

# **Sporthalle in Zürich mit vorgespannten BSH-Trägern**

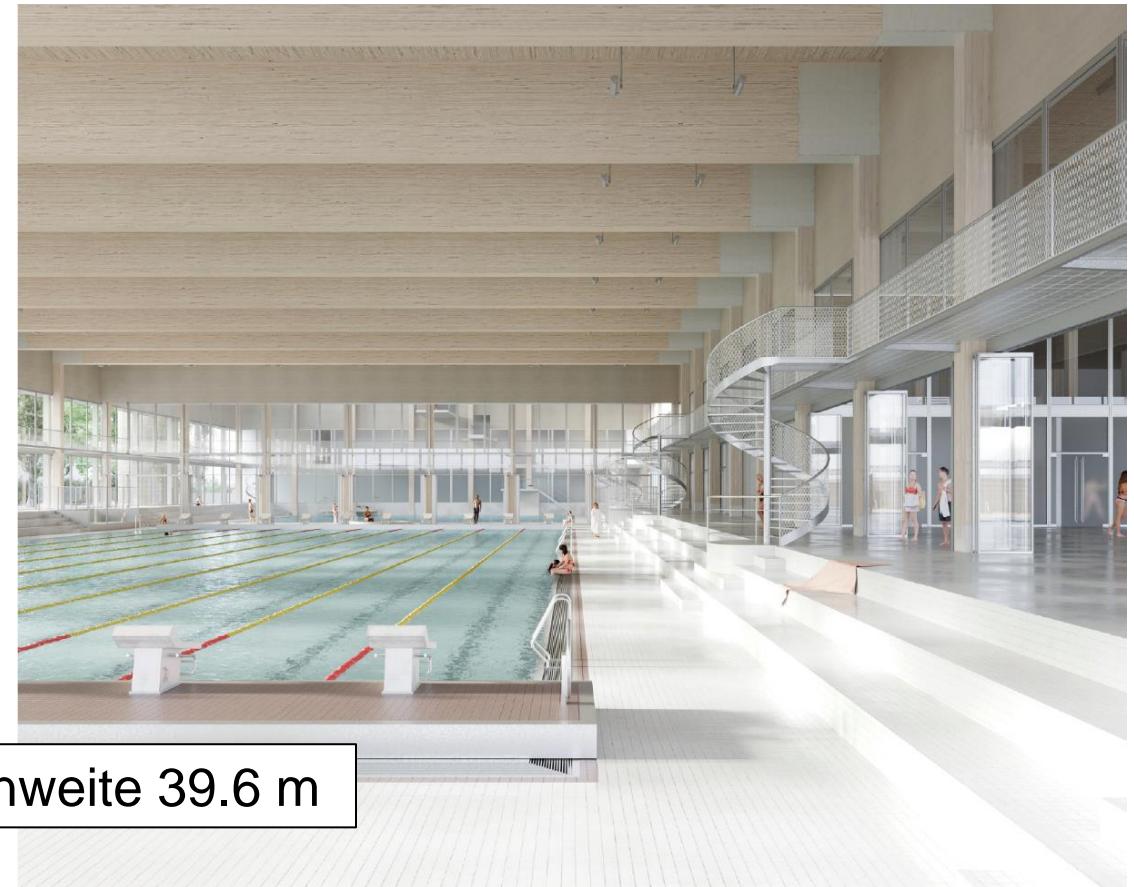
Marcel Muster

27. Internationales Holzbau-Forum Innsbruck  
29. November – 1. Dezember 2023

# Einleitung



Spannweite 39.6 m



Motivation

Anforderungen

Varianten

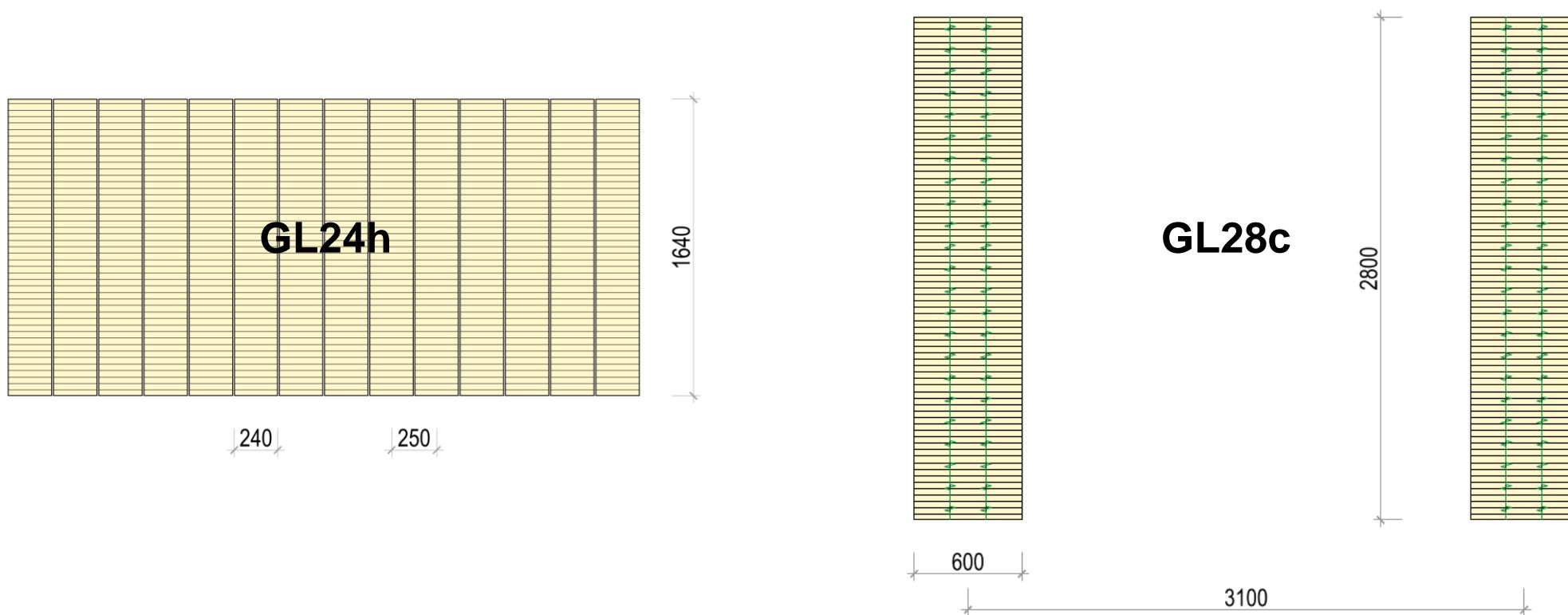
Vorgespannte Träger

Fazit

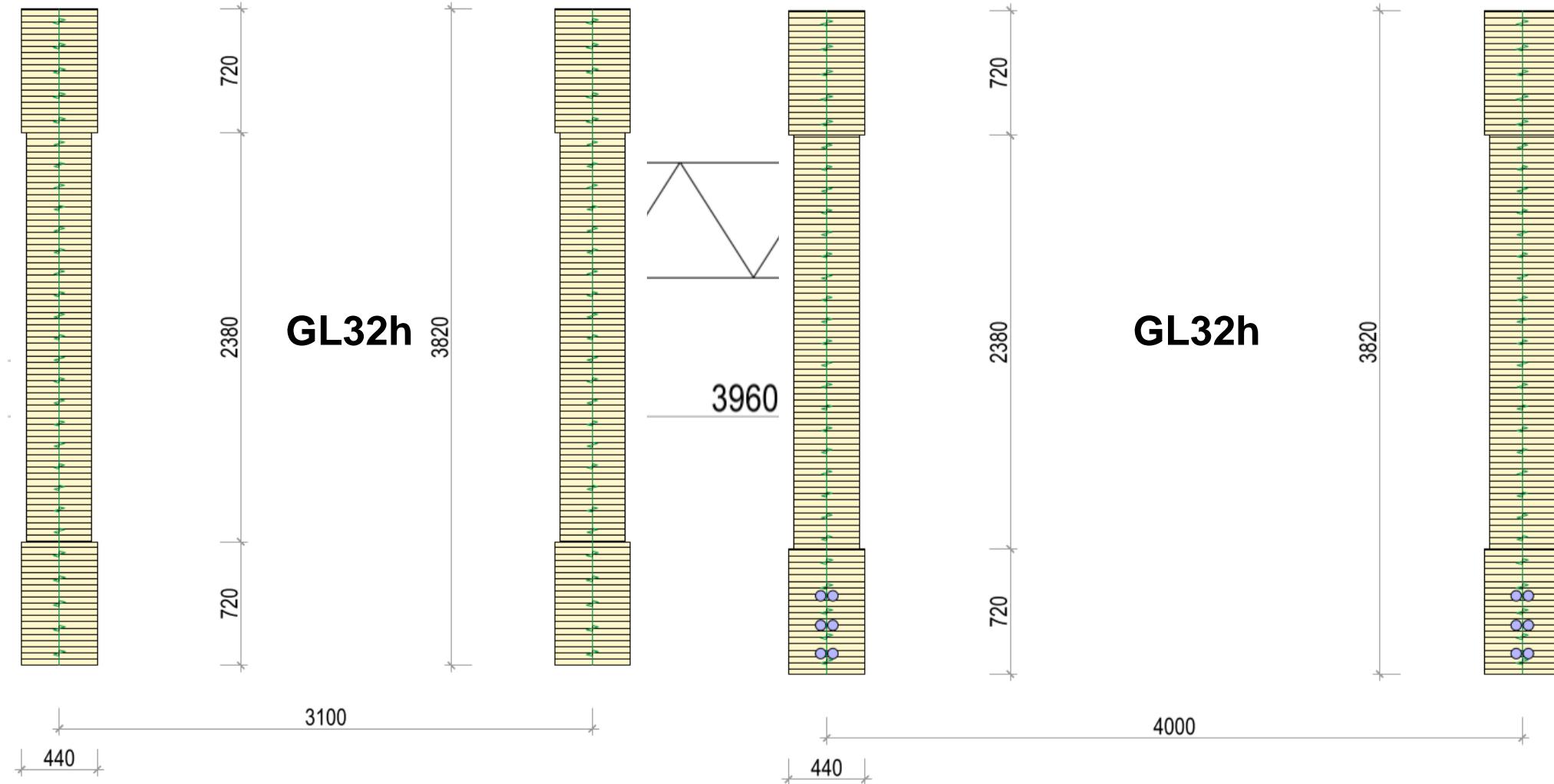
# Anforderungen

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

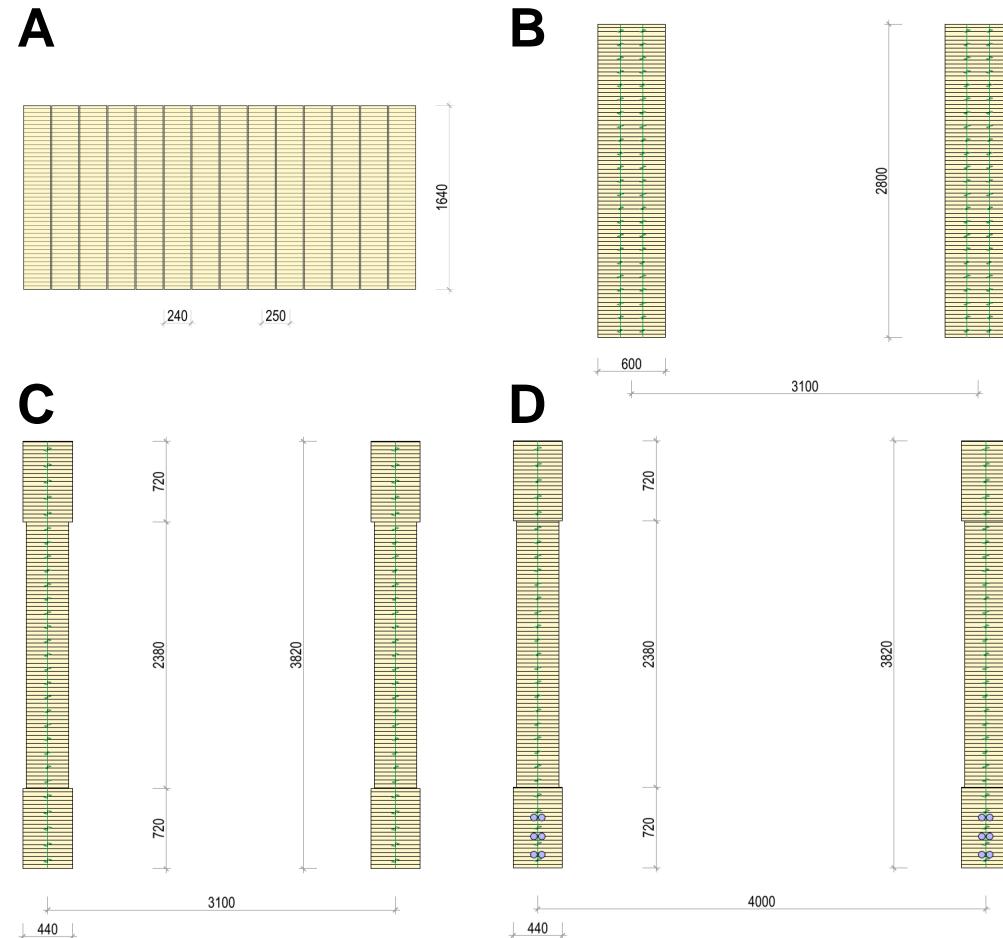
# Varianten



# Varianten

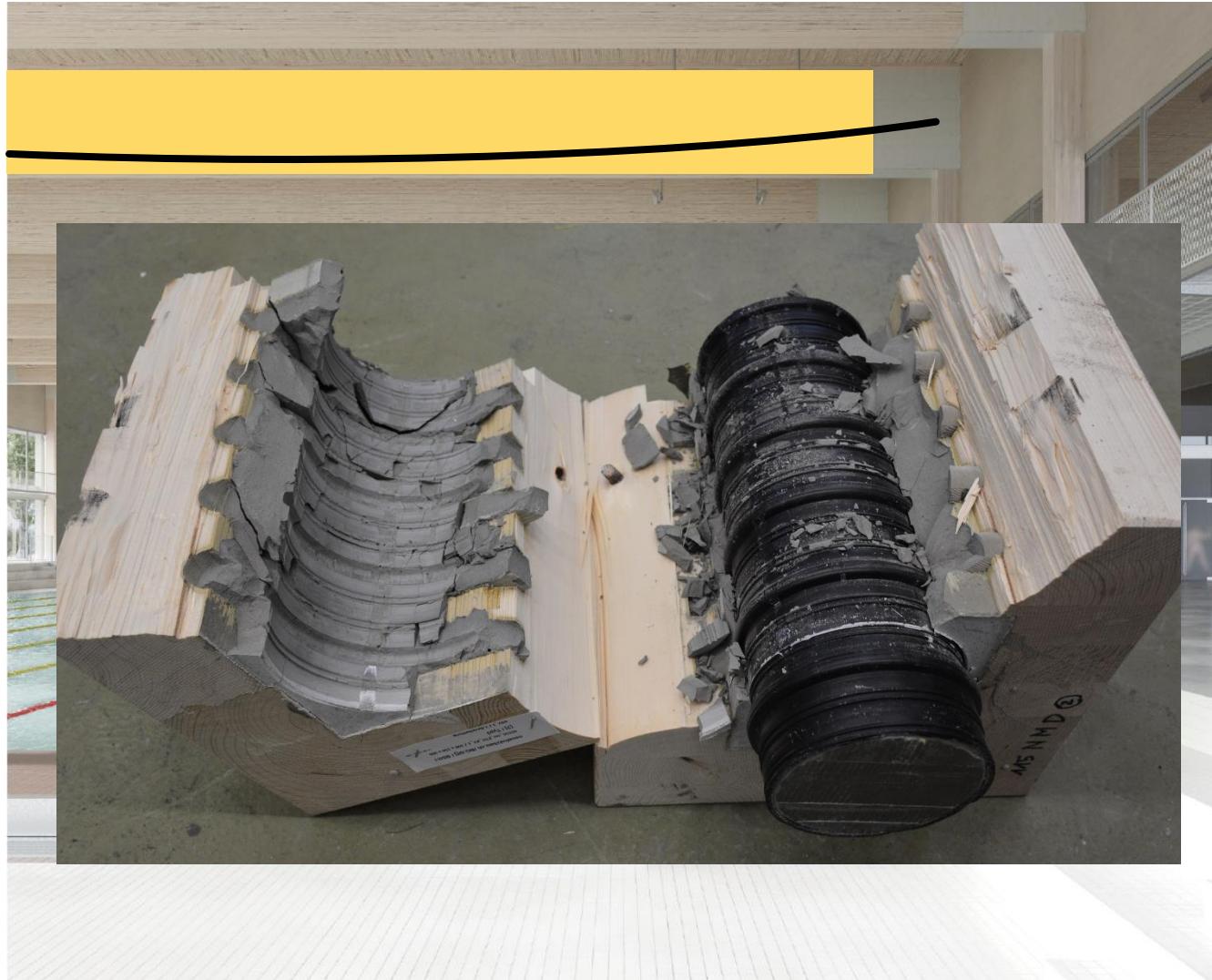


# Varianten



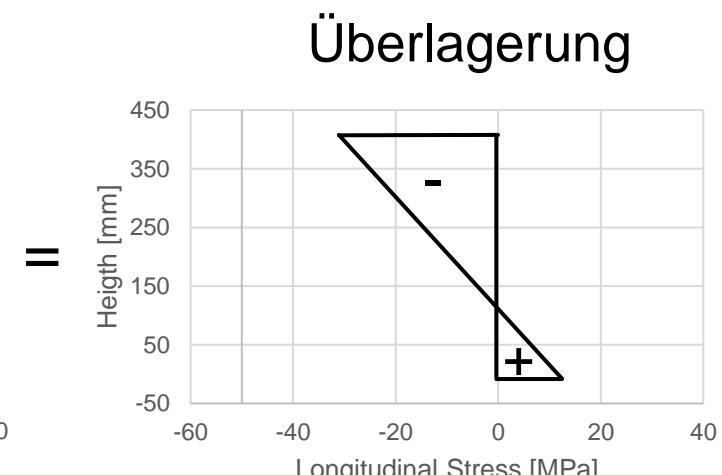
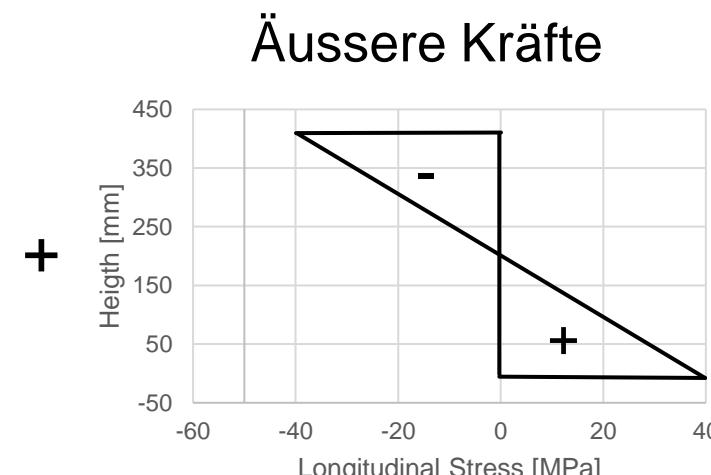
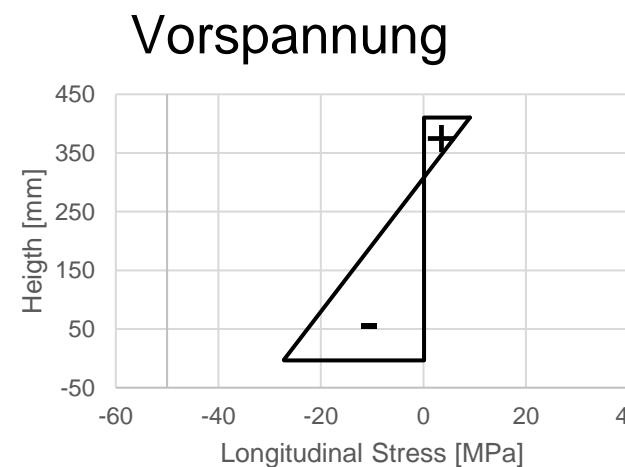
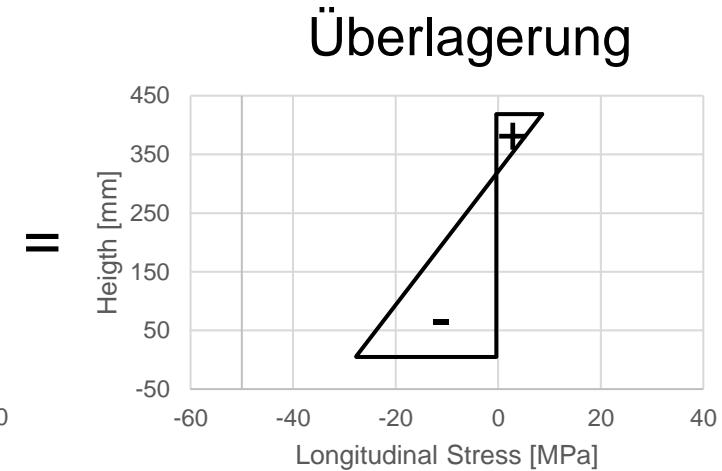
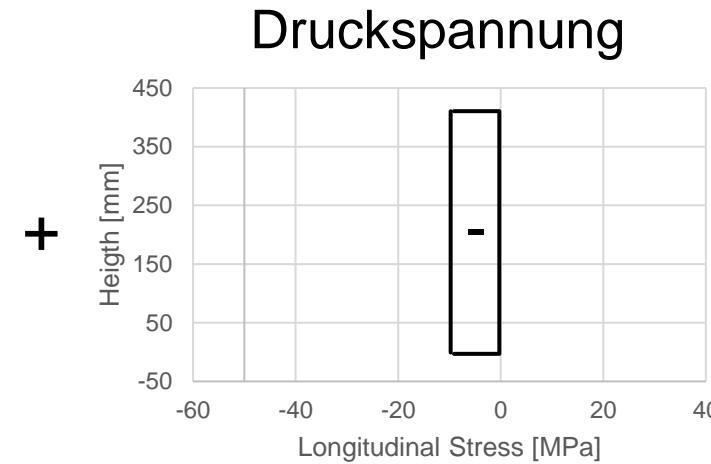
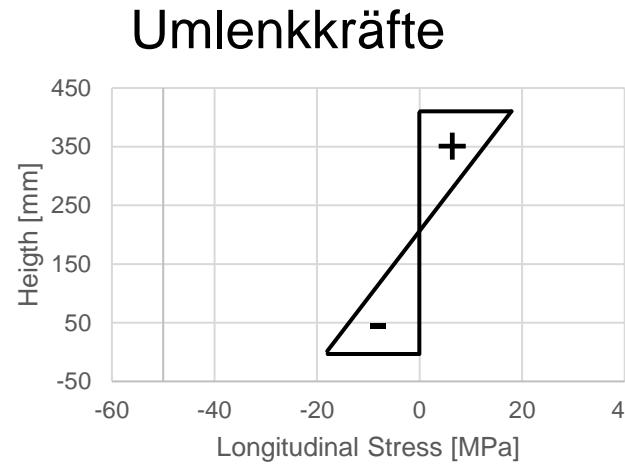
Varianten	A	B	C	D
<b>Quasi-ständige Verformung inkl. Kriechen</b>	284 mm	194 mm	115 mm	132 mm
<b>Erforderliche Überhöhung zur Einhaltung L/300</b>	152 mm	62 mm	0 mm	0 mm
<b>Verformung veränderliche Einwirkungen</b>	41 mm	40 mm	26 mm	31 mm
<b>Ausnutzung Biegung (und Zug) und Querkraft</b>	1.0 / 0.4	1.0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

# Motivation



Source:  
Wettbewerbsunterlagen  
Neubau Sportzentrum  
Oerlikon, Boltshauser  
Architekten AG

# Spannungsverteilung



# Biegeversuche



# Prüfplan

## 4-Punkt Biegeversuche an 11 Prüfkörpern

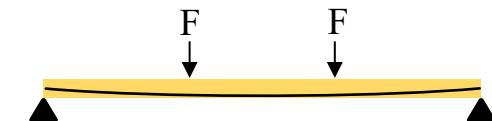
### Ohne Verbund

- 3 Fichte GL24h
- 1 Esche GL40h

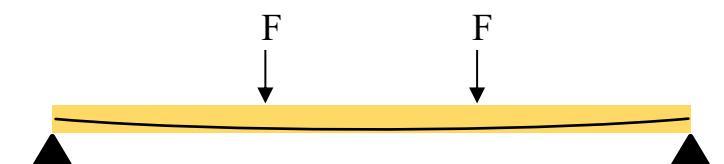
### Mit Verbund

- 3 Fichte GL24h
- 1 Esche GL40h

- 2 Fichte GL24h

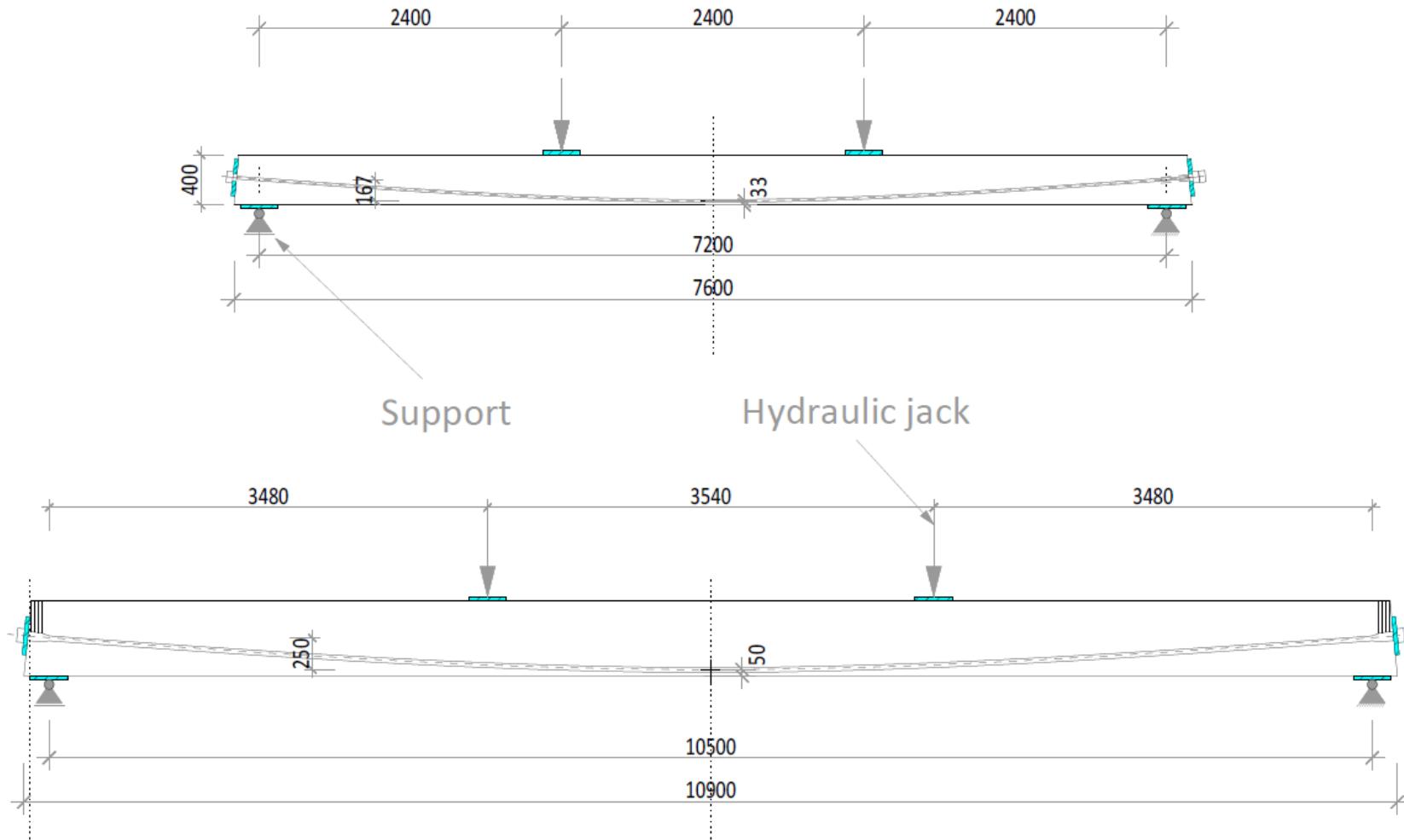


$L = 7.2 \text{ m}$ ,  $H = 400 \text{ mm}$ ,  $B = 120 \text{ mm}$



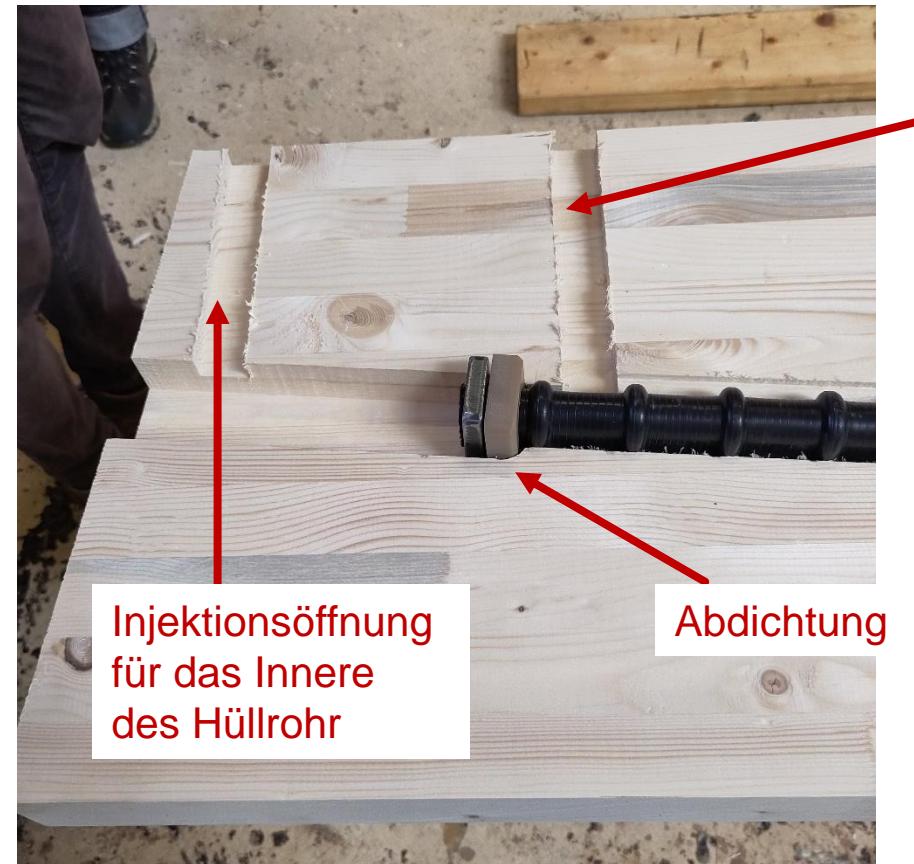
$L = 10.5 \text{ m}$ ,  $H = 600 \text{ mm}$ ,  $B = 150 \text{ mm}$

# Versuchsaufbau



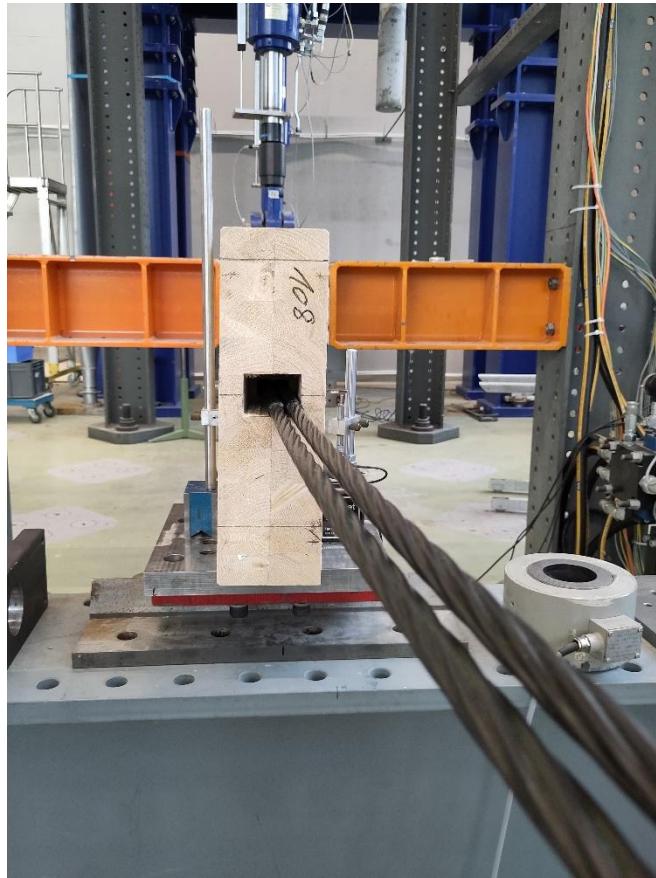
# Vorspannung im Verbund

- Vorbereitung und Blockverklebung



# Vorspannung ohne Verbund

Ermittlung der Biegesteifigkeit

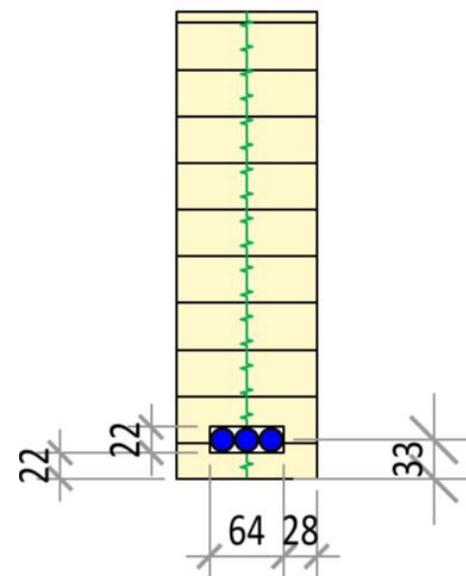


Vorspannung



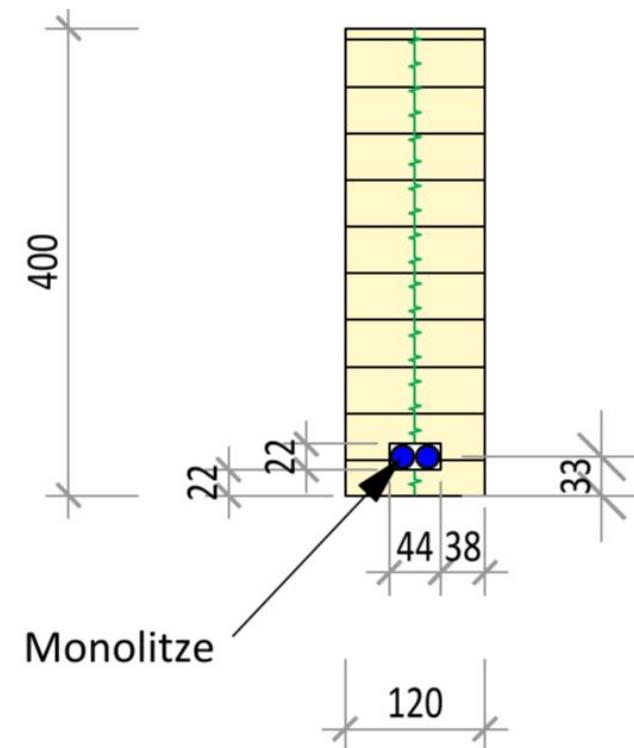
## Querschnitte ohne Verbund

Esche GL40h 7.2 m



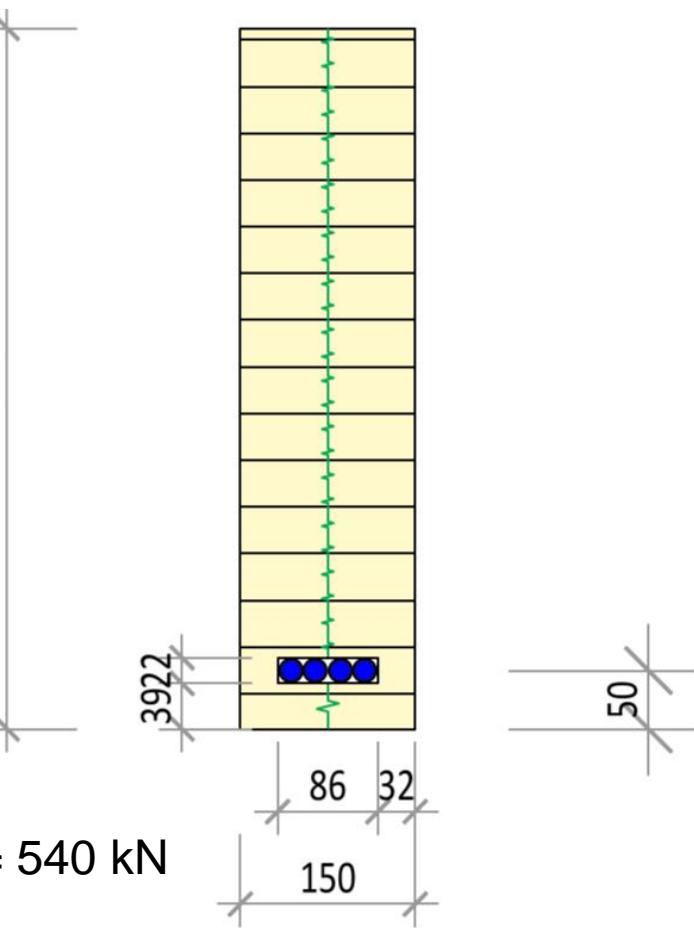
$$F_{PT} = 356 \text{ kN}$$

Fichte GL24h 7.2 m



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

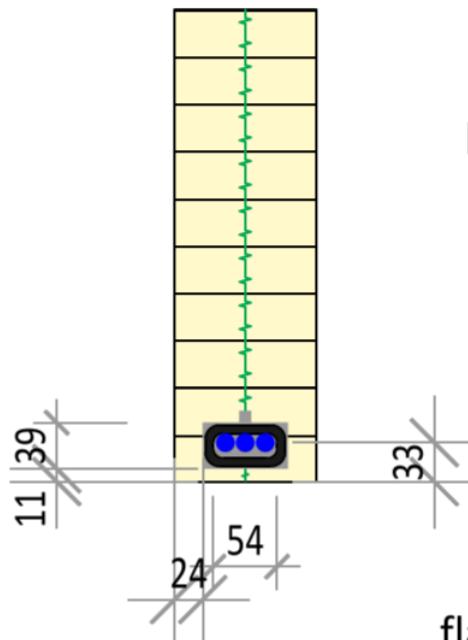
Fichte GL24h 10.5 m



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

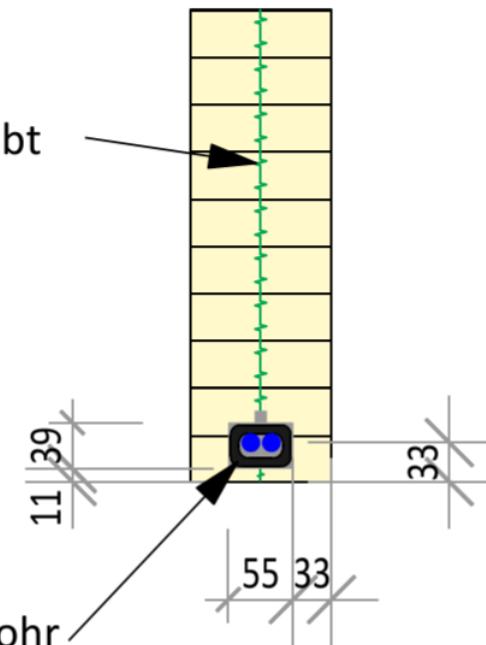
# Querschnitte mit Verbund

Esche GL40h 7.2 m



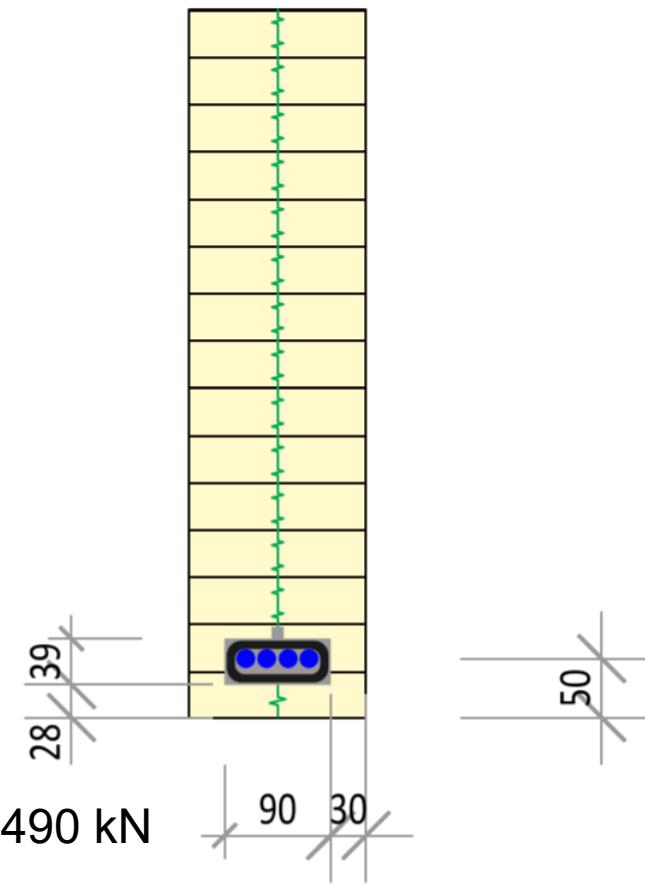
$$F_{PT} = 356 \text{ kN}$$

Fichte GL24h 7.2 m

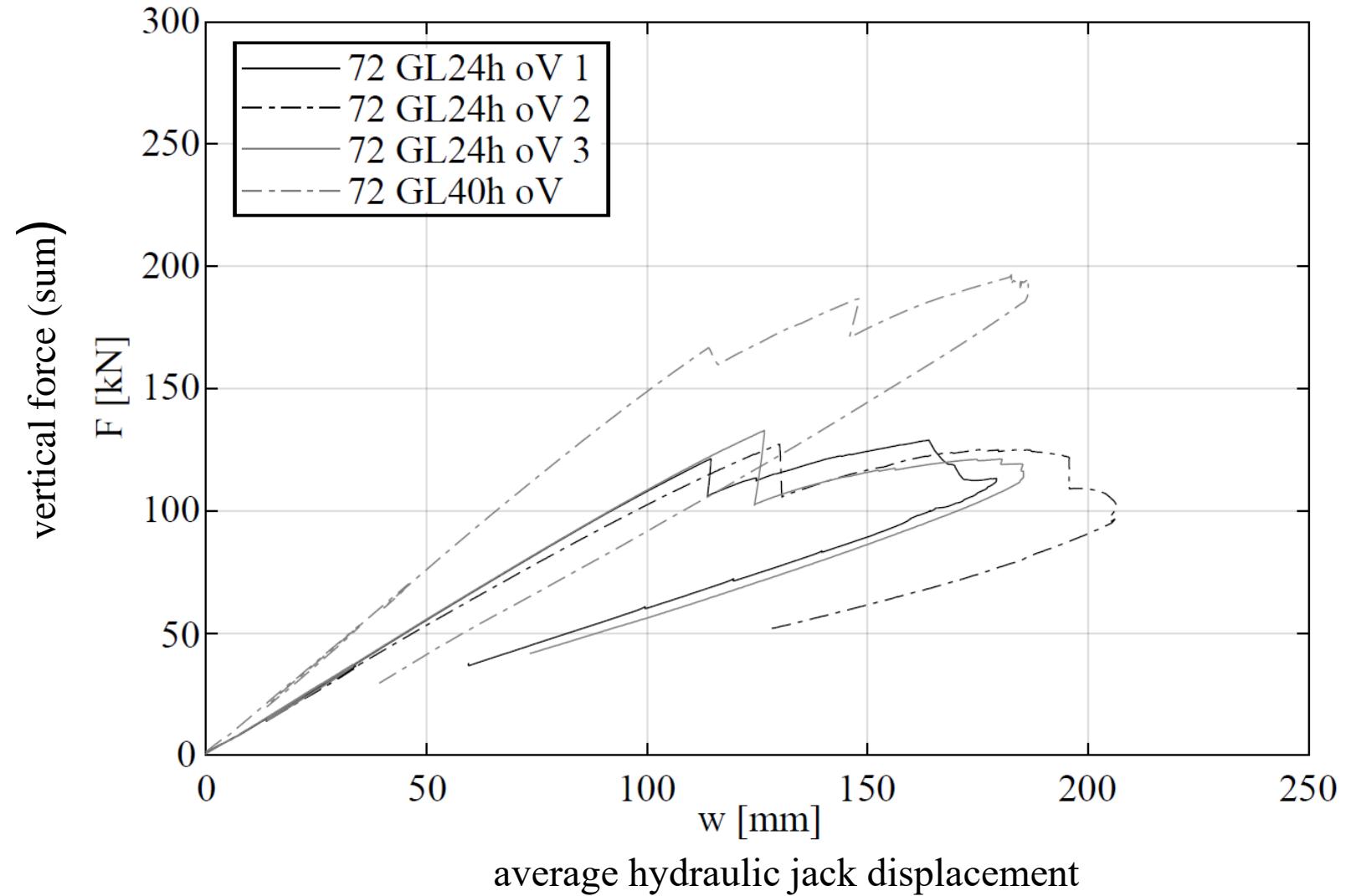


$$F_{PT} = 245 \text{ kN}$$

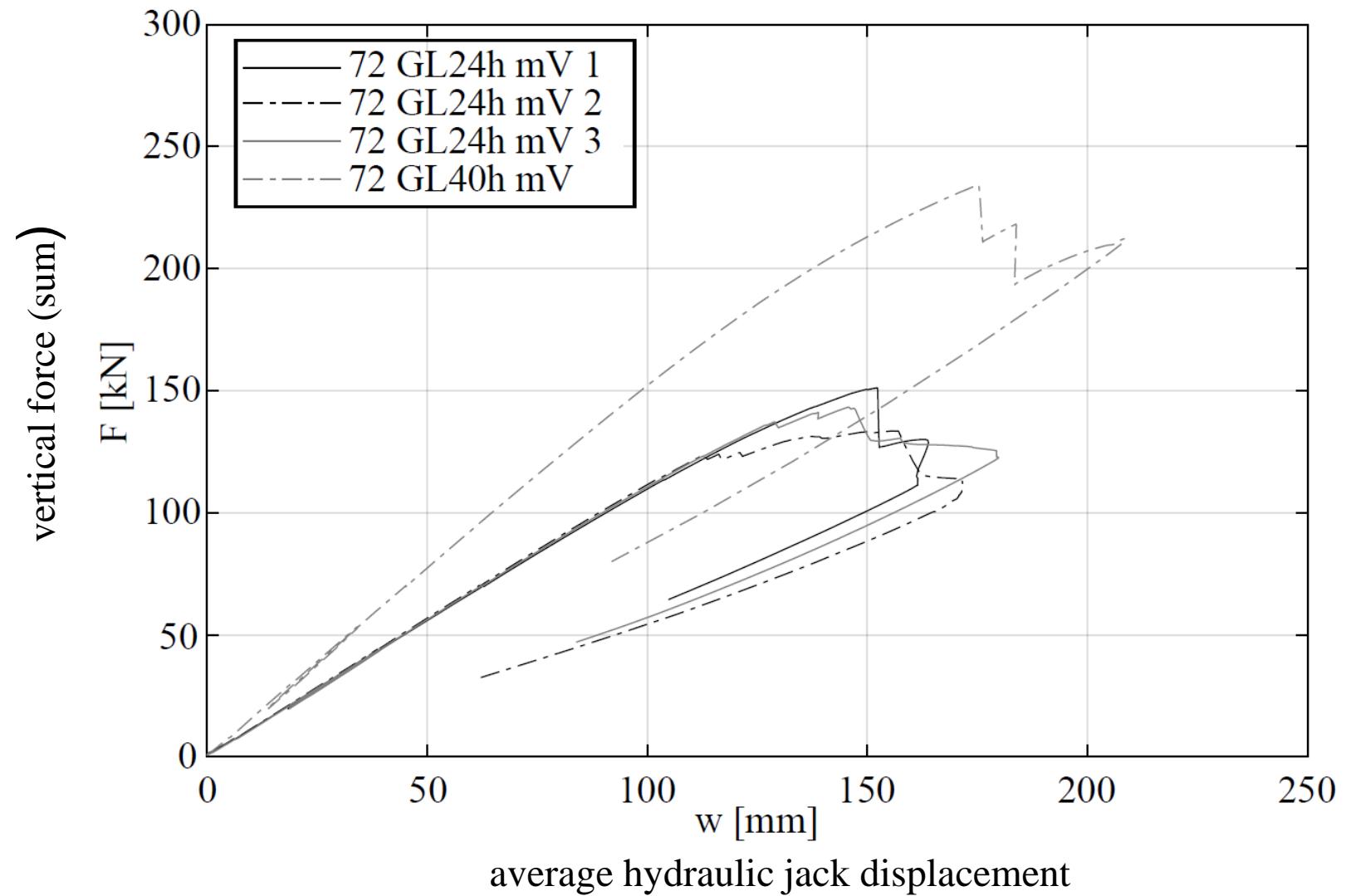
Fichte GL24h 10.5 m



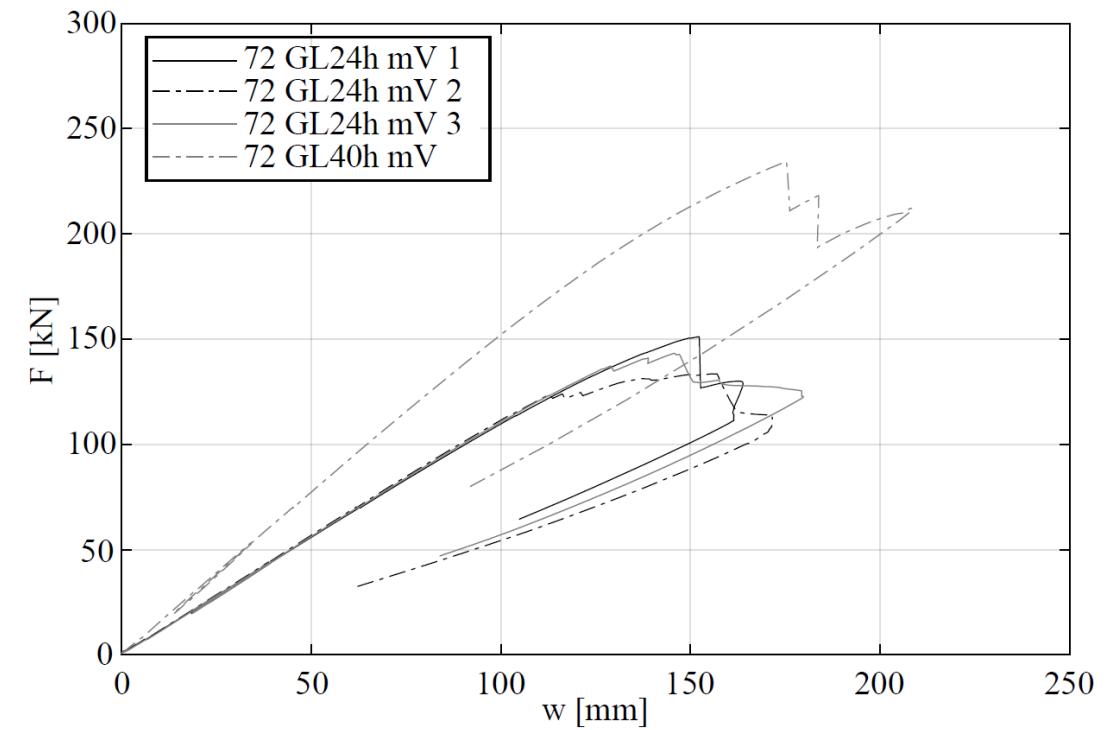
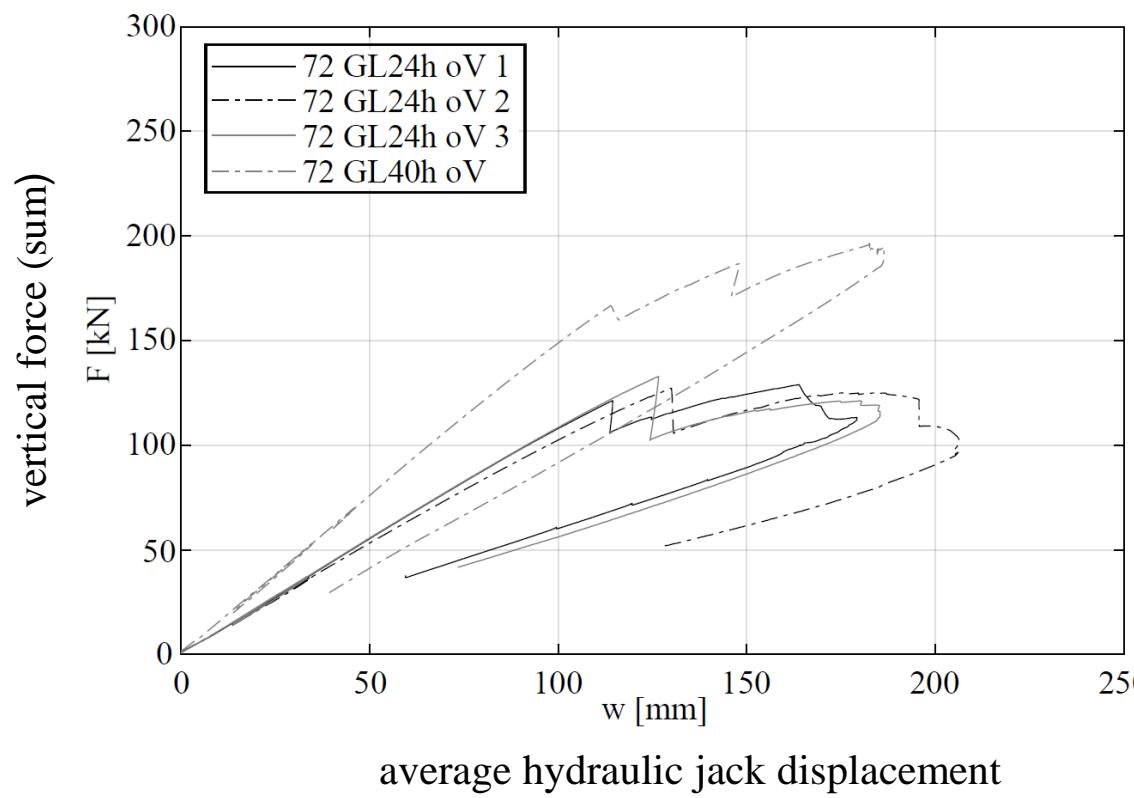
## Resultate 7.2 m ohne Verbund



## Resultate 7.2 m mit Verbund

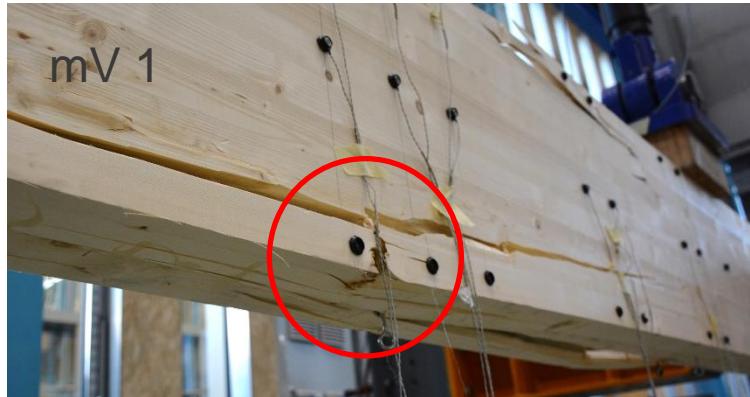


## Resultate 7.2 m - Vergleich

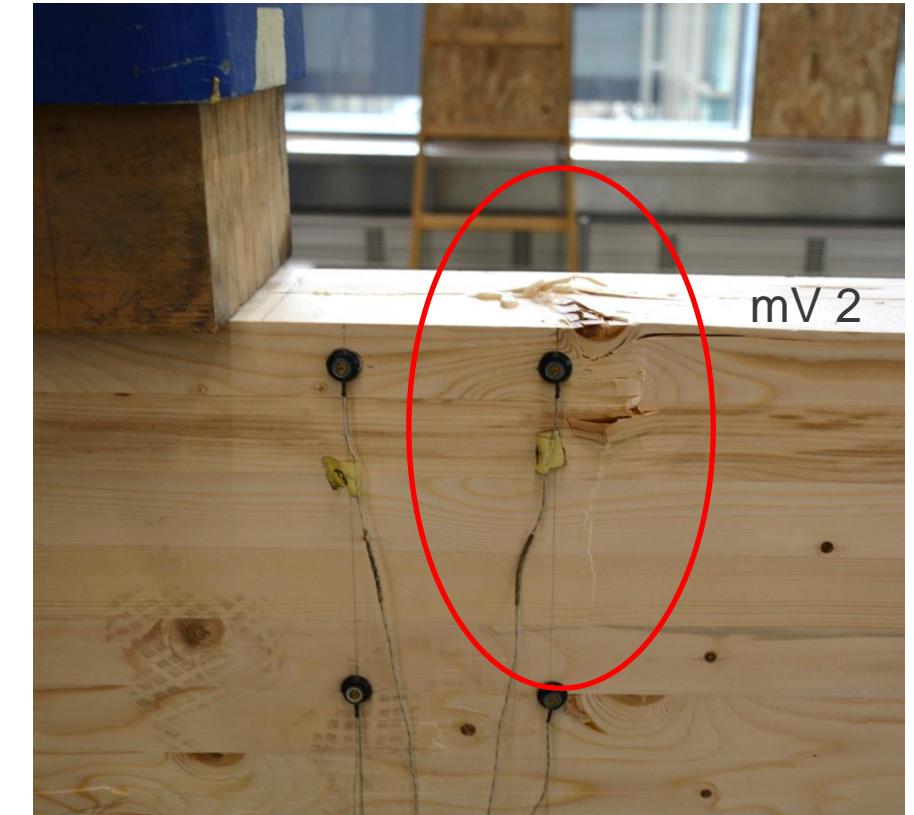


# Beobachtete Versagen GL24h mit Verbund

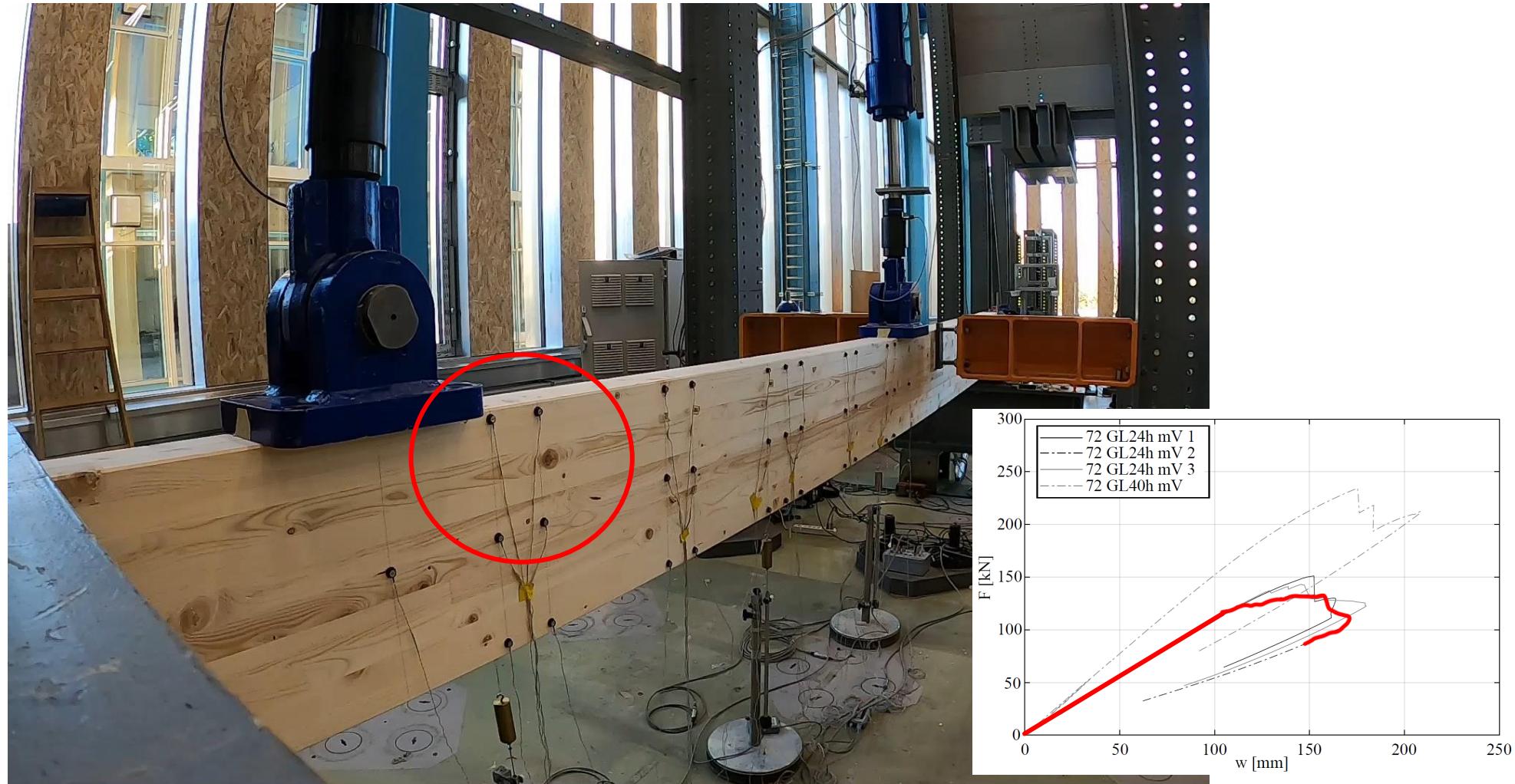
Zugseite



Druckseite



## GL24h 7.2m mV2 (mit Verbund)



# Nachweise

- Formel (6.19) EC5:

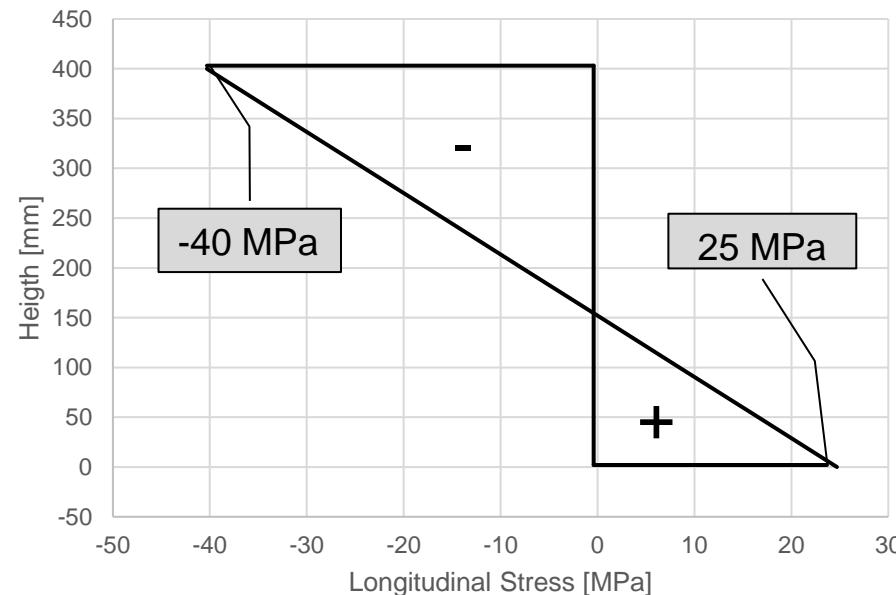
$$\left[ \frac{\sigma_{c,0,d}}{f_{c,0,d}} \right]^2 + \frac{\sigma_{m,y,d}}{f_{m,y,d}} \leq 1$$

Anteil Normalkraft

Anteil Biegung

# Nachweise

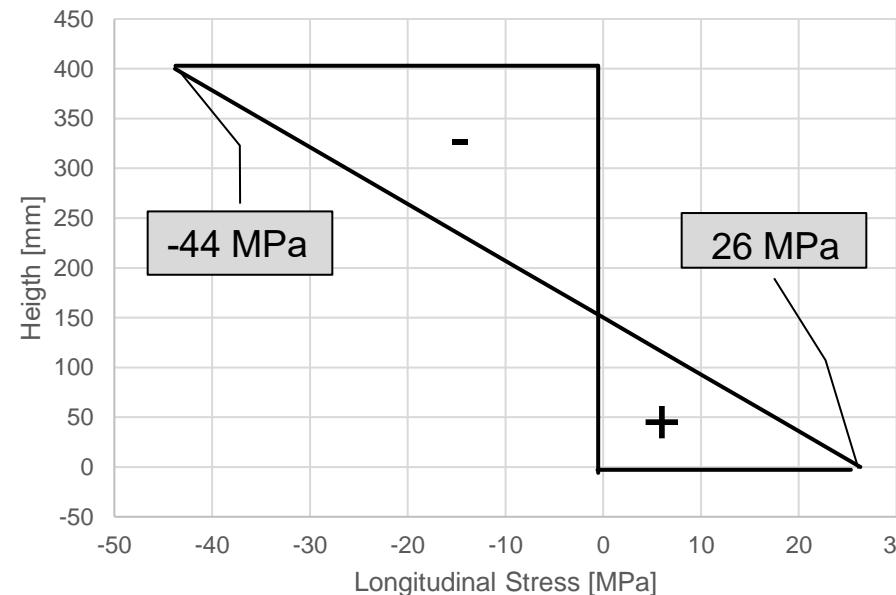
7.2 m oV bei  $F = 130 \text{ kN}$



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

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

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

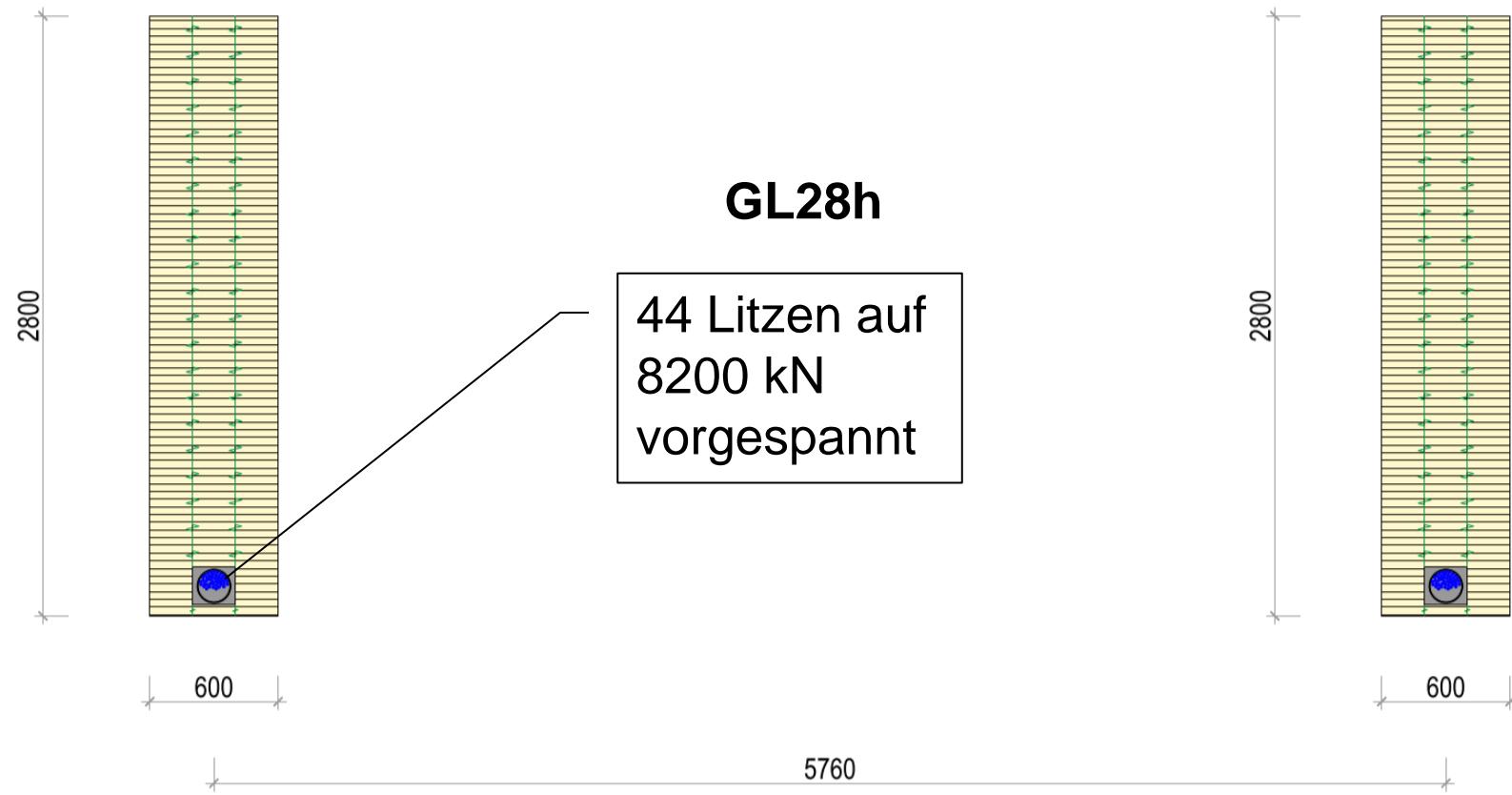


$$\left[ \frac{5.1 \text{ MPa}}{30.0 \text{ MPa}} \right]^2 + \frac{43.8 \text{ MPa} - 5.1 \text{ MPa}}{30.0 \text{ MPa}} = 1.32$$

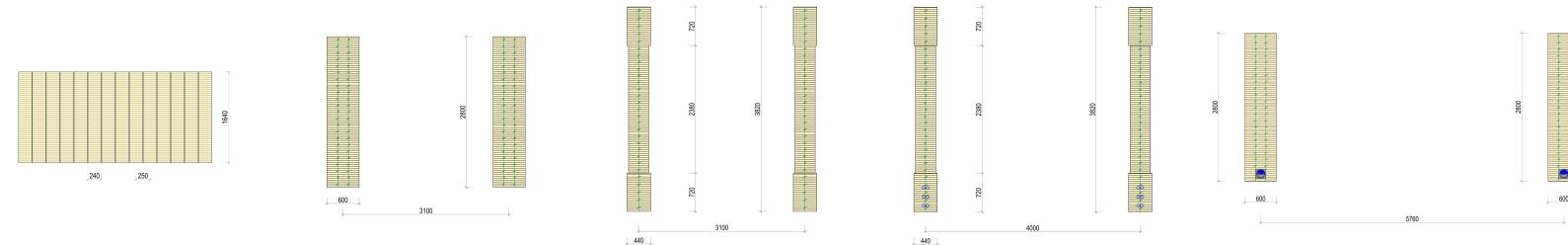
## Zusammenfassung vorgespannte Träger

- 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



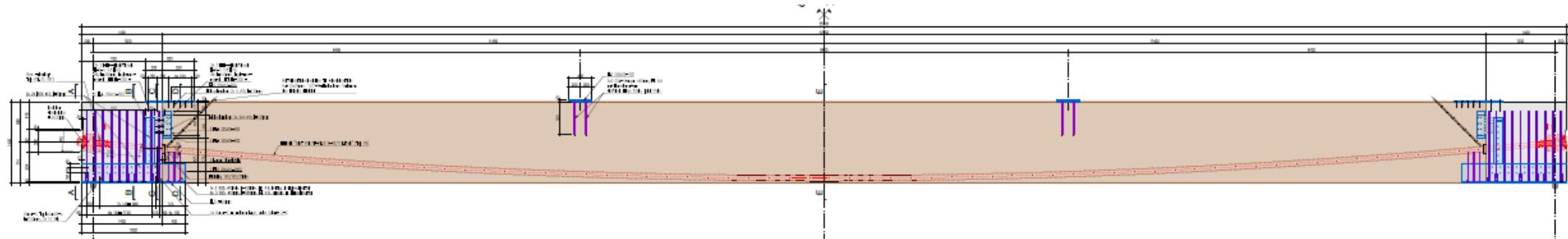
	A: BSH 1.5	B: BSH 2.8	C: FWK	D: FWK ZS	PT BSH
<b>Dimension</b>	1.50 x 0.24	2.80 x 0.60	3.82 x 0.44	3.82 x 0.44	2.80 x 0.60
<b>Sprungmass</b>	0.25	3.1	3.1	4.0	5.76
<b>W<sub>NL</sub> [mm]</b>	41	40	26	31	80
<b>m<sup>3</sup> / m<sup>2</sup></b>	1.57	0.54	0.32	0.25	0.29
		+ 0.22 = 0.76	+ 0.22 = 0.54	+ 0.24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

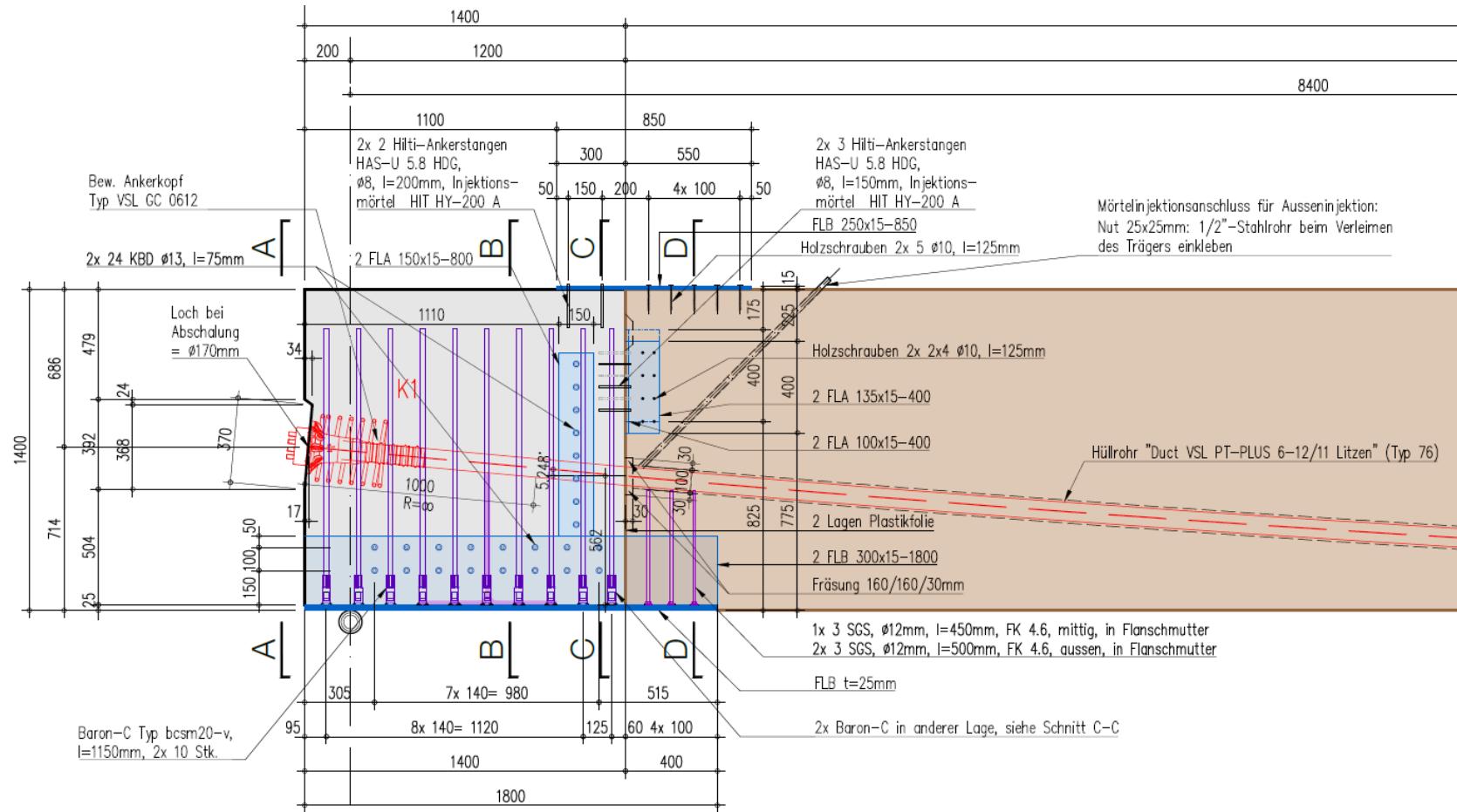
# Ausblick

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

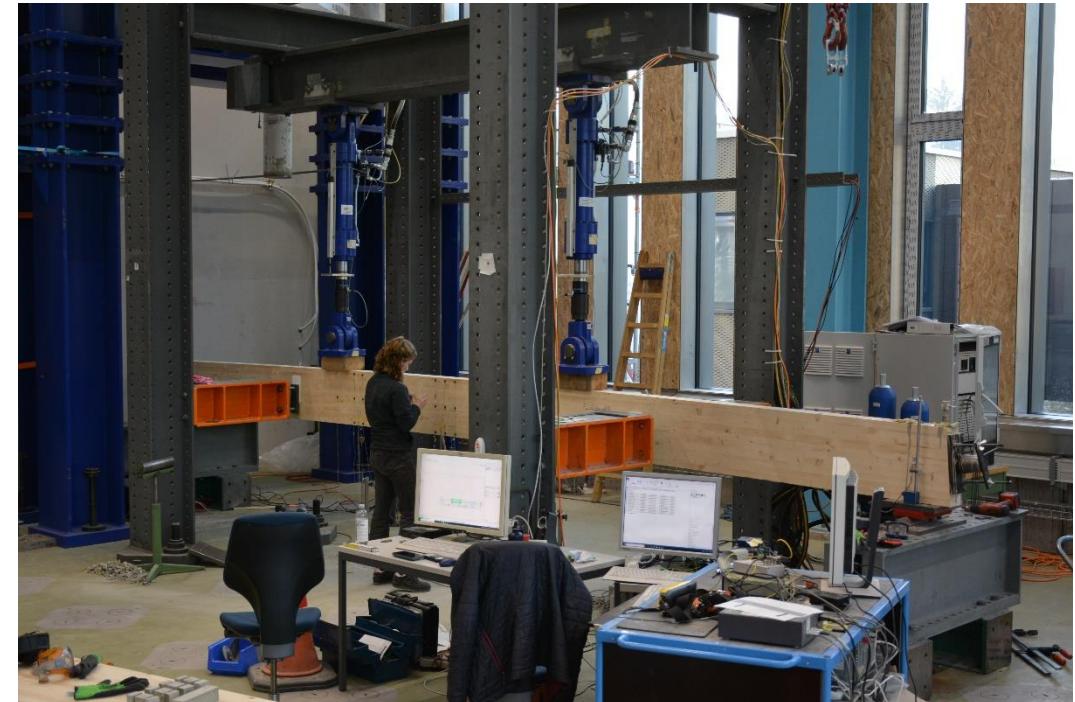


# Ausblick

## ■ Integration der Lastverteilscheibe aus Stahlbeton



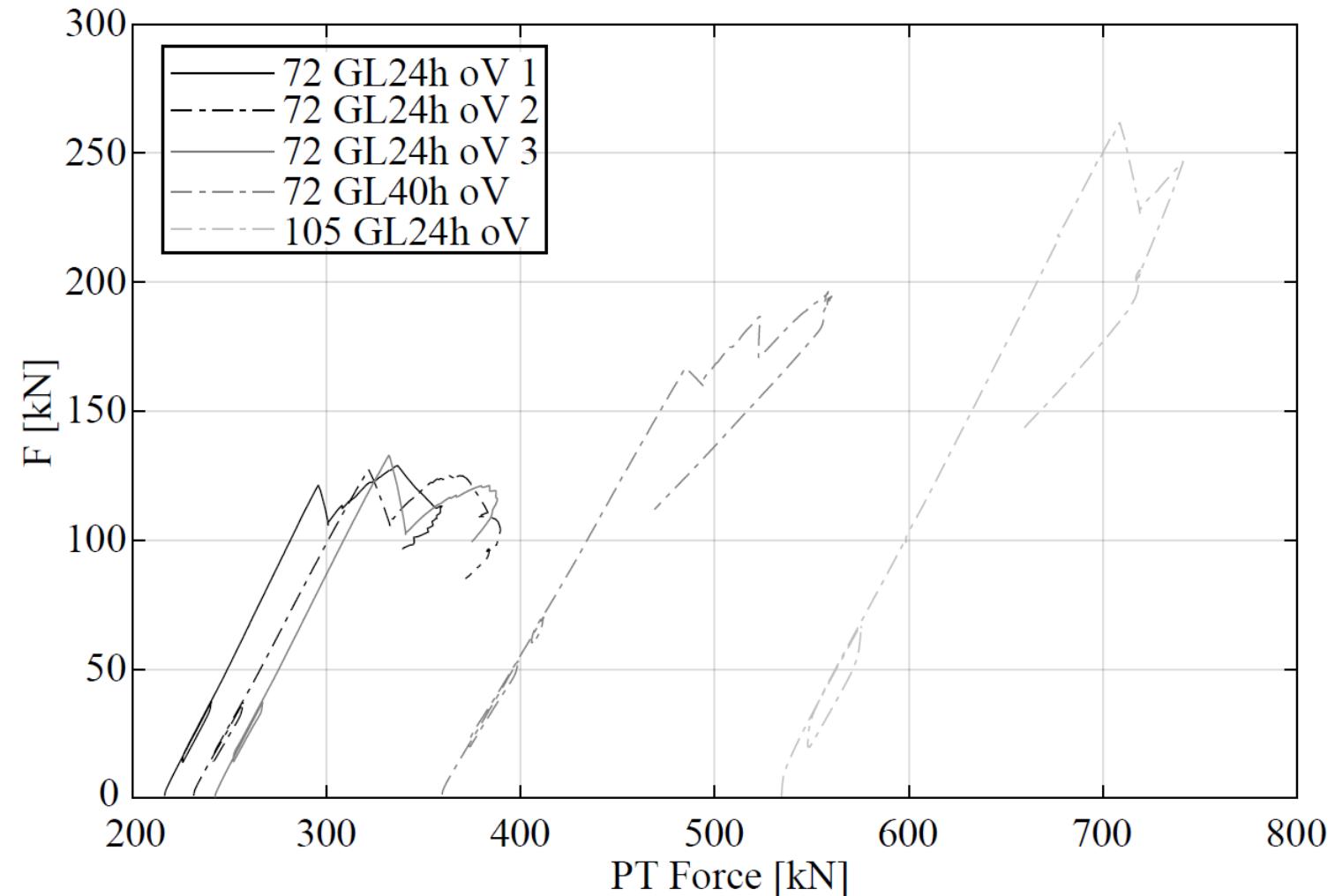
# Danke für Ihre Aufmerksamkeit



**SCHNETZER PUSKAS  
INGENIEURE**



# Total force – PT force



# Summary bending

Series	$h$ [-]	No. [-]	$EI_{GL}$ [MN/m <sup>2</sup> ]	$EI_{PT}$ [MN/m <sup>2</sup> ]	$\Delta_{EI}$ [%]<	$F_{PT,init}$ [kN]	$F_{PT, fail}$ [kN]	$F_{ult}$ [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  $\alpha = 5^\circ$

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

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

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 ( $k_{\text{glob},1}$ ) and second load application ( $k_{\text{glob},2}$ ), the ultimate failure load ( $F_{\text{ult}}$ ) and the failure load per m length ( $F_{\text{ult}}'$ ).

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