, 0]}}];
  Res = Transpose[Gammae[[e]]].{xi le, sigmae[[e, 1]] / f1eSka, 0} + RK[[e]] /. {le → Edata[[e, 5]], F → F1};
  plotf1[[e]] = ParametricPlot[{Res[[1]], Res[[2]]}, {xi, 0, 1},
    DisplayFunction → Identity, PlotStyle → {{RGBColor[1, 0, 0]}}];
  , {e, nE}];
Show[PlStructure1, PlStructure2, PlStructure3, PlStructure4, plotUe, DisplayFunction → $DisplayFunction,
  PlotRange → All, PlotLabel → {"Knotenverschiebungen:", FEName, "Last g & F = ", F1}];
```

otenverschiebungen:, Elast. Winkel mit 3 Elementen, Last g & F = ,



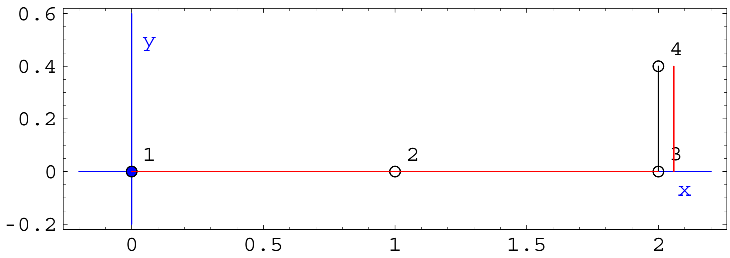
```
Show[PlStructure1,PlStructure2,PlStructure3,PlStructure4, plotMe,
     DisplayFunction->$DisplayFunction, PlotRange->All,
     PlotLabel->{"Biegemoment *",m3eSka,"Nm:",FEName,"Last g & F = ",F1}];
```

jemoment *, 1000, Nm:, Elast. Winkel mit 3 Elementen, Last g & F =



```
Show[PlStructure1,PlStructure2,PlStructure3,PlStructure4,plotf1,
     DisplayFunction->$DisplayFunction, PlotRange->All,
     PlotLabel->{"Normalkraft *",f1eSka,"N:",FEName,"Last g & F = ",F1}];
```

rmalkraft *, 500, N:, Elast. Winkel mit 3 Elementen, Last g & F = ,



## ■ 3.2 Berechnung der Statikloesung F = -200

```
F1 = -200
```

```
-200
```

## ■ Knotenverschiebungen zFstat = Jy . yF,  yF = KFy^-1 . hFy,

```
yF    = Inverse[KFy] . hFy/.F->F1;
zFstat = Chop[yF];
If[nR>0, Do [zFstat = Insert[zFstat,0,Indr[[j]] ], {j,nR}]];
zFstat
```

{0, 0, 0, $-1.5873\times10^{-6}$, -0.0547618, -0.0824173,
$-3.1746\times10^{-6}$, -0.121003, -0.0333403, 0.0119111, -0.121003, -0.0280086}

```
Print["Knoten k |  u1 (m) |  u2 (m)  | theta3 (rad) "];
Do[Print[k, "          | ", zFstat[[(k - 1) * nfk + 1]],
    "   | ", zFstat[[(k - 1) * nfk + 2]], "   |    ", zFstat[[(k - 1) * nfk + 3]]];
  ,
  {k,
   nK}];
```

Knoten k |  u1 (m) |  u2 (m)  | theta3 (rad)

1          | 0   | 0  |    0

2          | $-1.5873\times10^{-6}$   | -0.0547618  |    -0.0824173

3          | $-3.1746\times10^{-6}$   | -0.121003  |    -0.0333403

4          | 0.0119111   | -0.121003  |    -0.0280086

## ■ Auflagerkraefte in der Bedeutung der Koordinaten nach Indr: fbar = JFbar^T ( KF . zFstat - hF )

```
fbar = KF . zFstat -  hFsum; fbar = Chop[Expand[Delete[fbar,Partition[IndM,1]]]];MatrixForm[fbar]
```

$$\begin{pmatrix} 200. \\ 164.81 \\ 143.672 \end{pmatrix}$$

## ■ Schnittgröoessen  je Element: sigmae = He . epse = He .  Be . Te . zF

```
sigmae = Table[0, {nE}, {2}];
Print["Element e |  f1e (N) |    m3e (Nm)           |   me3(0)    |     me3(1)   "]
Do[
 sigmae[[e]] = Chop[Expand[ He.Be.Transpose[TeT[[e]]].zFstat /.
     {le → Edata⟦e, 5⟧, Ae → Edata⟦e, 2⟧, I33e → Edata⟦e, 3⟧, Ee → Edata⟦e, 1⟧}]];
 Print[e, "          | ", sigmae[[e, 1]], "    | ", sigmae[[e, 2]], "    | ",
  sigmae[[e, 2]] /. xi → 0, "    | ", Chop[sigmae[[e, 2]] /. xi → 1] ];
 ,
 {e,
  nE}]
```

Element e |  f1e (N) |    m3e (Nm)           |   me3(0)    |     me3(1)

1          | -200.   | -139.257 + 138.323 xi   | -139.257   | -0.934462

2          | -200.   | -0.934462 + 85.349 xi   | -0.934462   | 84.4145

3          | -29.431   | 80. - 80. xi   | 80.   | 0

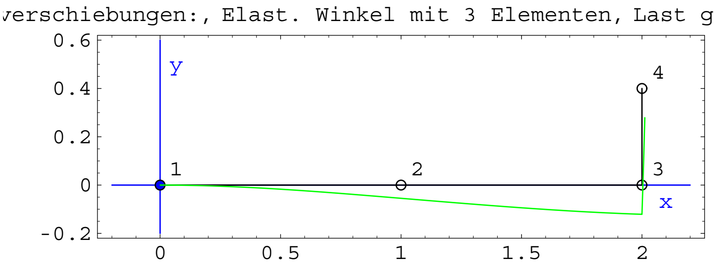
## ■ Normalspannung = sigmae[[1]]/Ae und Biegespannung = sigmae[[2]] / I33e * he

```
spannung = Table[0, {nE}, {2}];
Print["Element e |  Normalspg (N/m^2)  |    Biegespg (N/m^2)           "]
Do[
 spannung[[e, 1]] =
  Chop[sigmae[[e, 1]]] / Ae /. {le → Edata⟦e, 5⟧, Ae → Edata⟦e, 2⟧, I33e → Edata⟦e, 3⟧, Ee → Edata⟦e, 1⟧};
 spannung[[e, 2]] = Expand[sigmae[[e, 2]] / I33e * h1 /.
     {le → Edata⟦e, 5⟧, Ae → Edata⟦e, 2⟧, I33e → Edata⟦e, 3⟧, h1 → Edata⟦e, 7⟧}];
 Print[e, "          | ", spannung[[e, 1]], "    | ", spannung[[e, 2]]];
 , {e, nE}]
```

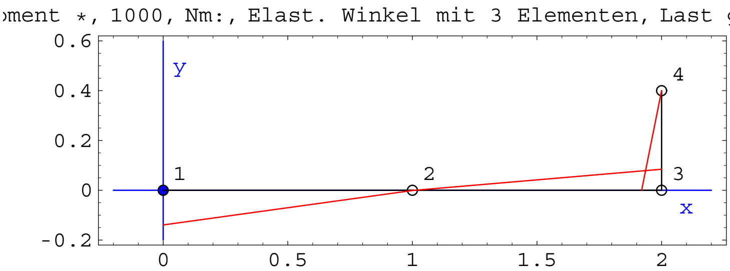
```
Element e |  Normalspg (N/m^2) |    Biegespg (N/m^2)

1          | -111111.    | -1.03154×10^8 + 1.02461×10^8 xi

2          | -111111.    | -692194. + 6.32215×10^7 xi

3          | -15490.    | 5.3184×10^7 - 5.3184×10^7 xi
```

## ■ Grafiken für Verschiebung und Biegemoment

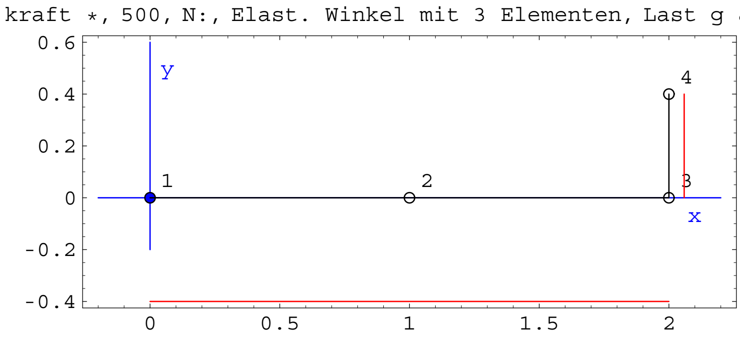
```
m3eSka = 1000;
fleSka = 500;
Ne3 = Join[Ne, {Table[0, {nFe}]}];  (*  Nullzeile anhaengen *)
Ue = Table[0, {nE}, {3}];
plotUe = Table[0, {nE}];
plotf1 = Table[0, {nE}];
plotMe = Table[0, {nE}];
Do[Ue⟦e⟧ = Transpose[Gammae⟦e⟧].Ne3.Transpose[TeT⟦e⟧].(zFstat + ZF) /. {le → Edata⟦e, 5⟧, F → F1};
  plotUe⟦e⟧ = ParametricPlot[{Ue⟦e, 1⟧, Ue⟦e, 2⟧}, {xi, 0, 1},
    DisplayFunction → Identity, PlotStyle → {{RGBColor[0, 1, 0]}}];
  Res = Transpose[Gammae⟦e⟧].{xi le, sigmae⟦e, 2⟧ / m3eSka, 0} + RK⟦e⟧ /. {le → Edata⟦e, 5⟧, F → F1};
  plotMe⟦e⟧ = ParametricPlot[{Res⟦1⟧, Res⟦2⟧}, {xi, 0, 1},
    DisplayFunction → Identity, PlotStyle → {{RGBColor[1, 0, 0]}}];
  Res = Transpose[Gammae⟦e⟧].{xi le, sigmae⟦e, 1⟧ / fleSka, 0} + RK⟦e⟧ /. {le → Edata⟦e, 5⟧, F → F1};
  plotf1⟦e⟧ = ParametricPlot[{Res⟦1⟧, Res⟦2⟧}, {xi, 0, 1},
    DisplayFunction → Identity, PlotStyle → {{RGBColor[1, 0, 0]}}];
  , {e, nE}];
Show[PlStructure1, PlStructure2, PlStructure3, PlStructure4, plotUe, DisplayFunction → $DisplayFunction,
  PlotRange → All, PlotLabel → {"Knotenverschiebungen:", FEName, "Last g & F = ", F1}];
```




```
Show[PlStructure1,PlStructure2,PlStructure3,PlStructure4, plotMe,
     DisplayFunction->$DisplayFunction, PlotRange->All,
     PlotLabel->{"Biegemoment *",m3eSka,"Nm:",FEName,"Last g & F = ",F1}];
```



```
Show[PlStructure1,PlStructure2,PlStructure3,PlStructure4,plotf1,
     DisplayFunction->$DisplayFunction, PlotRange->All,
     PlotLabel->{"Normalkraft *",f1eSka,"N:",FEName,"Last g & F = ",F1}];
```




## ■ 3.2 Berechnung der Statikloesung F = +200

```
F1 = 200
```

```
200
```

## ■ Knotenverschiebungen zFstat = Jy . yF,  yF = KFy^-1 . hFy,

```
yF    = Inverse[KFy] . hFy/.F->F1;
zFstat = Chop[yF];
If[nR>0, Do [zFstat = Insert[zFstat,0,Indr[[j]] ], {j,nR}]];
zFstat
```

$\{0, 0, 0, 1.5873\times 10^{-6}, -0.148824, -0.270542, 3.1746\times 10^{-6}, -0.497252, -0.40959, 0.165261, -0.497253, -0.414921\}$

```
Print["Knoten k |  u1 (m)  |  u2 (m)  | theta3 (rad) "];
Do[Print[k, "          | ", zFstat[[(k - 1) * nfk + 1]],
    "   | ", zFstat[[(k - 1) * nfk + 2]], "   |    ", zFstat[[(k - 1) * nfk + 3]]];
  ,
  {k,
   nK}];
```

Knoten k | u1 (m) | u2 (m) | theta3 (rad)

1 | 0 | 0 | 0

2 | $1.5873\times 10^{-6}$ | -0.148824 | -0.270542

3 | $3.1746\times 10^{-6}$ | -0.497252 | -0.40959

4 | 0.165261 | -0.497253 | -0.414921

## ■ Auflagerkraefte in der Bedeutung der Koordinaten nach Indr: fbar = JFbar^T ( KF . zFstat - hF )

```
fbar = KF . zFstat -  hFsum; fbar = Chop[Expand[Delete[fbar,Partition[IndM,1]]]];MatrixForm[fbar]
```

$$\begin{pmatrix} -200. \\ 164.81 \\ 303.672 \end{pmatrix}$$

## ■ Schnittgröoessen je Element: sigmae = He . epse = He . Be . Te . zF

```
sigmae = Table[0, {nE}, {2}];
Print["Element e |  f1e (N) |    m3e (Nm)          |   me3(0)   |    me3(1)  "]
Do[
 sigmae[[e]] = Chop[Expand[ He.Be.Transpose[TeT[[e]]].zFstat /.
     {le → Edata⟦e, 5⟧, Ae → Edata⟦e, 2⟧, I33e → Edata⟦e, 3⟧, Ee → Edata⟦e, 1⟧}]];
 Print[e, "         | ", sigmae[[e, 1]], "   | ", sigmae[[e, 2]], "   | ",
  sigmae[[e, 2]] /. xi → 0, "   | ", Chop[sigmae[[e, 2]] /. xi → 1] ];
 ,
 {e,
  nE}]
```

```
Element e |  f1e (N) |    m3e (Nm)          |   me3(0)   |    me3(1)

1         | 200.   | -299.257 + 138.323 xi   | -299.257   | -160.934

2         | 200.   | -160.934 + 85.349 xi   | -160.934   | -75.5855

3         | -29.431   | -80. + 80. xi   | -80.   | 0
```

## ■ Normalspannung = sigmae[[1]]/Ae und Biegespannung = sigmae[[2]] / I33e * he

```
spannung = Table[0, {nE}, {2}];
Print["Element e |  Normalspg (N/m^2) |    Biegespg (N/m^2)           "]
Do[
 spannung[[e, 1]] =
  Chop[sigmae[[e, 1]]] / Ae /. {le → Edata⟦e, 5⟧, Ae → Edata⟦e, 2⟧, I33e → Edata⟦e, 3⟧, Ee → Edata⟦e, 1⟧};
 spannung[[e, 2]] = Expand[sigmae[[e, 2]] / I33e * h1 /.
    {le → Edata⟦e, 5⟧, Ae → Edata⟦e, 2⟧, I33e → Edata⟦e, 3⟧, h1 → Edata⟦e, 7⟧}];
 Print[e, "          | ", spannung[[e, 1]], "   | ", spannung[[e, 2]]];
 , {e, nE}]
```

Element e | Normalspg (N/m^2) | Biegespg (N/m^2)

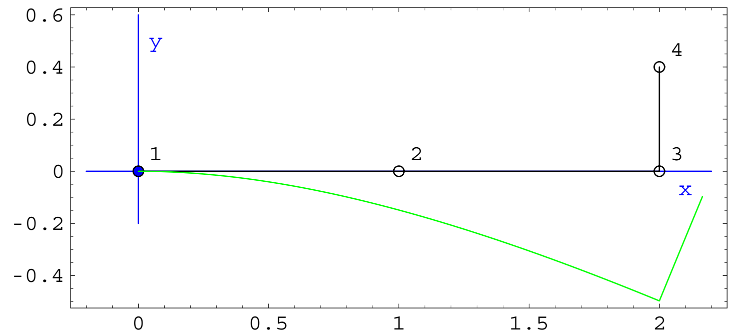
1 | 111111. | $-2.21672\times10^{8} + 1.02461\times10^{8}$ xi

2 | 111111. | $-1.19211\times10^{8} + 6.32215\times10^{7}$ xi

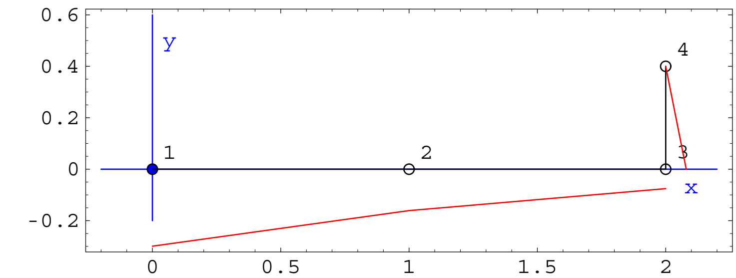
3 | -15490. | $-5.3184\times10^{7} + 5.3184\times10^{7}$ xi

## ■ Grafiken für Verschiebung und Biegemoment

```
m3eSka = 1000;
f1eSka = 500;
Ne3 = Join[Ne, {Table[0, {nFe}]}];  (*  Nullzeile anhaengen *)
Ue = Table[0, {nE}, {3}];
plotUe = Table[0, {nE}];
plotf1 = Table[0, {nE}];
plotMe = Table[0, {nE}];
Do[Ue[[e]] = Transpose[Gammae[[e]]].Ne3.Transpose[TeT[[e]]].(zFstat + ZF) /. {le → Edata[[e, 5]], F → F1};
  plotUe[[e]] = ParametricPlot[{Ue[[e, 1]], Ue[[e, 2]]}, {xi, 0, 1},
    DisplayFunction → Identity, PlotStyle → {{RGBColor[0, 1, 0]}}];
  Res = Transpose[Gammae[[e]]].{xi le, sigmae[[e, 2]]/m3eSka, 0} + RK[[e]] /. {le → Edata[[e, 5]], F → F1};
  plotMe[[e]] = ParametricPlot[{Res[[1]], Res[[2]]}, {xi, 0, 1},
    DisplayFunction → Identity, PlotStyle → {{RGBColor[1, 0, 0]}}];
  Res = Transpose[Gammae[[e]]].{xi le, sigmae[[e, 1]] / f1eSka, 0} + RK[[e]] /. {le → Edata[[e, 5]], F → F1};
  plotf1[[e]] = ParametricPlot[{Res[[1]], Res[[2]]}, {xi, 0, 1},
    DisplayFunction → Identity, PlotStyle → {{RGBColor[1, 0, 0]}}];
  , {e, nE}];
Show[PlStructure1, PlStructure2, PlStructure3, PlStructure4, plotUe, DisplayFunction → $DisplayFunction,
  PlotRange → All, PlotLabel → {"Knotenverschiebungen:", FEName, "Last g & F = ", F1}];
```




```
Show[PlStructure1,PlStructure2,PlStructure3,PlStructure4, plotMe,
     DisplayFunction->$DisplayFunction, PlotRange->All,
     PlotLabel->{"Biegemoment *",m3eSka,"Nm:",FEName,"Last g & F = ",F1}];
```




```
Show[PlStructure1,PlStructure2,PlStructure3,PlStructure4,plotf1,
     DisplayFunction->$DisplayFunction, PlotRange->All,
     PlotLabel->{"Normalkraft *",f1eSka,"N:",FEName,"Last g & F = ",F1}];
```