

# Sporthalle in Zürich mit vorgespannten BSH-Trägern

Marcel Muster

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29. November – 1. Dezember 2023

# Einleitung



Spannweite 39.6 m



Motivation

Anforderungen

Varianten

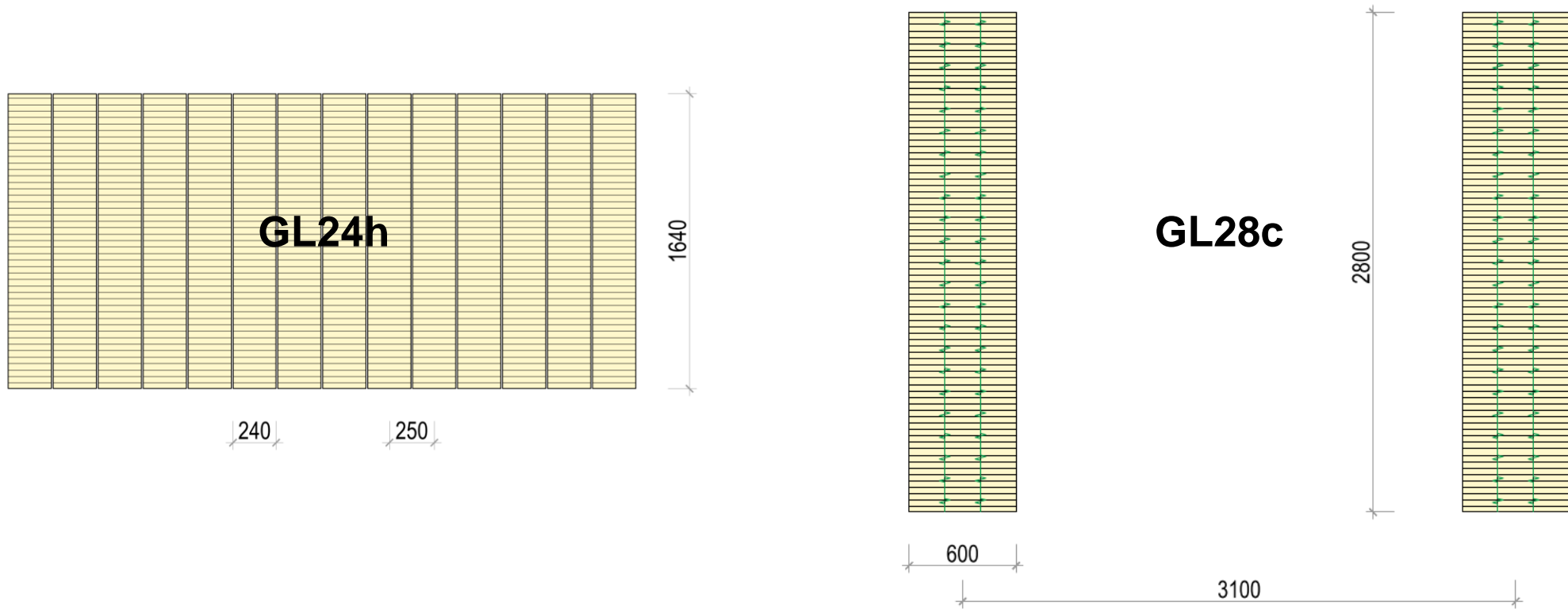
Vorgespannte Träger

Fazit

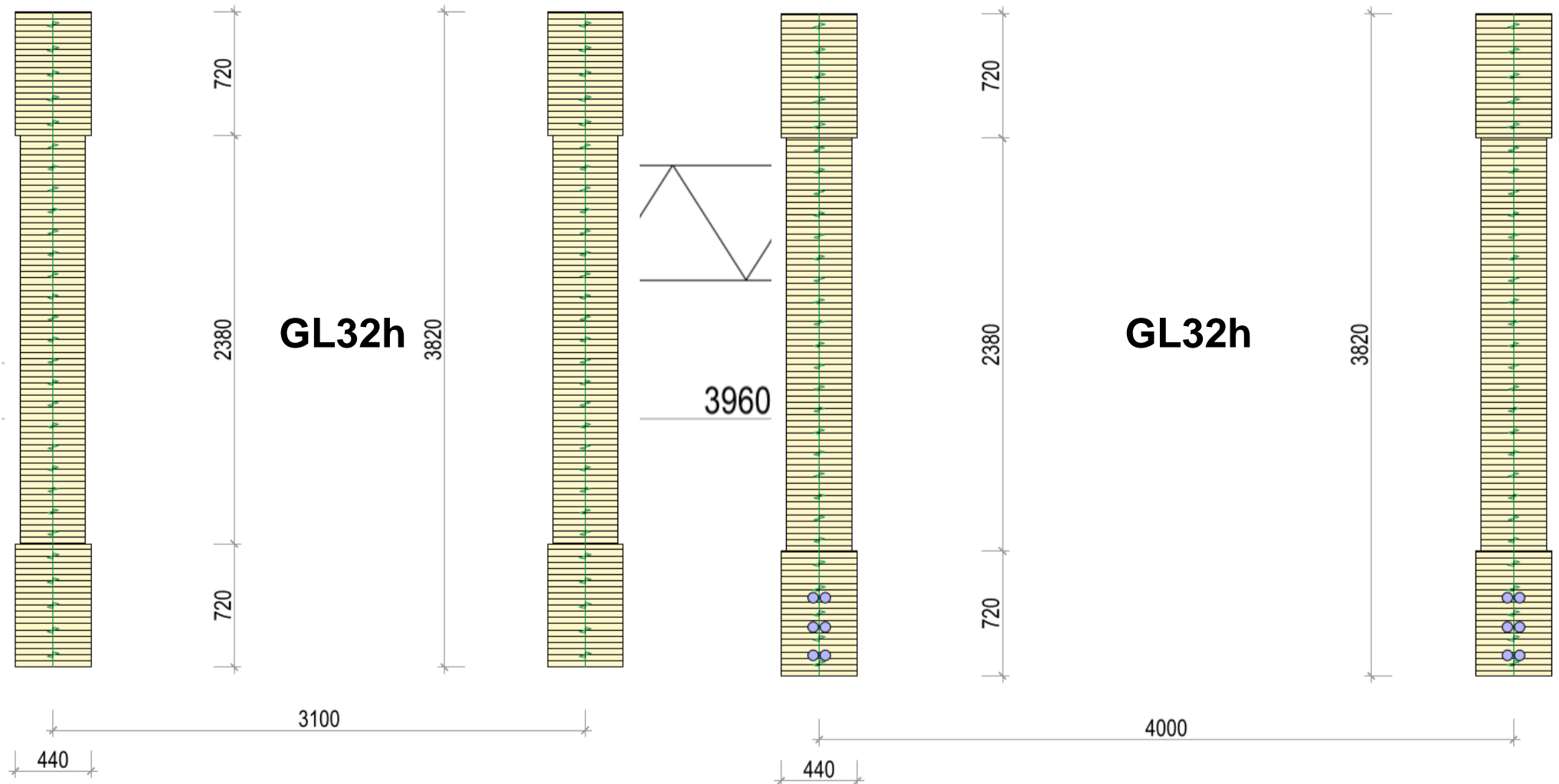
# Anforderungen

- Sprungmass (Raumhöhe, Raumkonzept)
- Tragfähigkeit
- Quasi-ständige Durchbiegung inkl. Kriechen  $< L/300$  (=132 mm)
- Durchbiegungen durch veränderliche Einwirkungen  $< L/350$  (=113 mm)
- Schwingungen

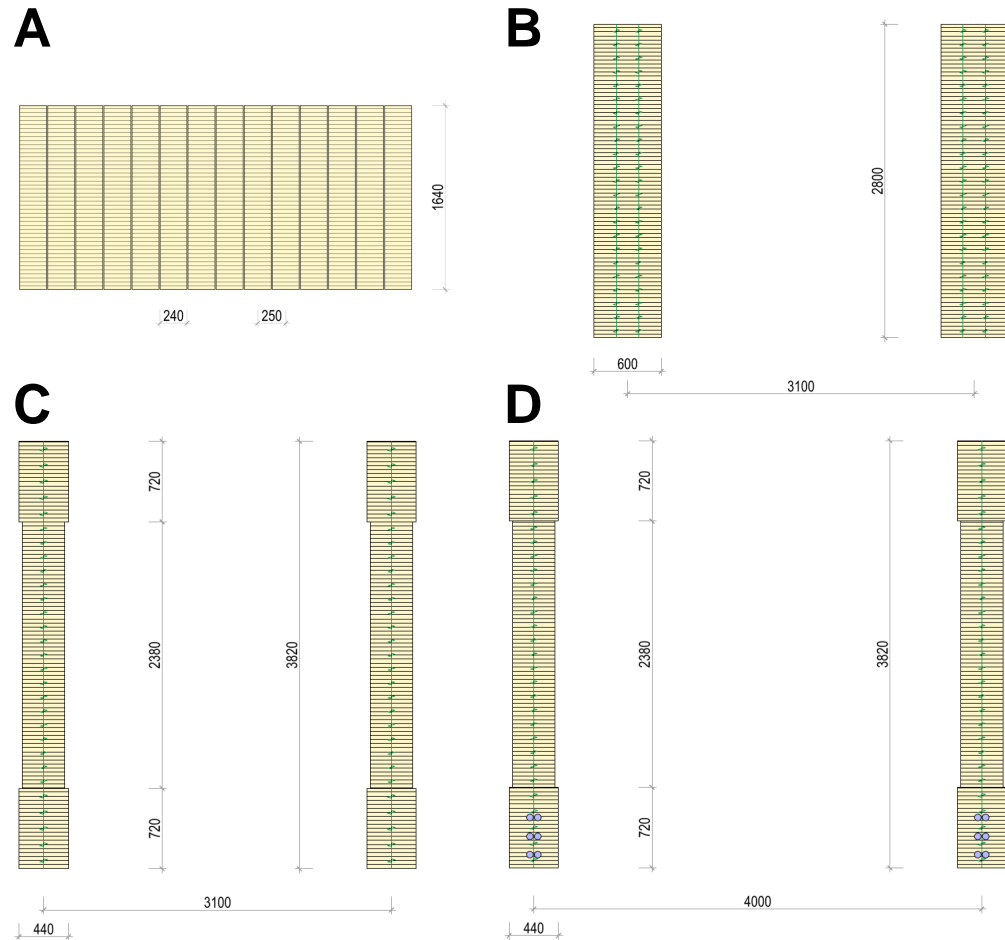
# Varianten



# Varianten

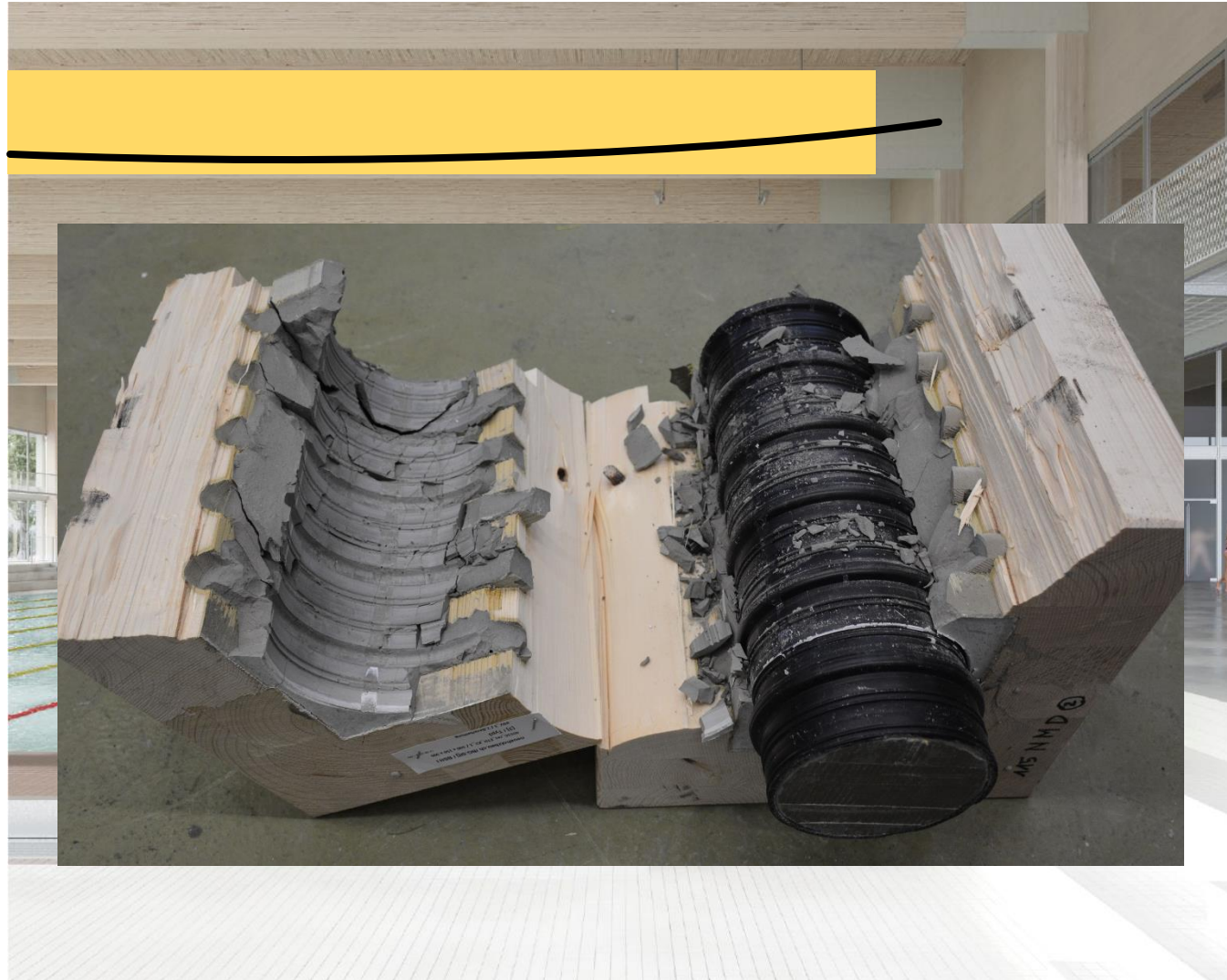


# Varianten



| Varianten   | A         | B           | C           | D           |
|---|-----------|-------------|-------------|-------------|
| Quasi-ständige Verformung inkl. Kriechen                                    | 284 mm    | 194 mm      | 115 mm      | 132 mm      |
| Erforderliche Überhöhung zur Einhaltung L/300                               | 152 mm    | 62 mm       | 0 mm        | 0 mm        |
| Verformung veränderliche Einwirkungen                                       | 41 mm     | 40 mm       | 26 mm       | 31 mm       |
| Ausnutzung Biegung (und Zug) und Querkraft                                  | 1.0 / 0.4 | 1.0 / 0.8   | 1.0 / 0     | 0.9 / 0     |
| Volumen pro m <sup>2</sup> + Sek.struktur [m <sup>3</sup> /m <sup>2</sup> ] | 1.57      | 0.54 + 0.22 | 0.32 + 0.22 | 0.25 + 0.24 |

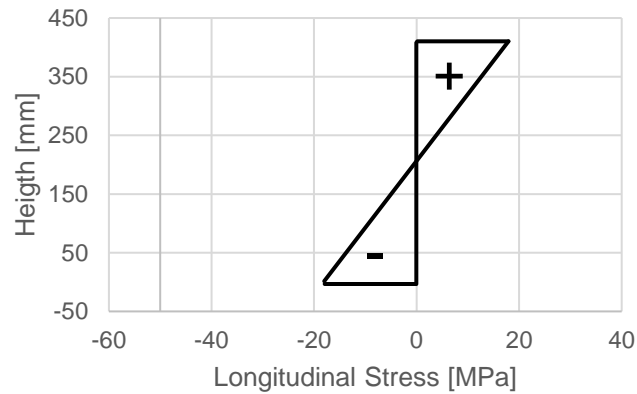
# Motivation



Source:  
Wettbewerbsunterlagen  
Neubau Sportzentrum  
Oerlikon, Boltshauser  
Architekten AG

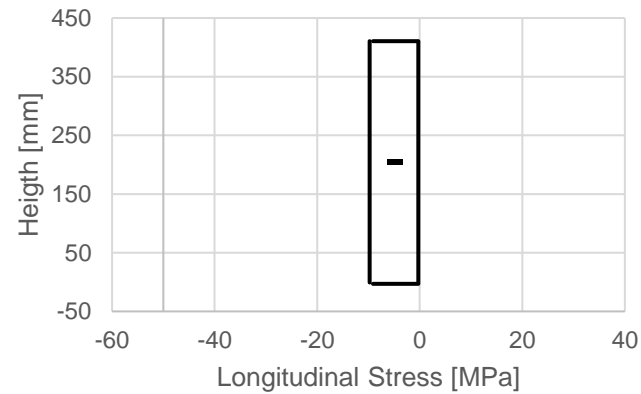
# Spannungsverteilung

## Umlenkkräfte



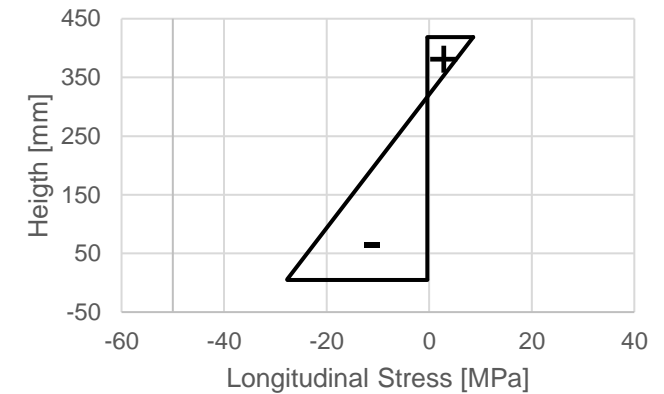
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## Druckspannung

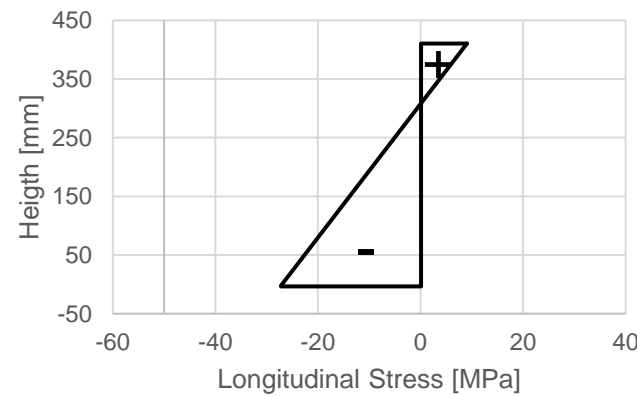


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## Überlagerung

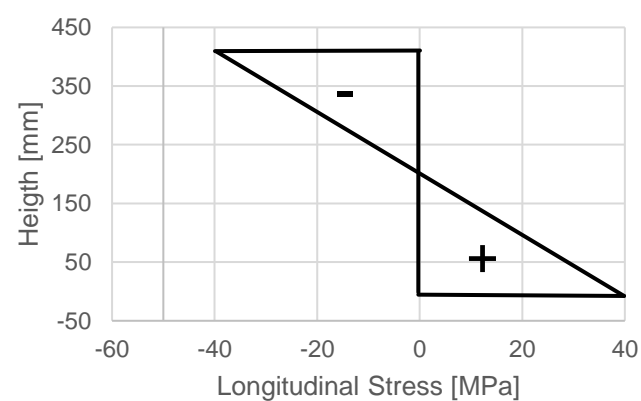


## Vorspannung



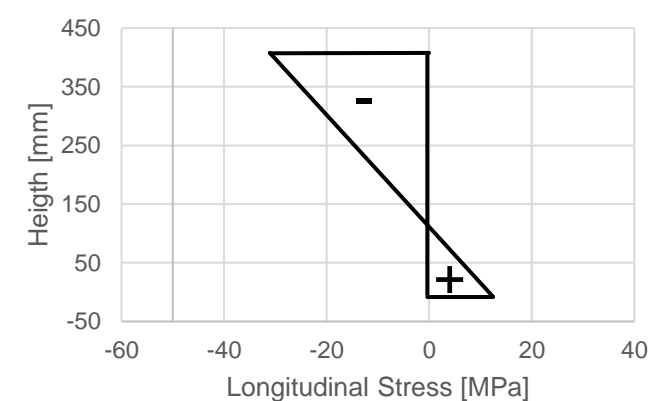
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## Äussere Kräfte



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## Überlagerung





# Biegeversuche



# Prüfplan

## 4-Punkt Biegeversuche an 11 Prüfkörpern

### Ohne Verbund

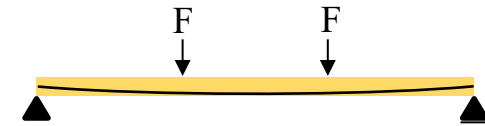
- 3 Fichte GL24h
- 1 Esche GL40h

- 1 Fichte GL24h

### Mit Verbund

- 3 Fichte GL24h
- 1 Esche GL40h

- 2 Fichte GL24h

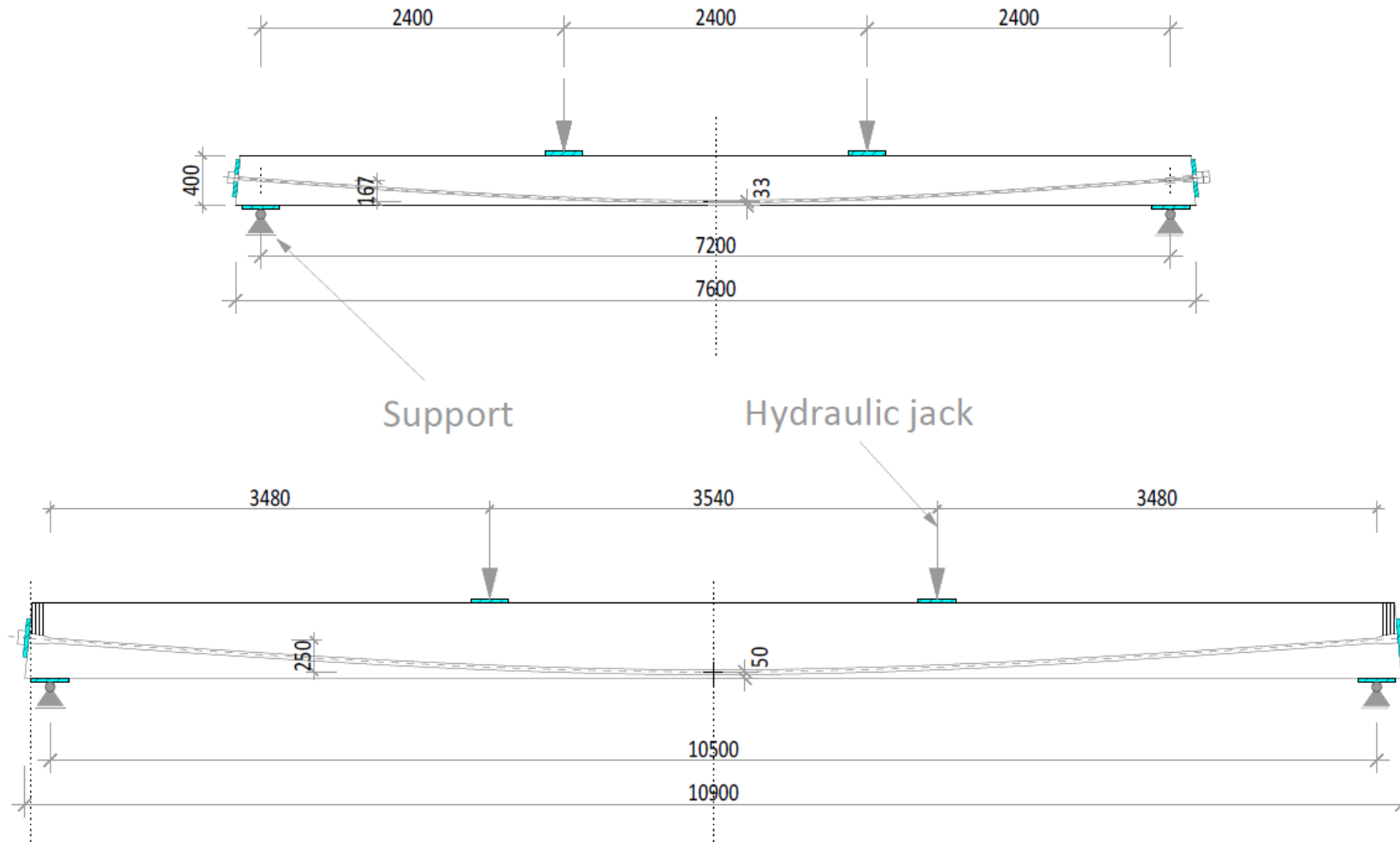


$L = 7.2 \text{ m}$ ,  $H = 400 \text{ mm}$ ,  $B = 120 \text{ mm}$



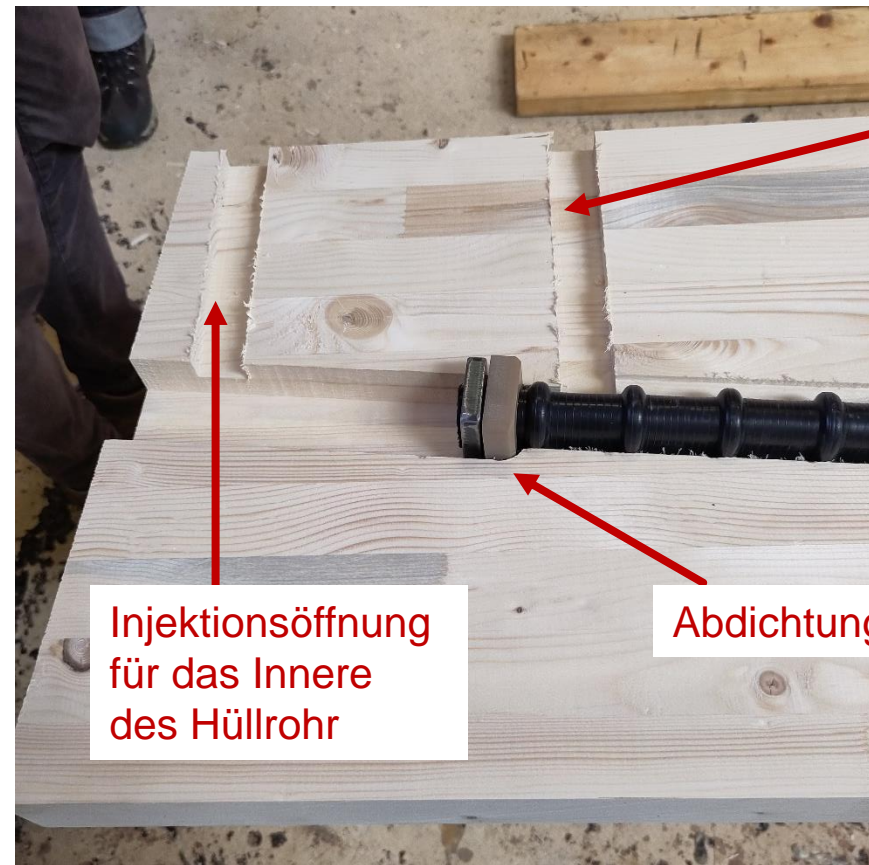
$L = 10.5 \text{ m}$ ,  $H = 600 \text{ mm}$ ,  $B = 150 \text{ mm}$

# Versuchsaufbau



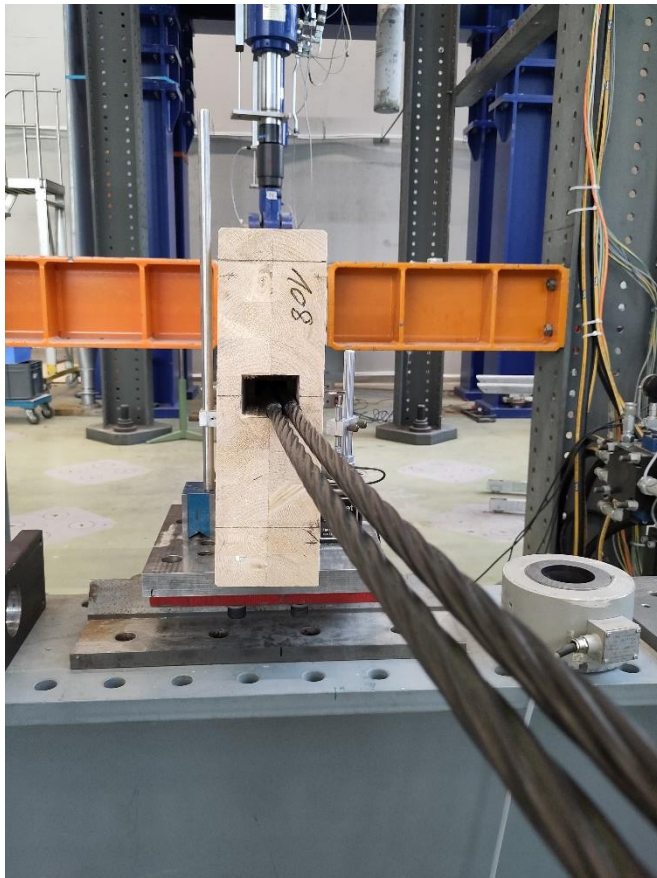
# Vorspannung im Verbund

- Vorbereitung und Blockverklebung

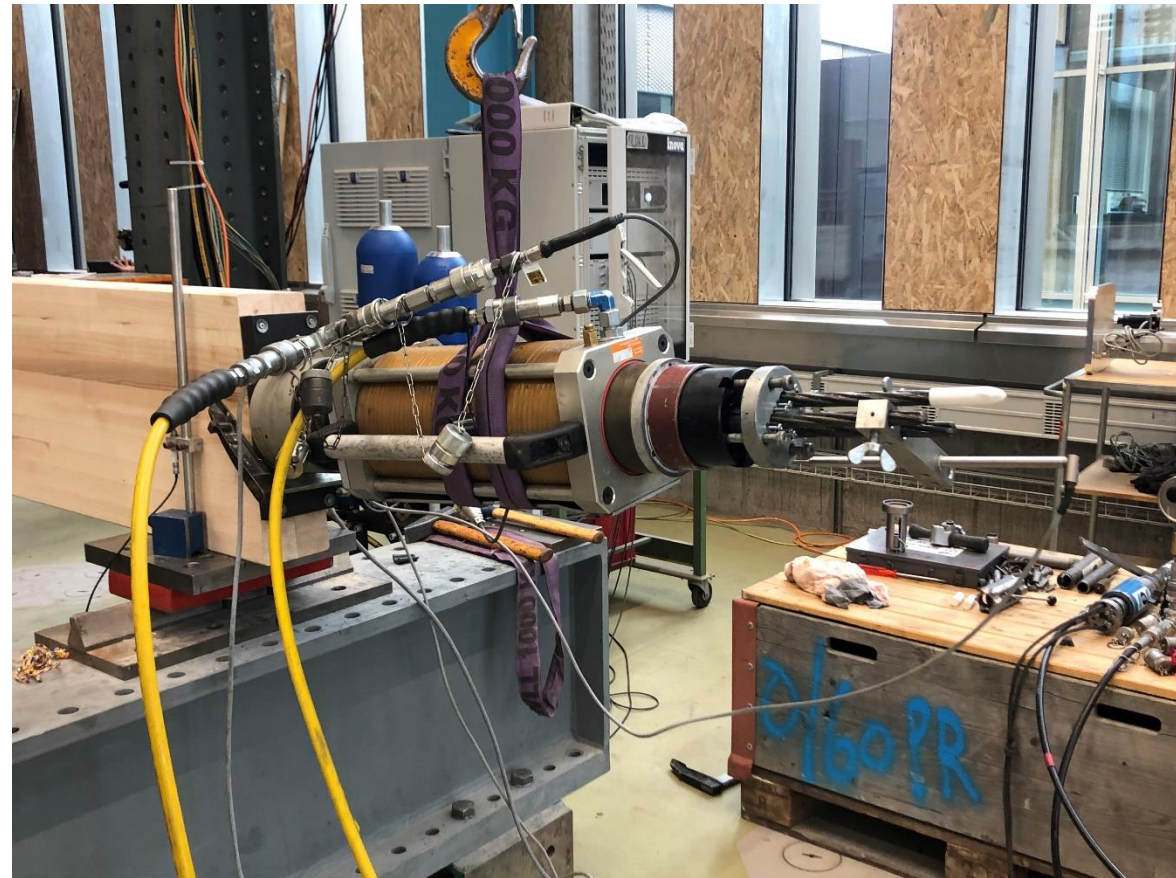


# Vorspannung ohne Verbund

Ermittlung der Biegesteifigkeit

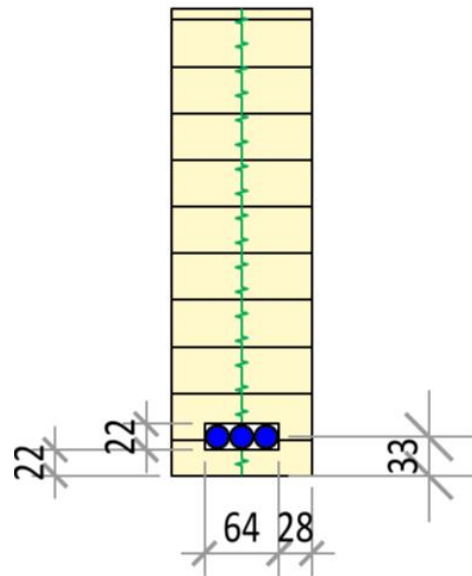


Vorspannung



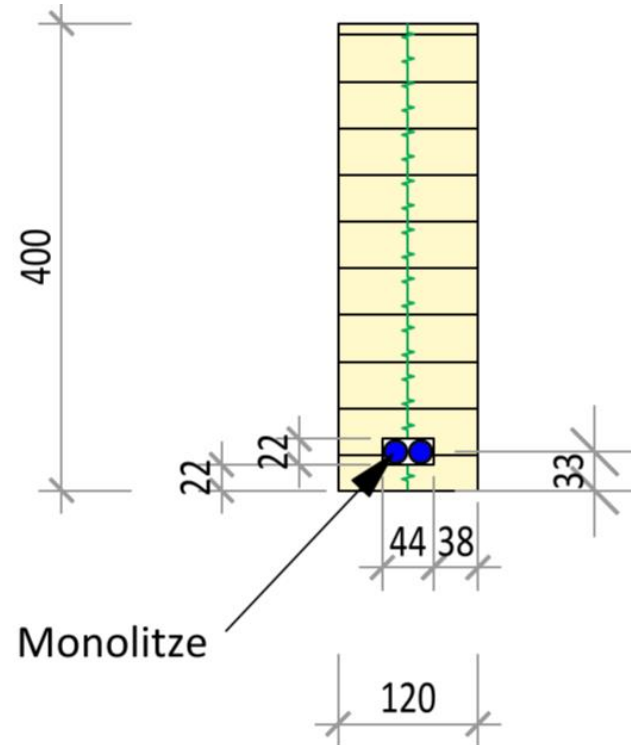
# Querschnitte ohne Verbund

Esche GL40h 7.2 m



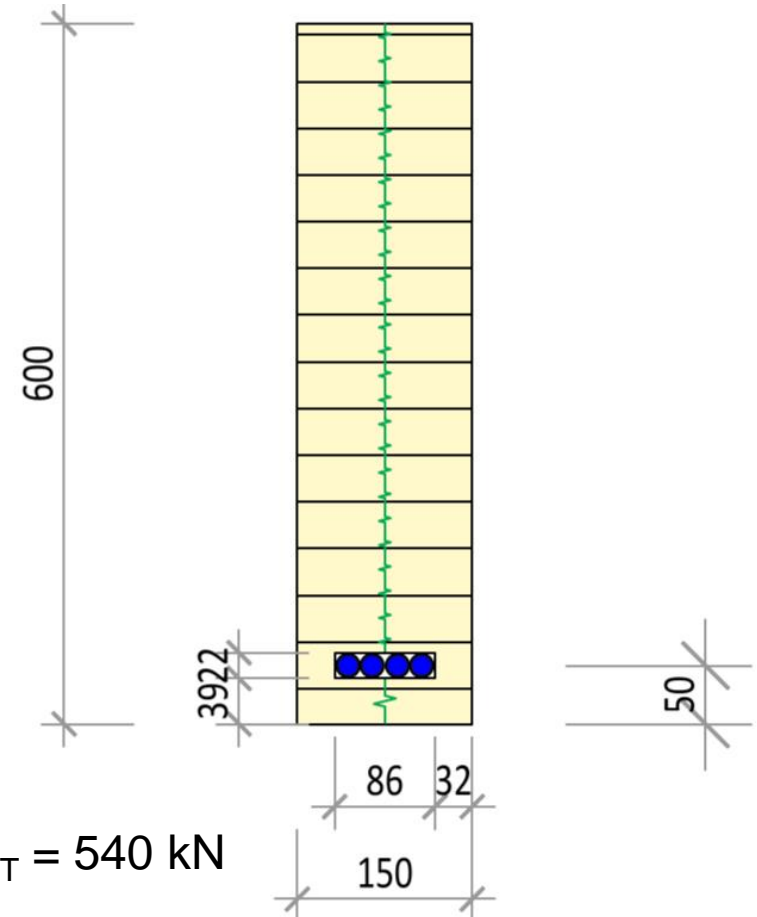
$$F_{PT} = 356 \text{ kN}$$

Fichte GL24h 7.2 m



$$F_{PT} = 245 \text{ kN}$$

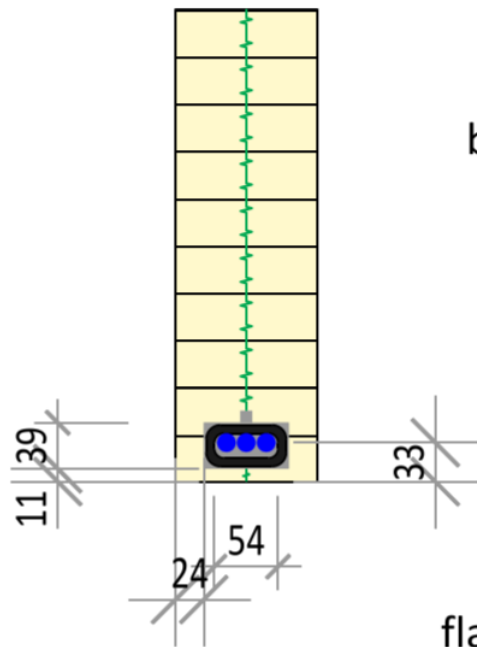
Fichte GL24h 10.5 m



$$F_{PT} = 540 \text{ kN}$$

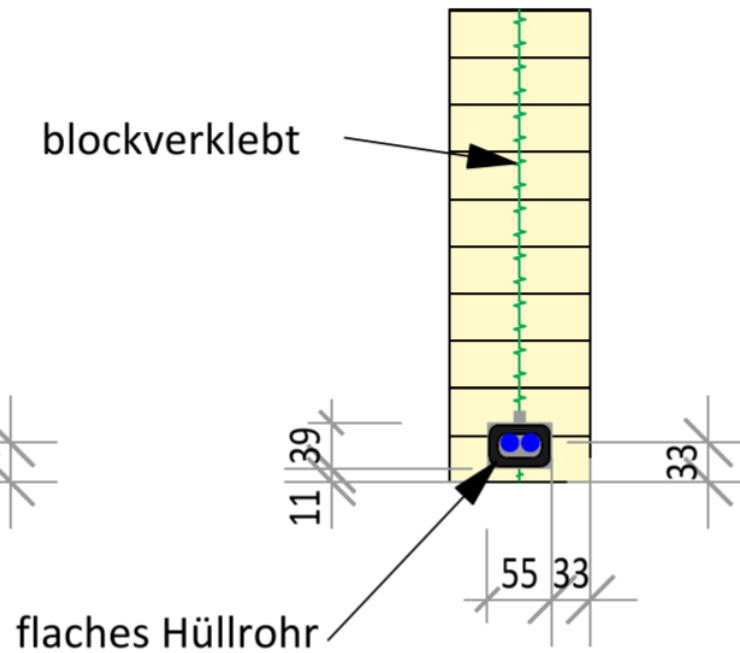
# Querschnitte mit Verbund

Esche GL40h 7.2 m



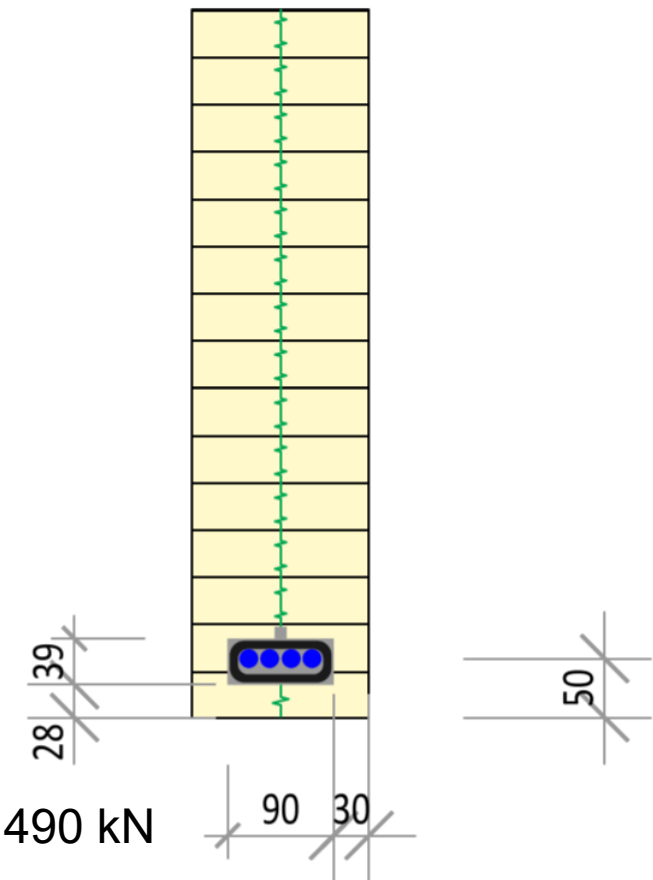
$$F_{PT} = 356 \text{ kN}$$

Fichte GL24h 7.2 m



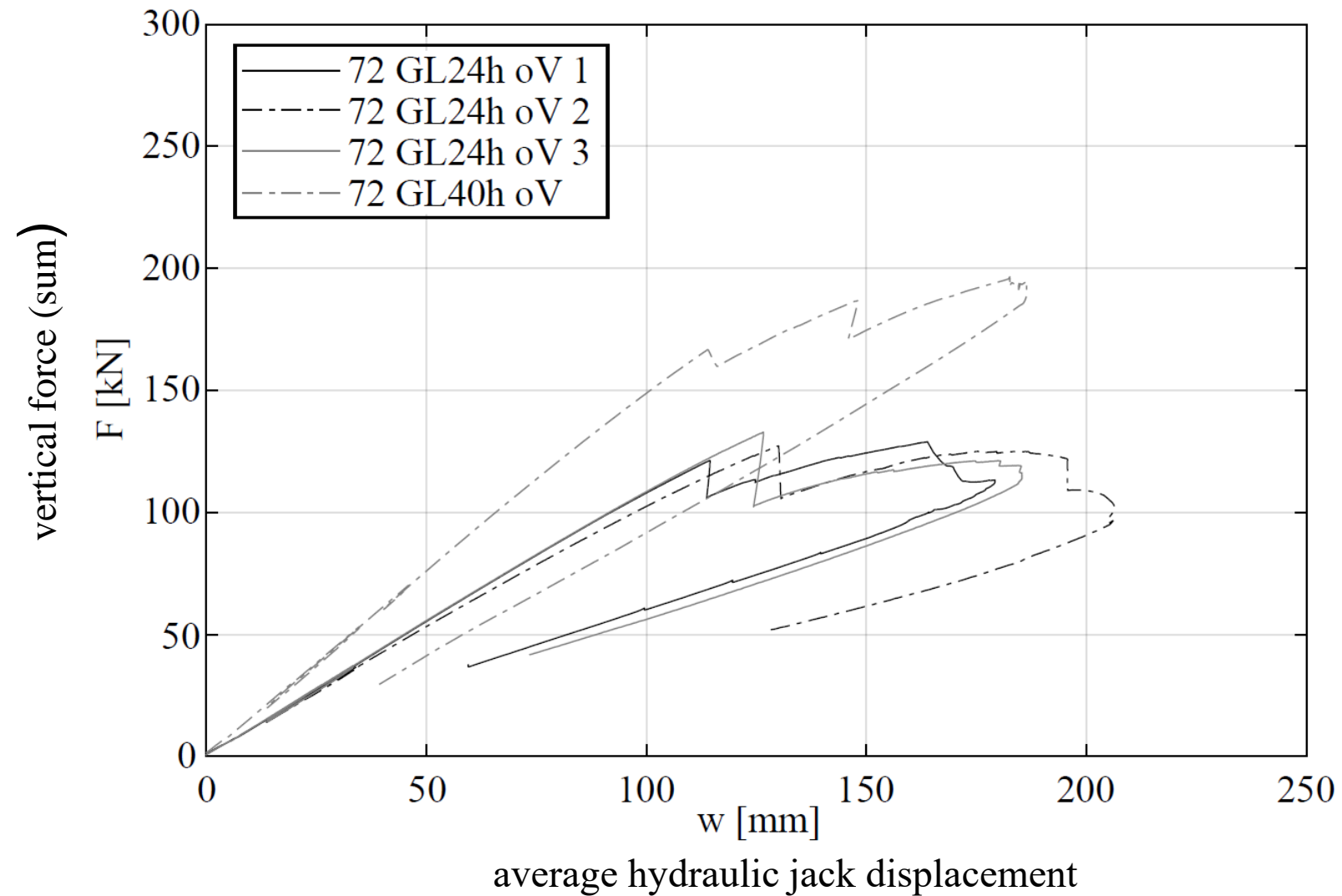
$$F_{PT} = 245 \text{ kN}$$

Fichte GL24h 10.5 m



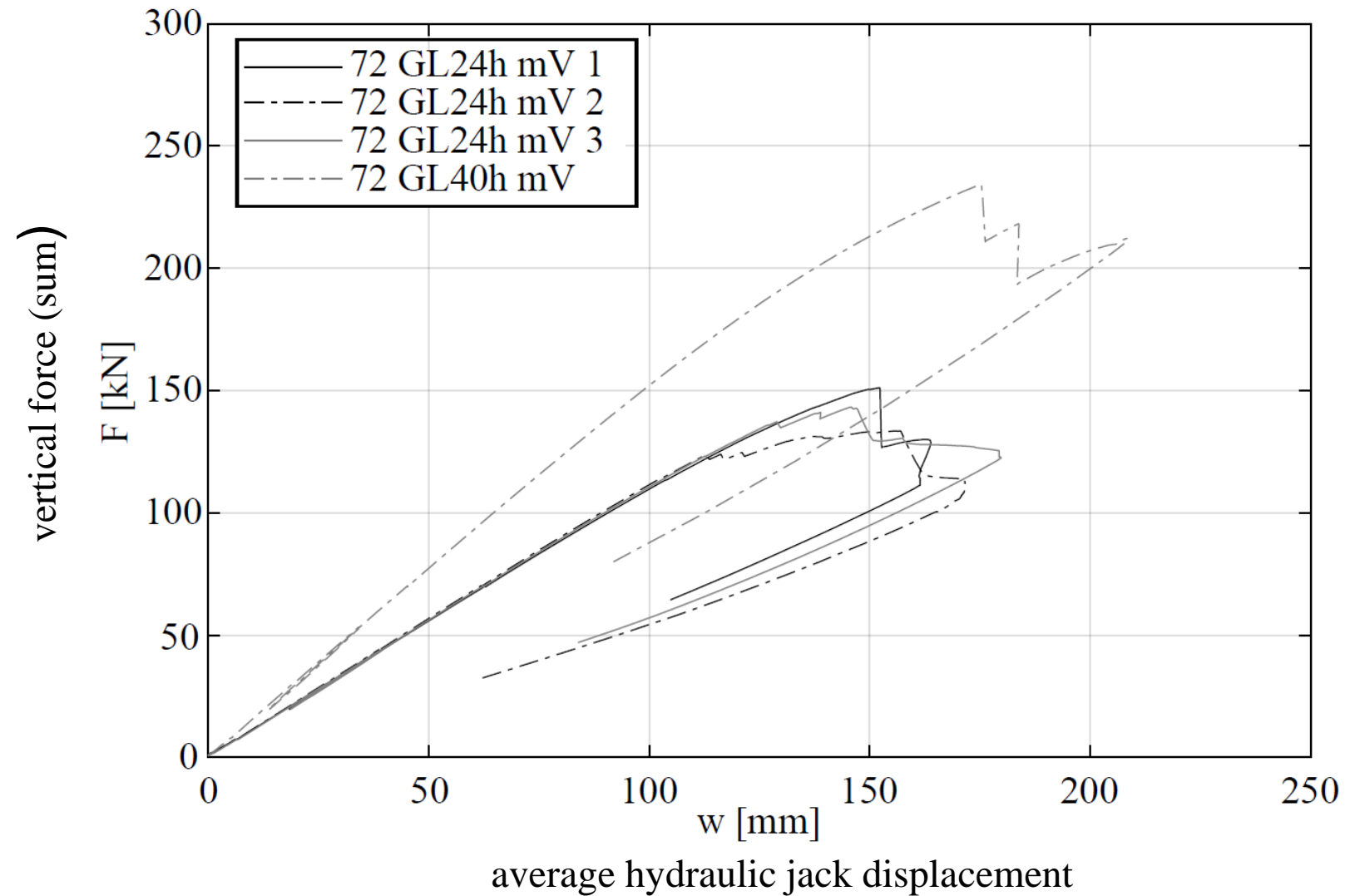
$$F_{PT} \sim 490 \text{ kN}$$

## Resultate 7.2 m ohne Verbund

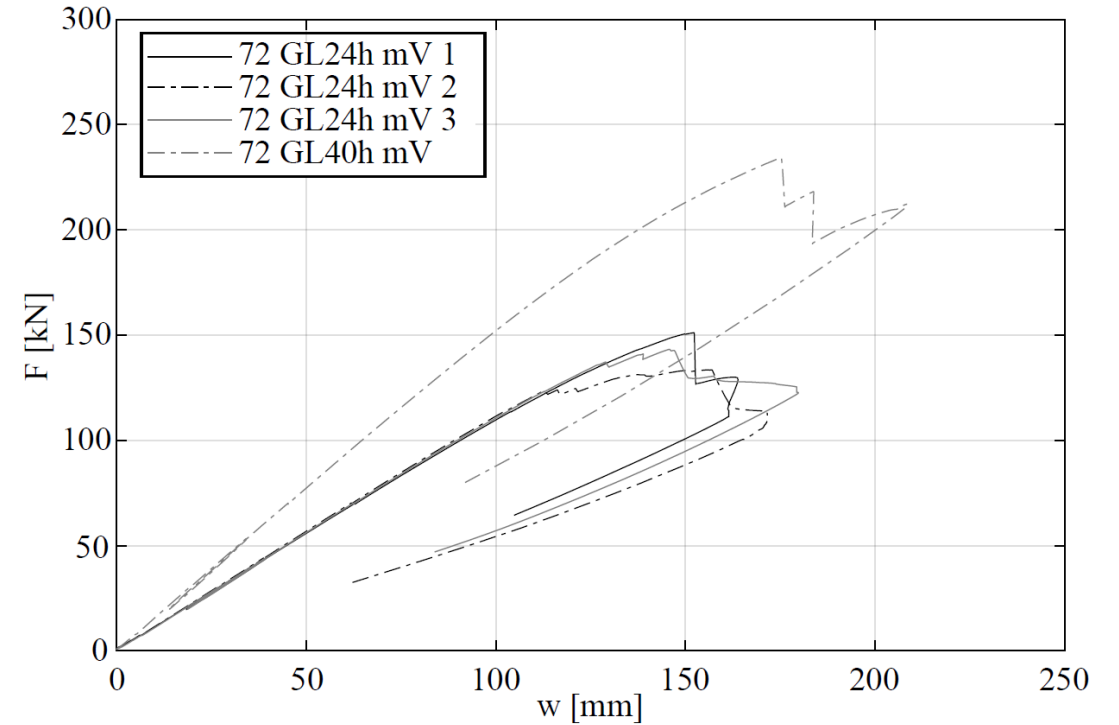
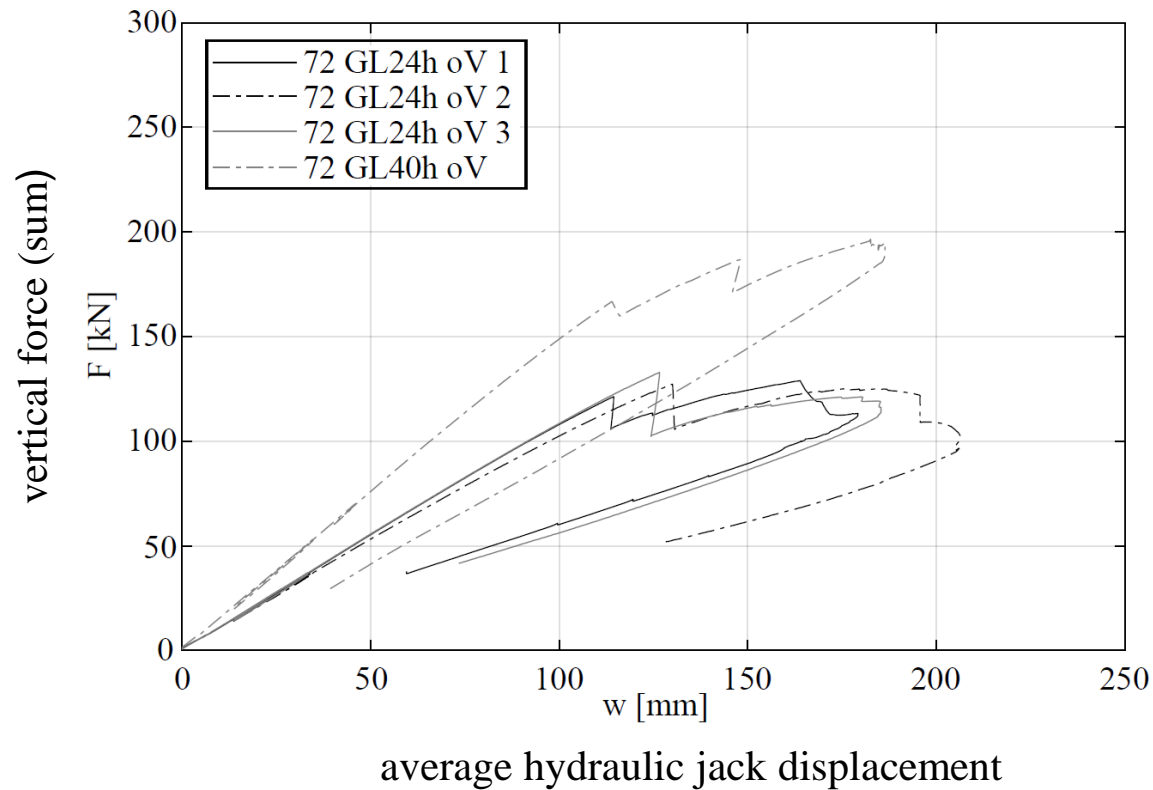




## Resultate 7.2 m mit Verbund

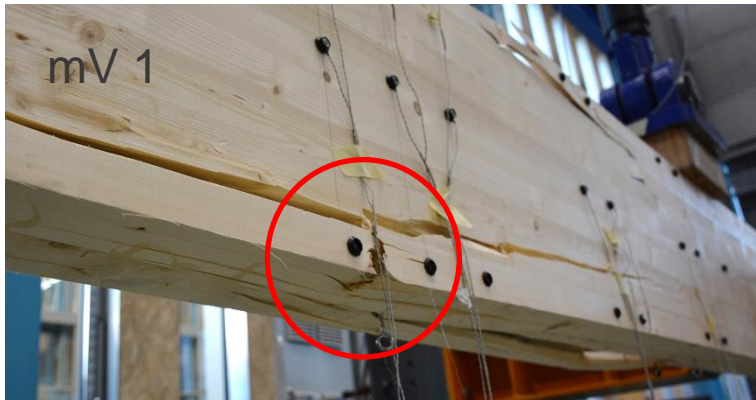


## Resultate 7.2 m - Vergleich

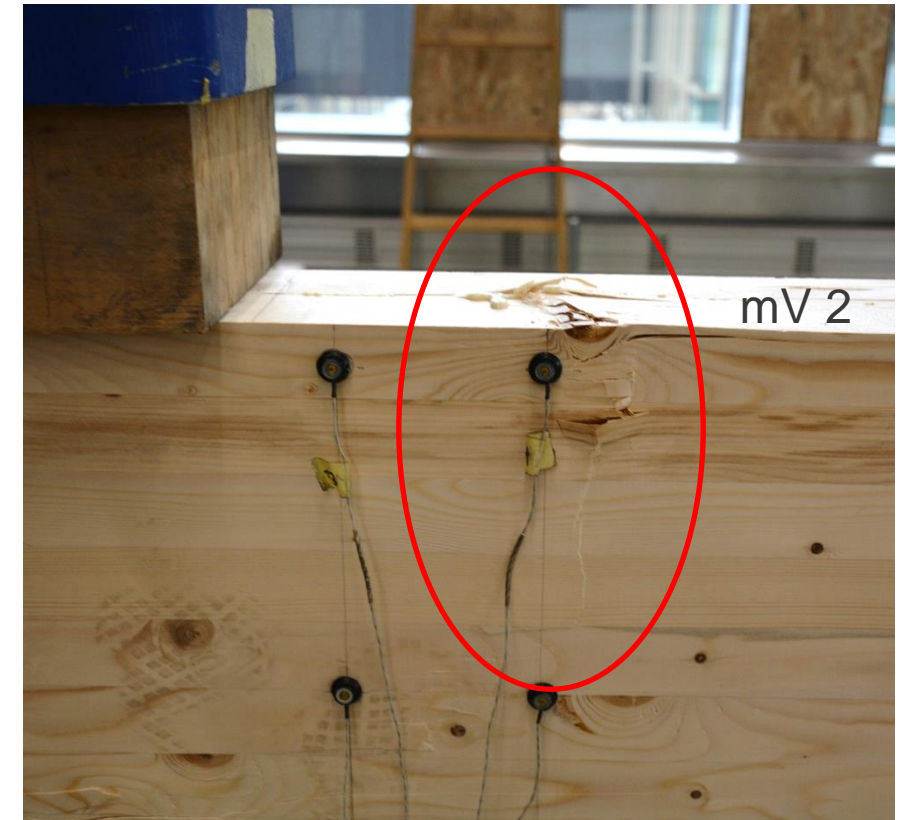


# Beobachtete Versagen GL24h mit Verbund

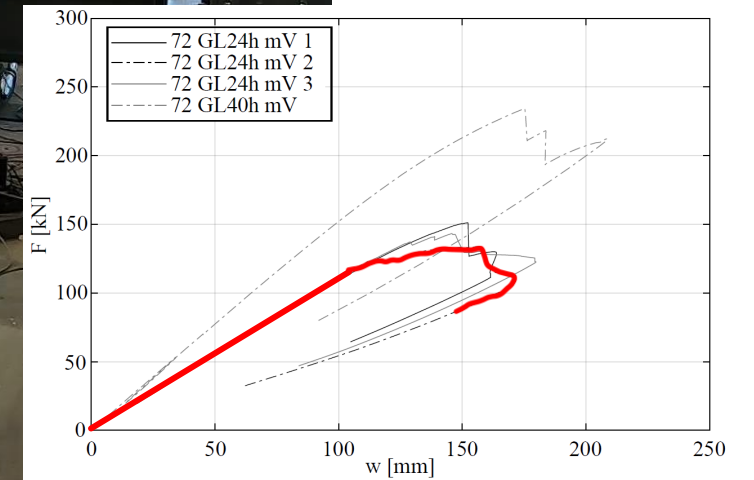
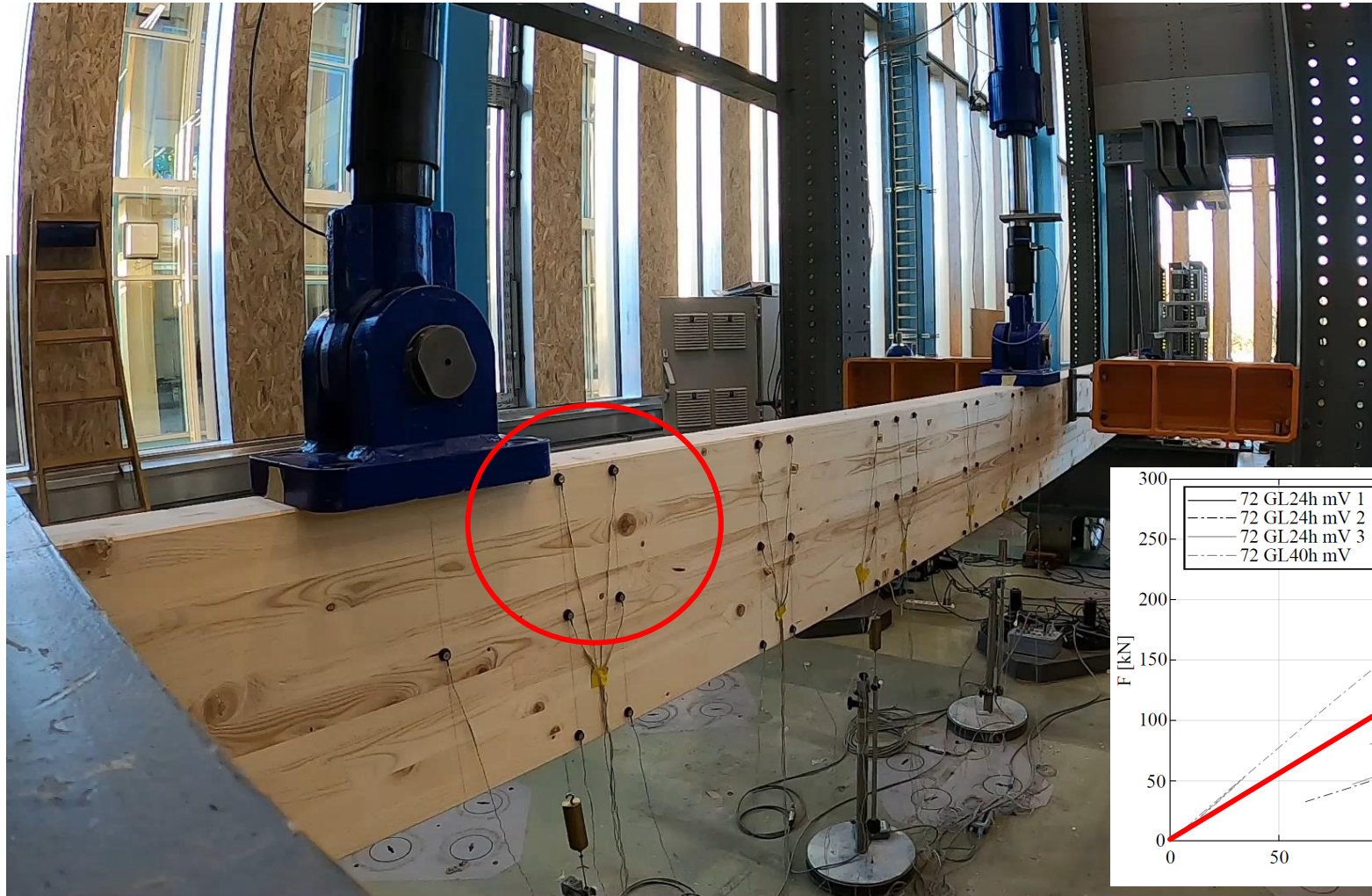
Zugseite



Druckseite



## GL24h 7.2m mV2 (mit Verbund)



## Nachweise

- Formel (6.19) EC5:

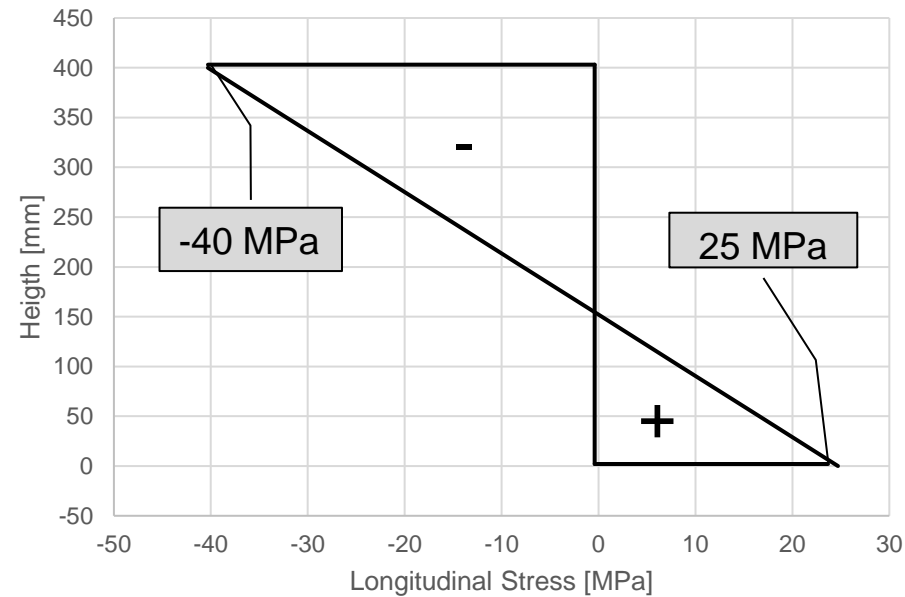
$$\left[ \frac{\sigma_{c,0,d}}{f_{c,0,d}} \right]^2 + \frac{\sigma_{m,y,d}}{f_{m,y,d}} \leq 1$$

Anteil Normalkraft

Anteil Biegung

# Nachweise

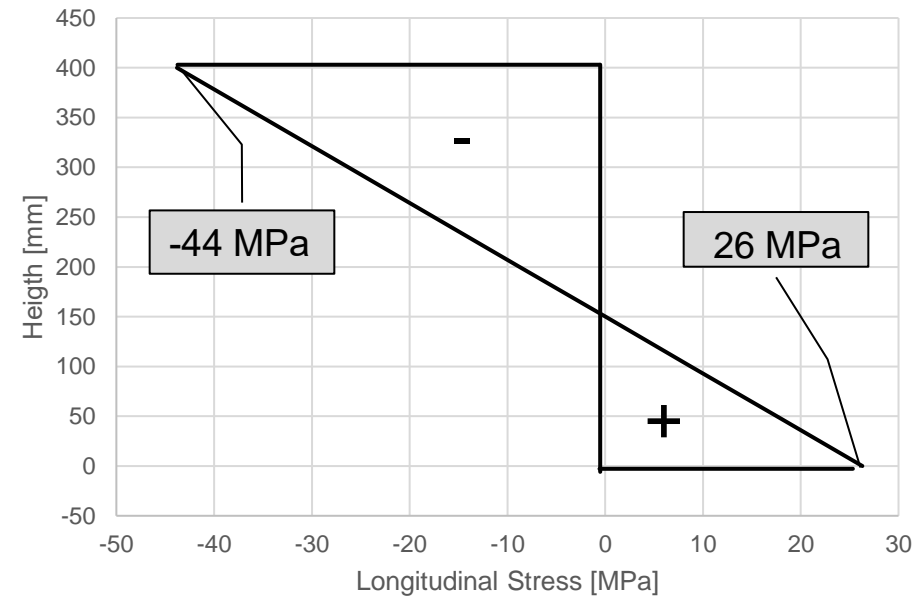
7.2 m oV bei  $F = 130 \text{ kN}$



$$\left[ \frac{6.8 \text{ MPa}}{30.0 \text{ MPa}} \right]^2 + \frac{40.3 \text{ MPa} - 6.8 \text{ MPa}}{30.0 \text{ MPa}} = 1.17$$

$$\frac{40.3 \text{ MPa}}{30.0 \text{ MPa}} = 1.34$$

7.2 m mV bei  $F = 143 \text{ kN}$

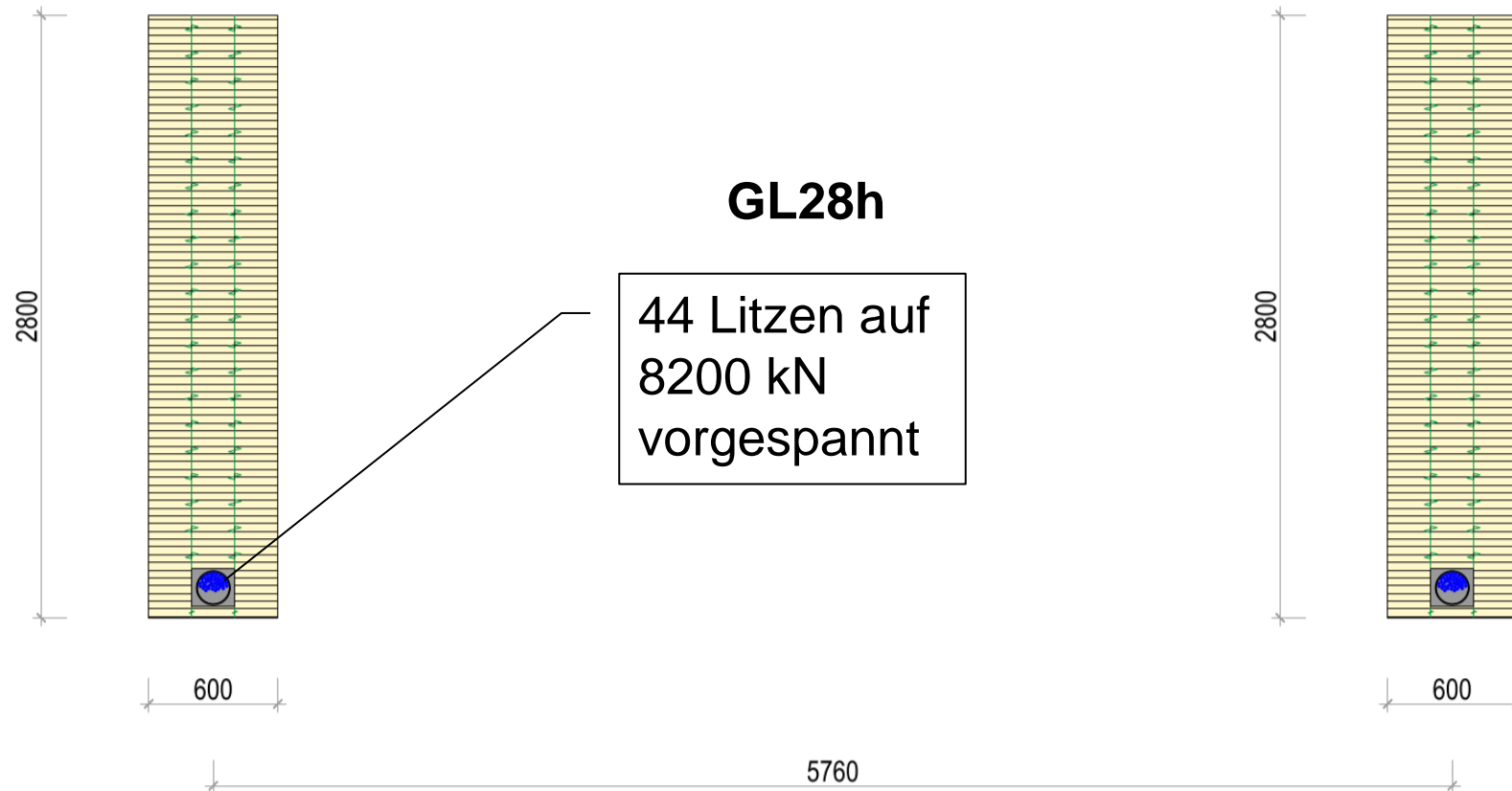


$$\left[ \frac{5.1 \text{ MPa}}{30.0 \text{ MPa}} \right]^2 + \frac{43.8 \text{ MPa} - 5.1 \text{ MPa}}{30.0 \text{ MPa}} = 1.32$$

## Zusammenfassung vorgespannte Träger

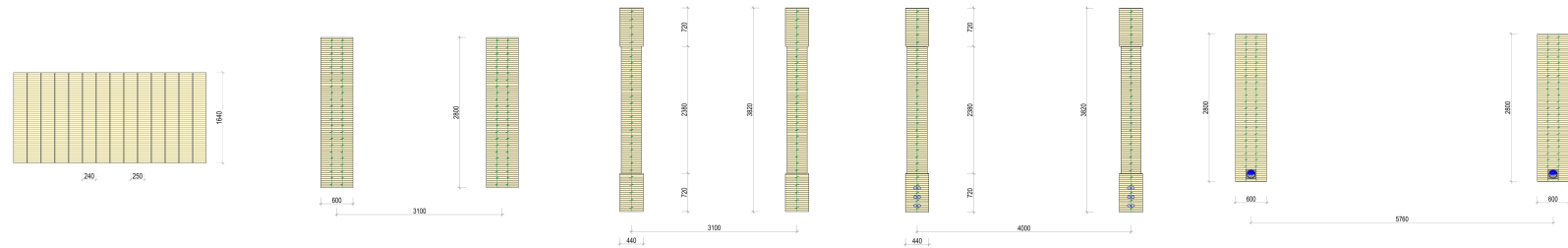
- Steigerung der Tragfähigkeit – ohne Verbund: 64%
- Steigerung der Tragfähigkeit – mit Verbund: 77%
- Steigerung der Biegesteifigkeit – ohne Verbund: 12%
- Steigerung der Biegesteifigkeit – mit Verbund: 21%
- Spannungs- und Dehnungsanalysen zeigen eine Druckversagen
- Formel (6.19) erlaubt eine Bemessung auf der sicheren Seite

# Übertragung auf weitgespannte Träger





# Gegenüberstellung



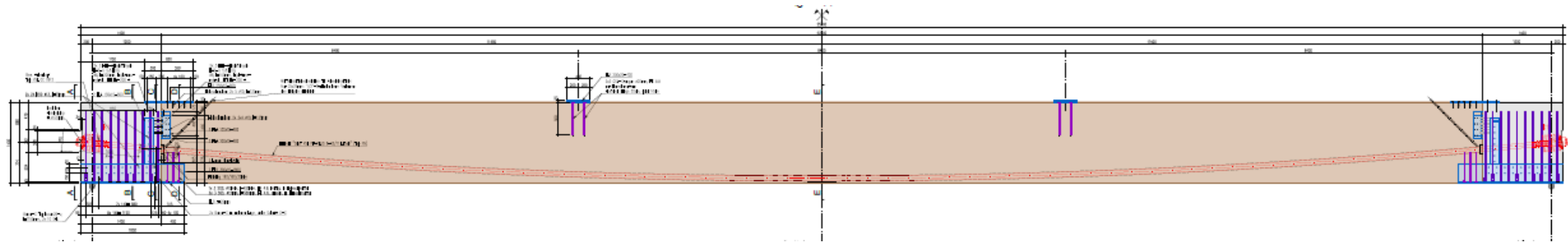
|                                  | <b>A: BSH 1.5</b> | <b>B: BSH 2.8</b> | <b>C: FWK</b> | <b>D: FWK ZS</b> | <b>PT BSH</b> |
|----------------------------------|-------------------|-------------------|---------------|------------------|---------------|
| <b>Dimension</b>                 | 1.50 x 0.24       | 2.80 x 0.60       | 3.82 x 0.44   | 3.82 x 0.44      | 2.80 x 0.60   |
| <b>Sprungmass</b>                | 0.25              | 3.1               | 3.1           | 4.0              | 5.76          |
| <b><math>W_{NL}</math> [mm]</b>  | 41                | 40                | 26            | 31               | 80            |
| <b><math>m^3 / m^2</math></b>    | 1.57              | 0.54              | 0.32          | 0.25             | 0.29          |
|                                  |                   | + 0.22 = 0.76     | + 0.22 = 0.54 | + 0.24 = 0.49    | + 0.28 = 0.57 |
| <b>kg Stahl/<math>m^2</math></b> | 0                 | 0                 | >1            | >1               | 9             |

## Fazit

- Einfache Produktionsmethode (inkl. Verbund)
- Anwendung interessant für blockverklebte Träger
- Vorgespannte Träger ähnlich effizient wie FWT, aber mit geringerer Höhe
- Krafteinleitung in BSH-Träger muss genauer untersucht werden
- Mit Verbund bringt Vorteile, Nachspannen und Rückbau jedoch ungünstig

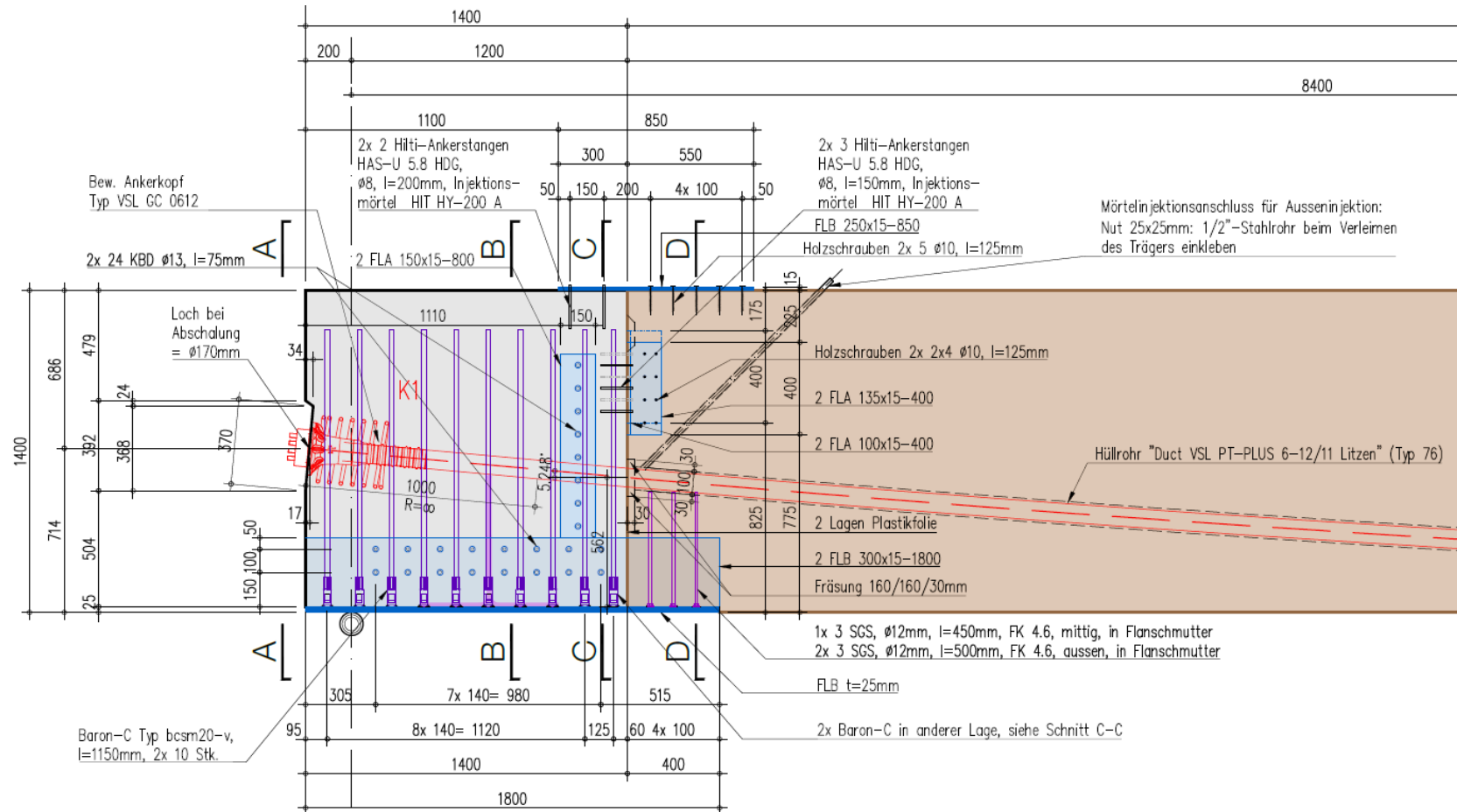
# Ausblick

- Proof of concept: Versuche 25 Meter an der FHNW Muttenz

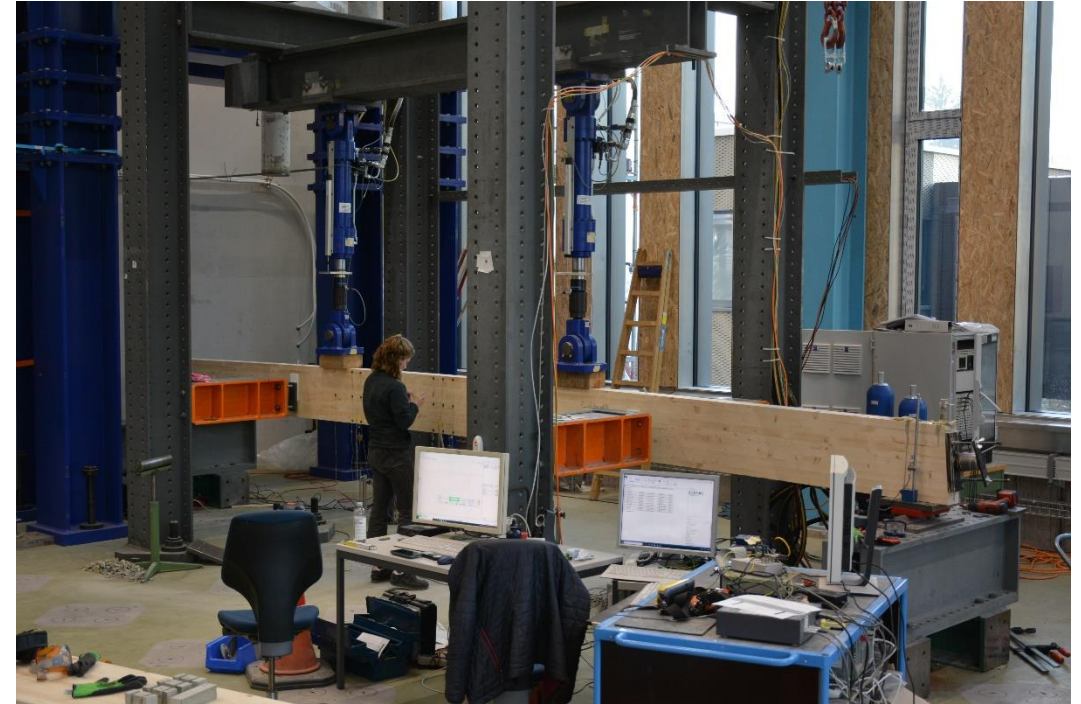


# Ausblick

- Integration der Lastverteilscheibe aus Stahlbeton

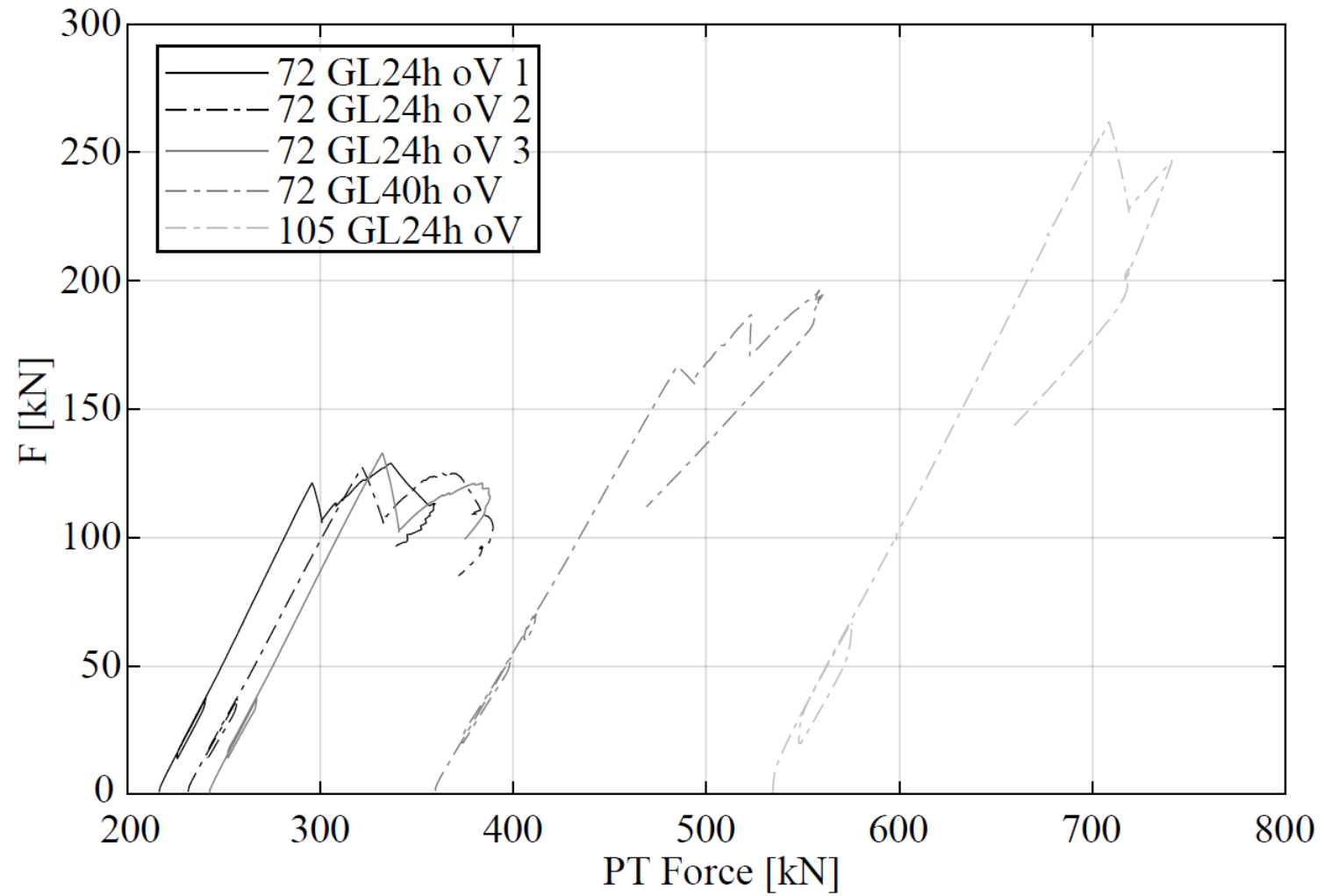


# Danke für Ihre Aufmerksamkeit





## Total force – PT force



## Summary bending

| Series<br>[-] | $h$<br>[mm] | No.<br>[-] | $EI_{GL}$<br>[MN/m <sup>2</sup> ] | $EI_{PT}$<br>[MN/m <sup>2</sup> ] | $\Delta E_I$<br>[%]< | $F_{PT,init}$<br>[kN] | $F_{PT,fail}$<br>[kN] | $F_{ult}$<br>[kN] |
|---------------|-------------|------------|-----------------------------------|-----------------------------------|----------------------|-----------------------|-----------------------|-------------------|
| 72-24h-oV     | 400         | 1          | 6.1                               | 6.7                               | 10.4                 | 245                   | 337                   | 129               |
|               |             | 2          | 5.7                               | 6.3                               | 11.0                 | 245                   | 322                   | 127               |
|               |             | 3          | 6.1                               | 6.8                               | 10.8                 | 245                   | 331                   | 133               |
| 72-24h-mV     | 400         | 1          | 5.7                               | 6.8                               | 20.7                 | 245                   | -                     | 151               |
|               |             | 2          | 5.7                               | 7.0                               | 23.4                 | 245                   | -                     | 134               |
|               |             | 3          | 5.6                               | 6.9                               | 22.7                 | 245                   | -                     | 143               |
| 72-40h-oV     | 400         | 1          | 8.2                               | 9.4                               | 13.8                 | 356                   | 558                   | 196               |
| 72-40h-mV     | 400         | 1          | 7.8                               | 9.6                               | 23.8                 | 356                   | -                     | 234               |
| 105-24h-oV    | 600         | 1          | 27.8                              | 31.7                              | 14.0                 | 543                   | 709                   | 262               |
| 105-24h-mV    | 600         | 1          | 28.9                              | 35.0                              | 21.1                 | 461                   | -                     | 264               |
|               |             | 2          | 29.4                              | 35.0                              | 18.9                 | 521                   | -                     | 276               |



## Calculation

$$\Delta s = l + \frac{8}{2} \times \frac{\Delta f^2}{l}$$

## Load introduction

Deviation forces  $u = 6.31 \text{ kN/m}$

Residual with  $b_{\text{Rest}} = 65 \text{ mm}$

$$\sigma_{t,90} = 0.1 \text{ N/mm}^2$$

PT force  $F_{\text{PT}} = 245 \text{ kN}$

Load dispersion angle  $\alpha = 5^\circ$

$$\sigma_{c,0} = 245 \text{ kN} / (400 \text{ mm} \times 120 \text{ mm}) = 5.1 \text{ N/mm}^2$$

$$\sigma_{t,90} = 0.45 \text{ N/mm}^2$$

$$\text{Sum } \sigma_{c,90,\text{tot}} = 0.55 \text{ N/mm}^2$$

## Push-out / Pull-out

Table 1: Test programme and results of the push-out and pull-out tests including the number of specimens ( $n$ ), the global stiffness (mean values) of the first ( $k_{glob,1}$ ) and second load application ( $k_{glob,2}$ ), the ultimate failure load ( $F_{ult}$ ) and the failure load per m length ( $F_{ult}'$ ).

|          | Series<br>[-] | Milling size<br>[mm] | Milling type<br>[-] | $n$<br>[-] | Grout<br>[-] | $k_{glob,1}$<br>[kN/mm] | $k_{glob,2}$<br>[kN/mm] | $F_{ult,mean}$<br>[kN] | $F_{ult,mean}'$<br>[kN/m] |
|----------|---------------|----------------------|---------------------|------------|--------------|-------------------------|-------------------------|------------------------|---------------------------|
| push-out | 59 G-M        | 80 x 80              | flat                | 3          | mortar       | 122                     | 163                     | 146                    | 520                       |
|          | 59 N-M        | 80 x 80              | notched             | 3          | mortar       | 114                     | 154                     | 164                    | 587                       |
|          | 59 G-GSA      | 80 x 80              | flat                | 3          | GSA          | 99.6                    | 153                     | 160                    | 570                       |
|          | 115 G-M       | 140 x 140            | flat                | 3          | mortar       | 204                     | -                       | 178                    | 634                       |
|          | 115 N-M       | 140 x 140            | notched             | 3          | mortar       | 190                     | -                       | 285                    | 1018                      |
|          | 115 G-GSA     | 140 x 140            | flat                | 2          | GSA          | 163                     | 157                     | 327                    | 1166                      |
| pull-out | 59 G-M-Z      | 80 x 80              | flat                | 3          | mortar       | 26.1                    | 40.6                    | 49.3                   | 176                       |
|          | 59 N-M-Z      | 80 x 80              | notched             | 3          | mortar       | 27.1                    | 21.6                    | 95.2                   | 340                       |
|          | 115 G-M-Z     | 140 x 140            | flat                | 3          | mortar       | 26.7                    | 66.0                    | 85.8                   | 303                       |
|          | 115 N-M-Z     | 140 x 140            | notched             | 3          | mortar       | 21.9                    | 59.4                    | 126                    | 450                       |