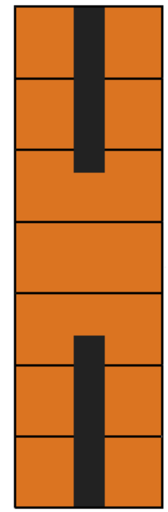
鋼板挿入集成材梁の樹種とせん断挙動

環境構造工学講座　大黒屋 信英

$$v = \frac{P\ell^3}{48\boxed{EI}} + \frac{P\ell}{4k\boxed{GA}}$$



$$\boxed{EI = E_{木} I_{木} + E_{鋼} I_{鋼}}$$

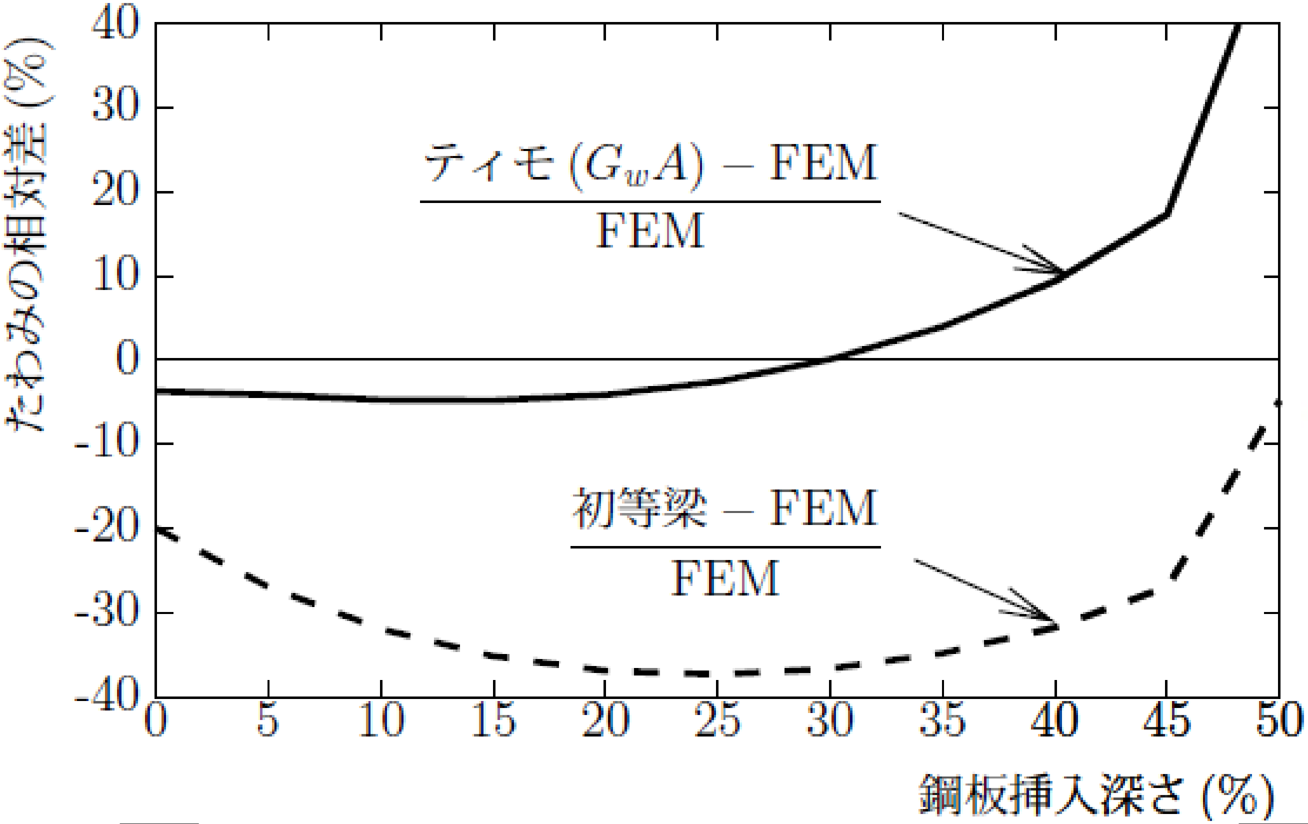
曲げは大きく改善!

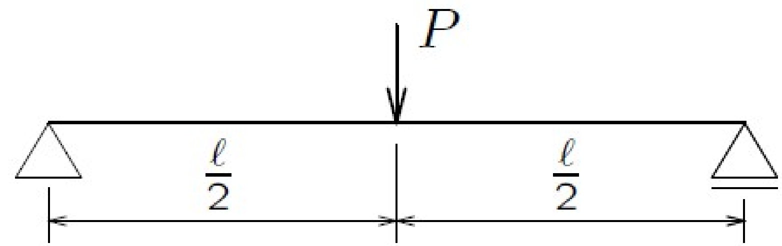
$$\boxed{GA \neq G_{木} A_{木} + G_{鋼} A_{鋼}}$$

せん断は改善されない!

せん断変形が大きい!

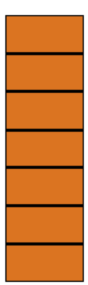
鋼板挿入の影響

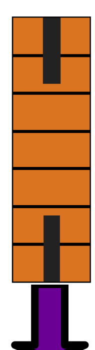


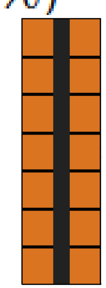


$\ell = 2\text{m}, \ P = 10\text{kN}$

$$v_{\text{初等}} = \frac{P\ell^3}{48EI}$$



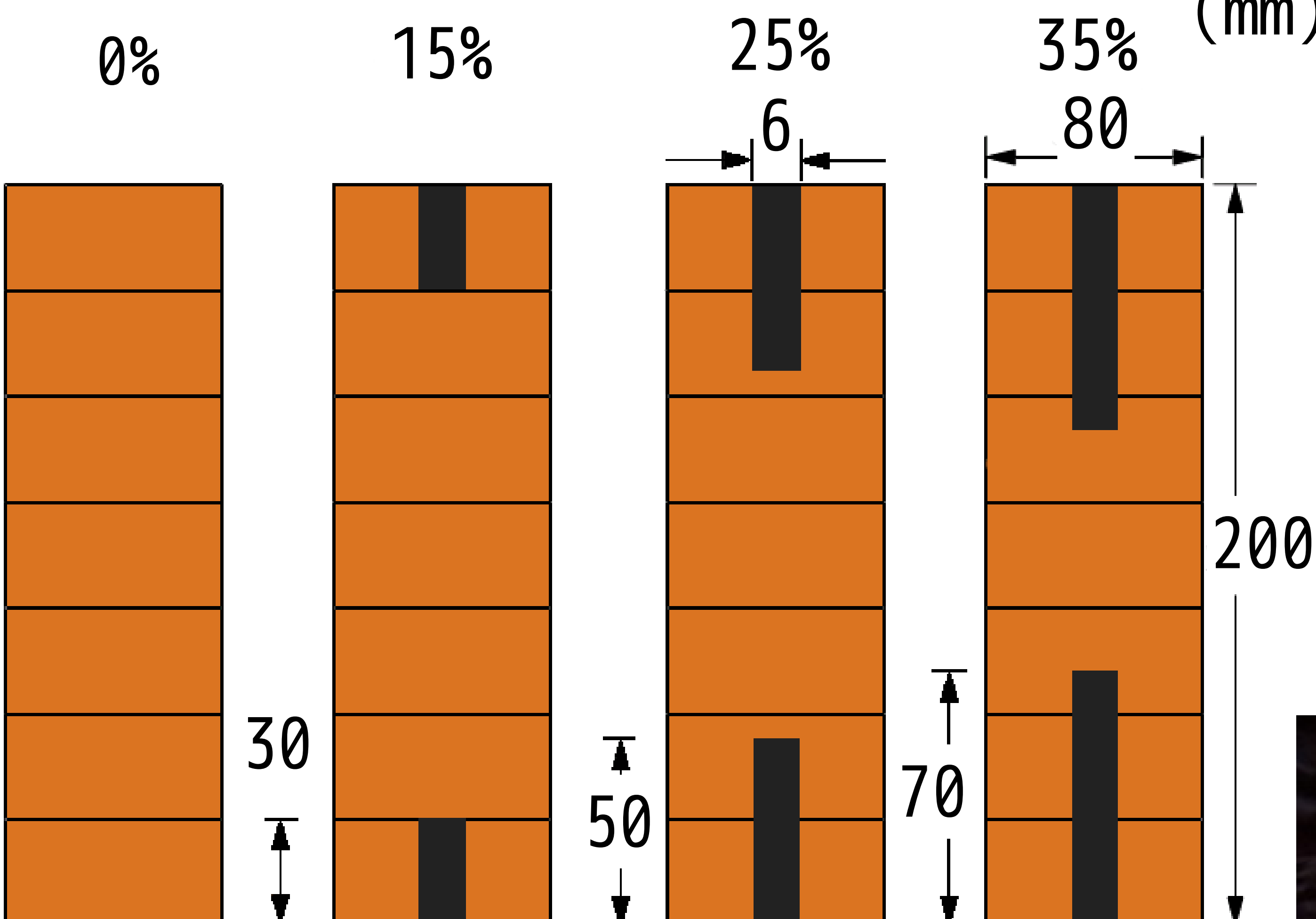




せん断変形最大

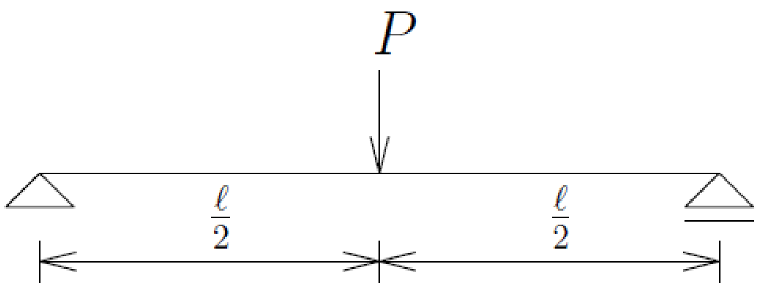
$$v_{\text{ティモ}} = \frac{P\ell^3}{48EI} + \frac{P\ell}{4kGA}$$

実験モデル



スギ集成材
ヤング率
7.5GPa

カラマツ集成材
ヤング率
16.6GPa



曲げ試験より

E と G を求める

(ASTM D198-05)

鋼板挿入集成材

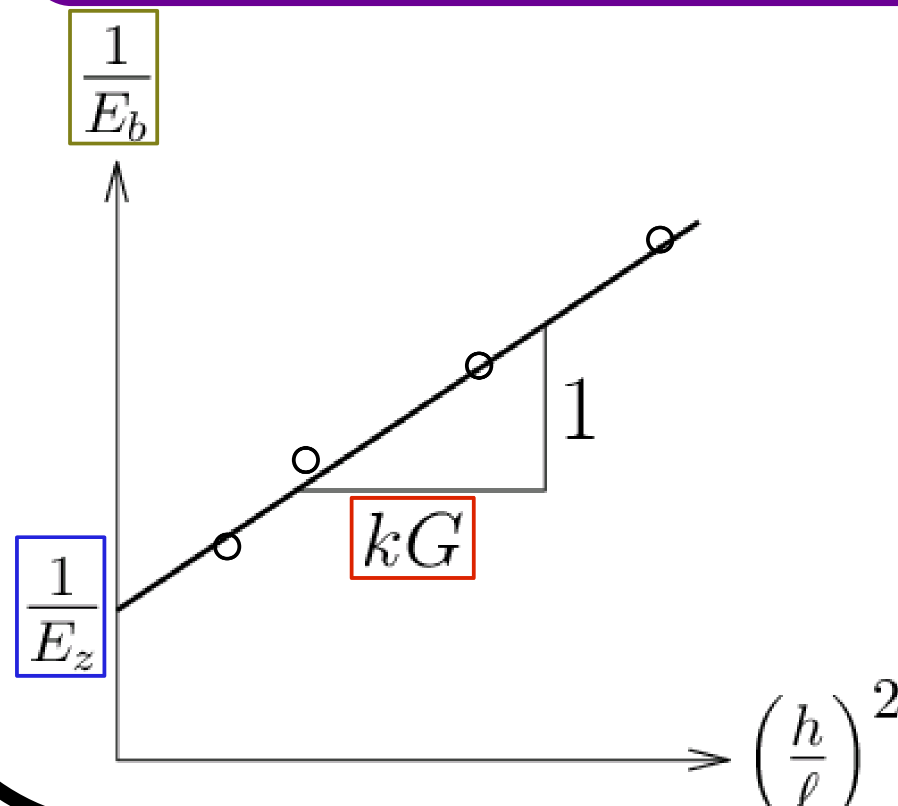
=異方性 $k \neq \frac{5}{6}$

せん断弾性 kG

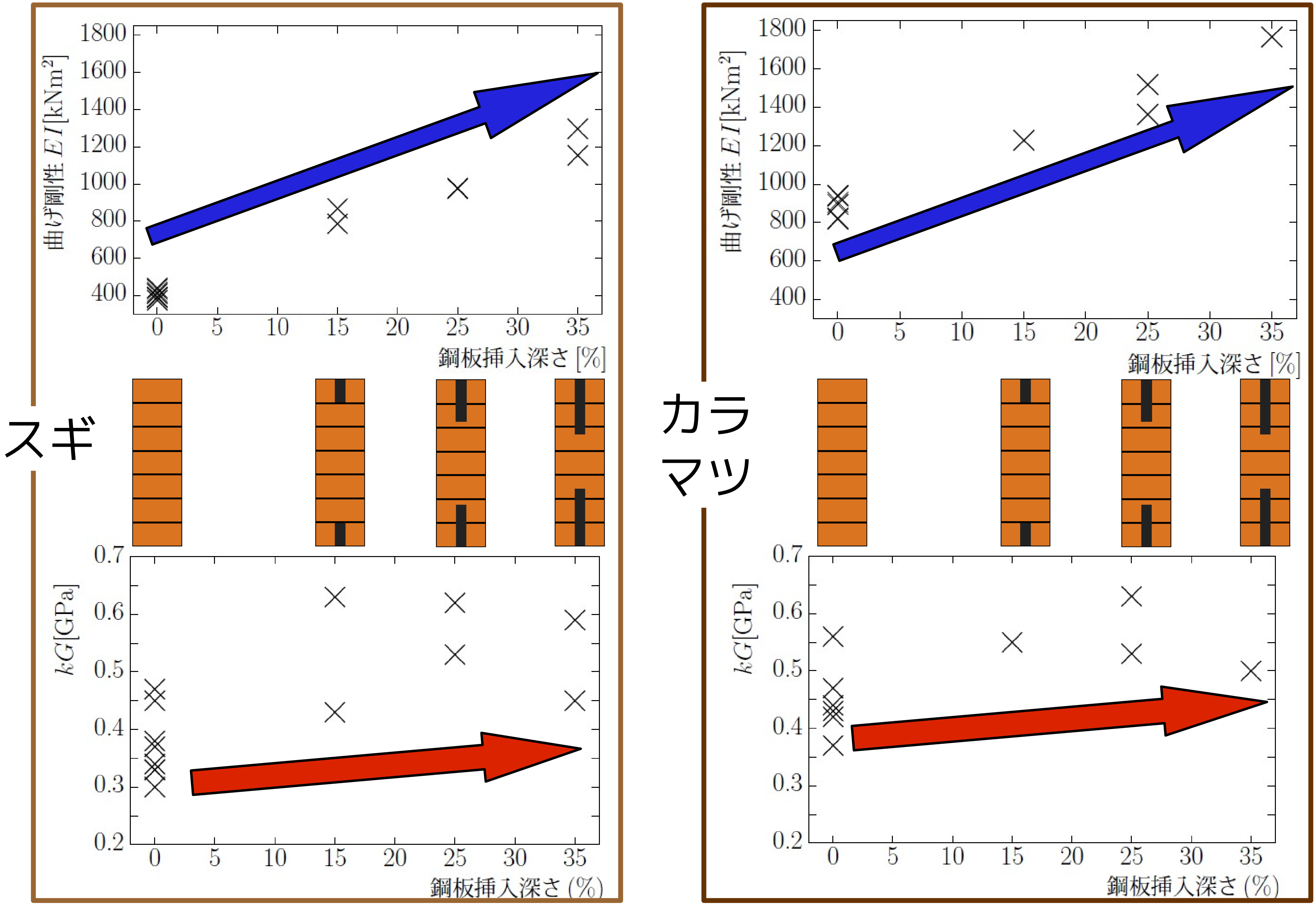
として推定

$$\frac{P\ell^3}{48\boxed{E_b}I} = \frac{P\ell^3}{48\boxed{E_z}I} + \frac{P\ell}{4\boxed{kG}A}$$

$$\frac{1}{\boxed{E_b}} = \frac{1}{\boxed{E_z}} + \frac{1}{\boxed{kG}}\left(\frac{h}{\ell}\right)^2$$

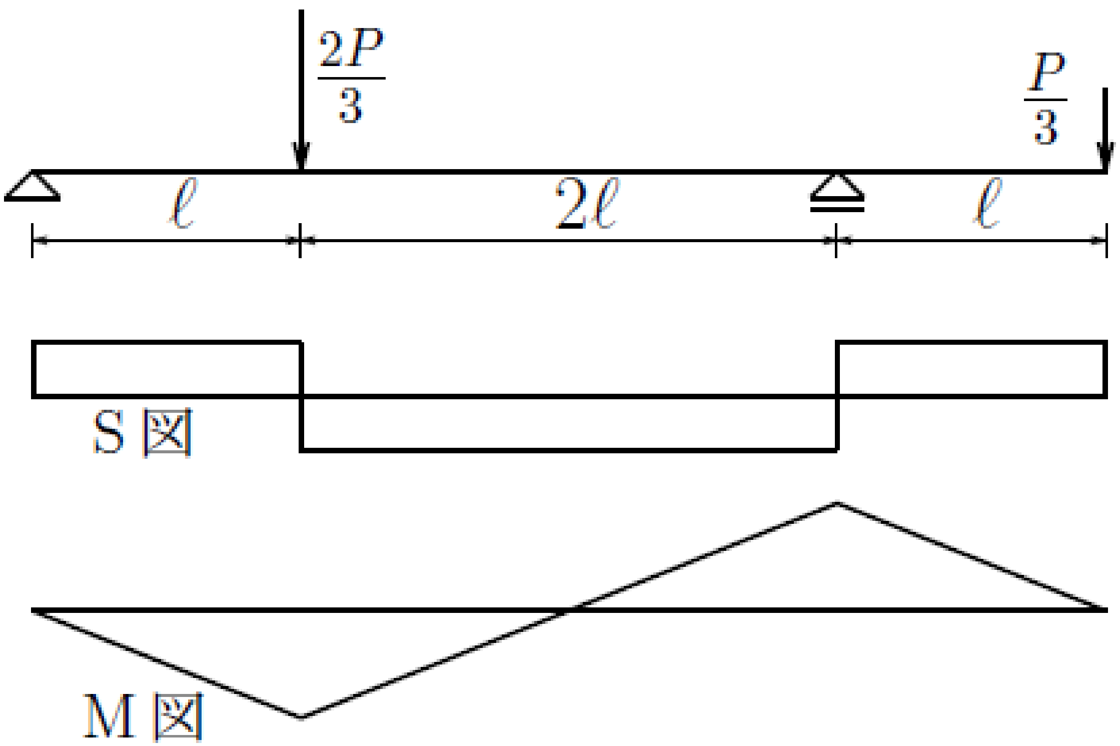


EI と kG の測定



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

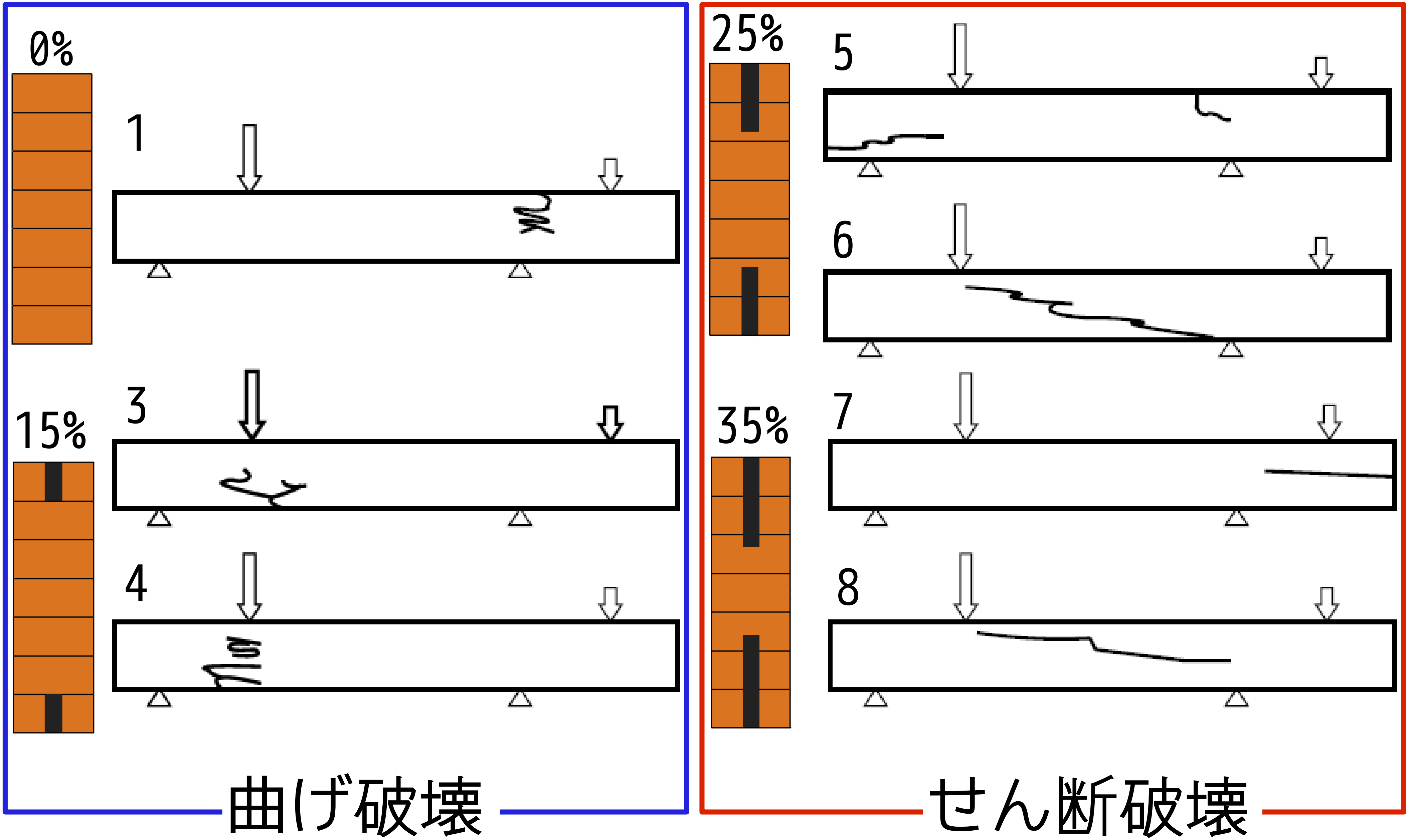
逆対称4点曲げ試験



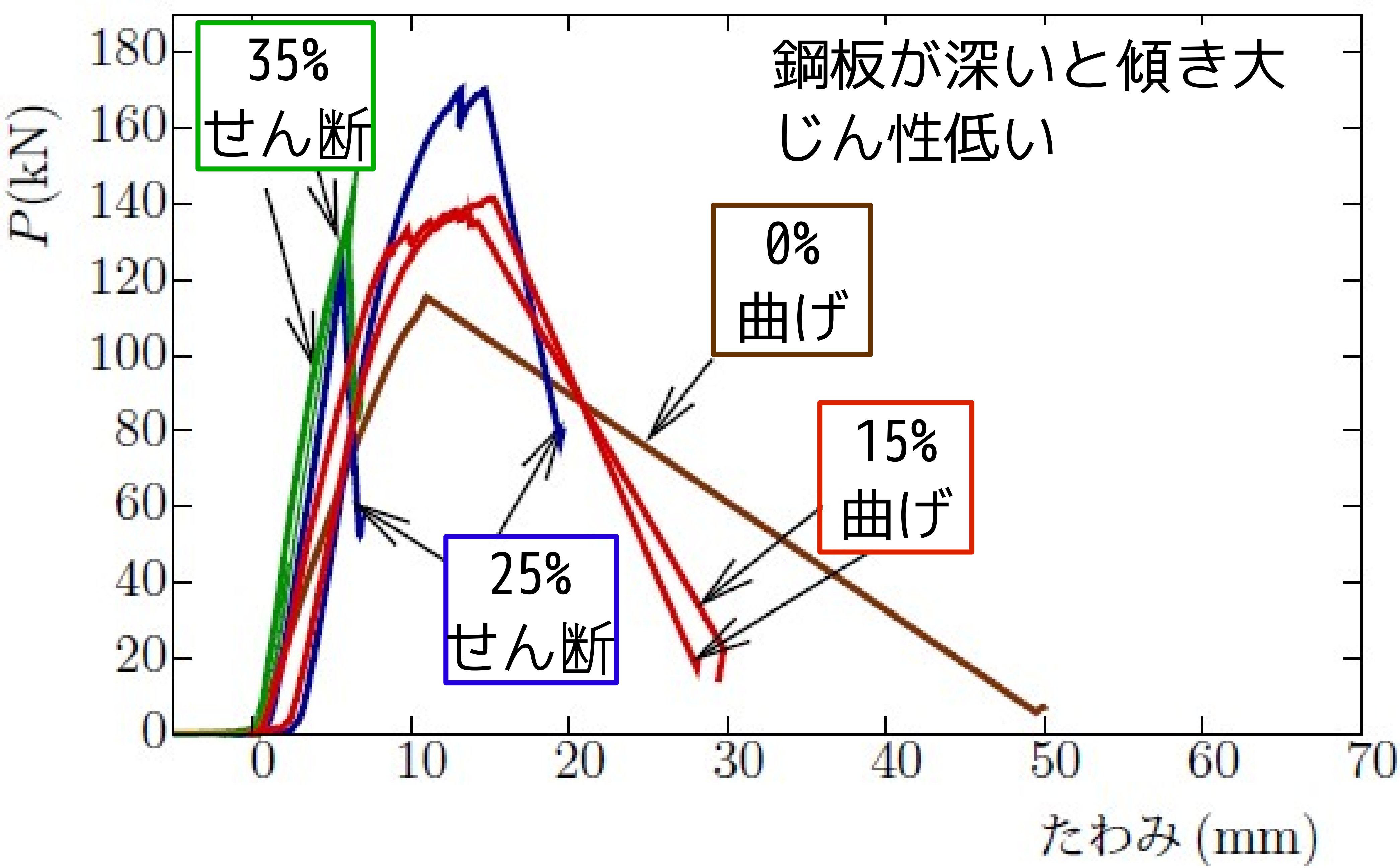
曲げ破壊

せん断破壊

スギの破壊形状

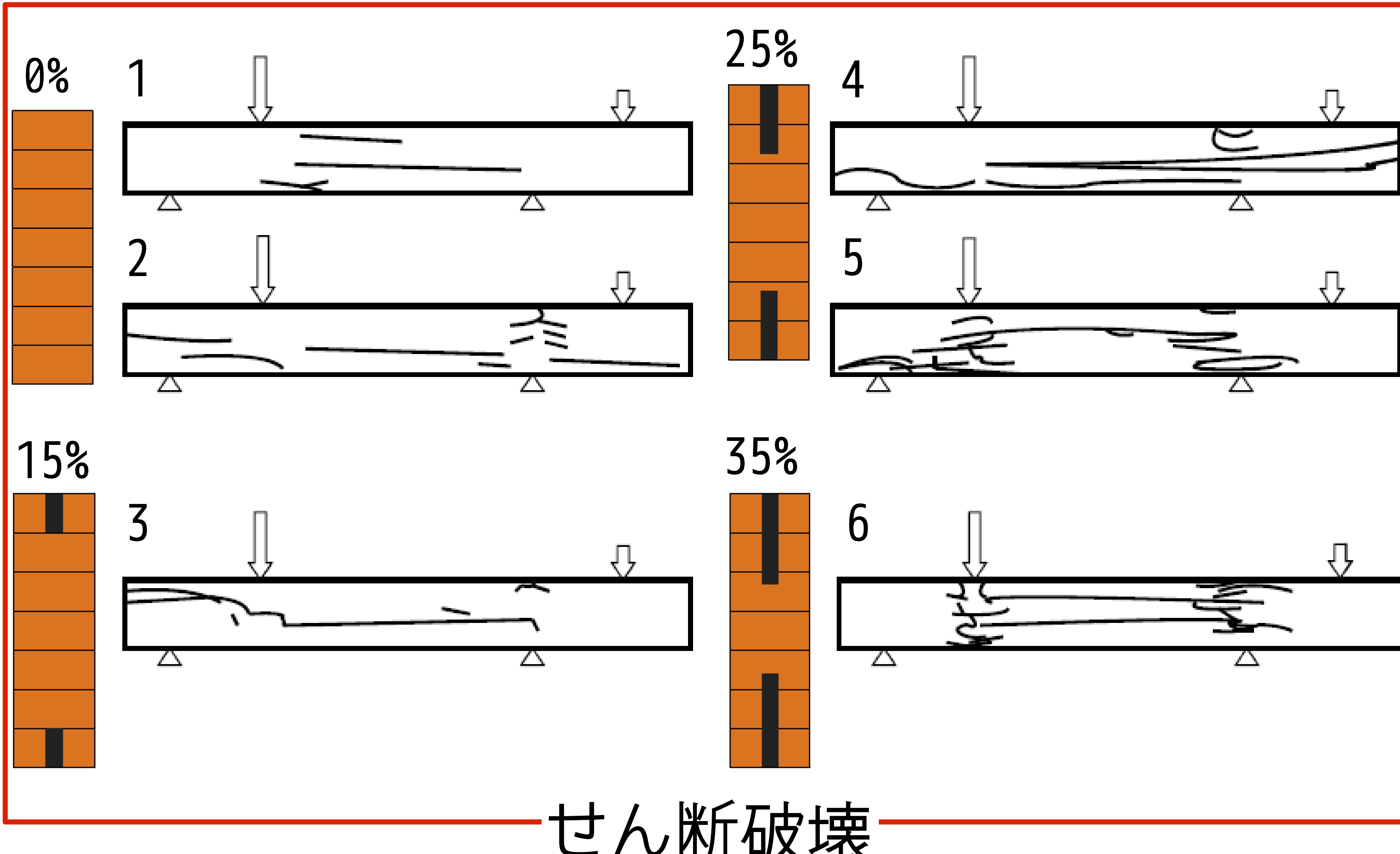


スギ破壊試験



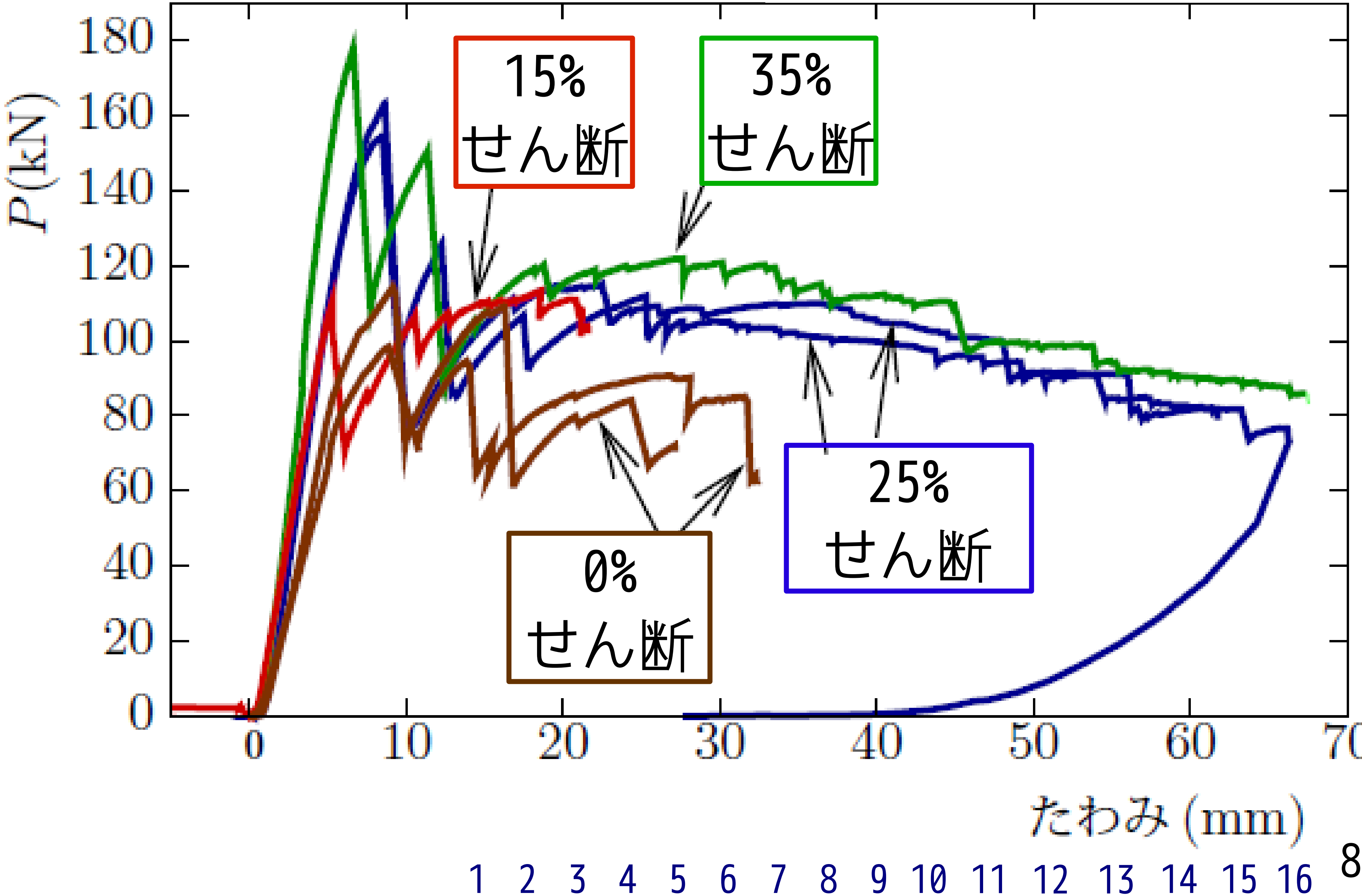
35%
せん断
鋼板が深いと傾き大
じん性低い
0%
曲げ
15%
曲げ
25%
せん断
P(kN)
たわみ (mm)
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
50
60
70

カラマツの破壊形状

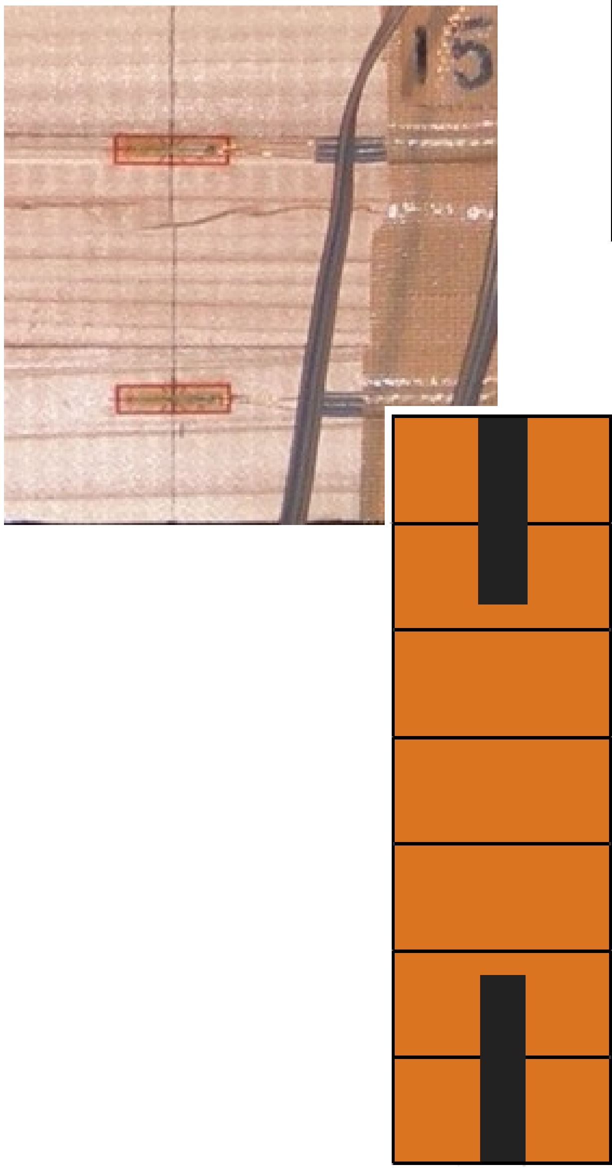


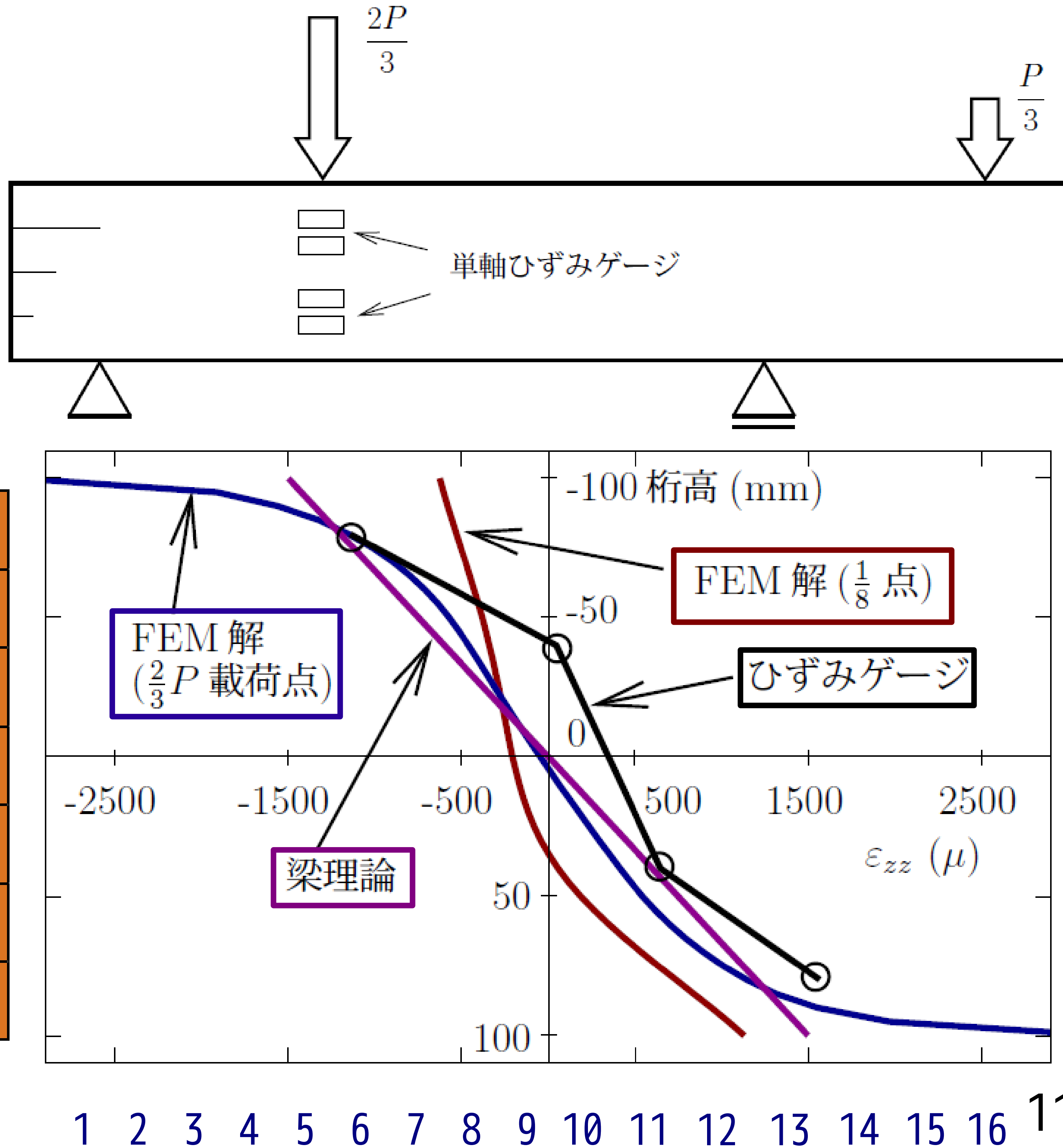
カラマツ破壊試験

鋼板が深いと傾き大
じん性あり



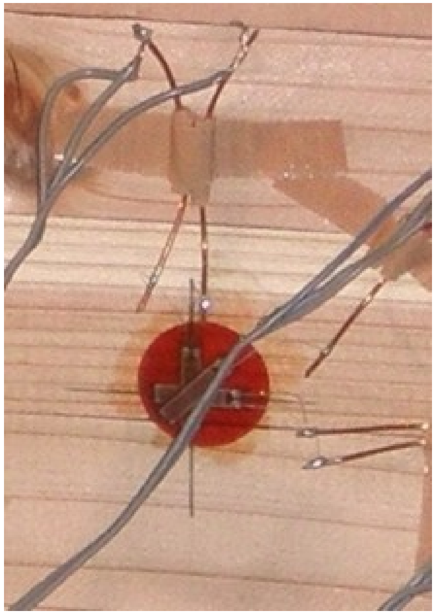
軸ひずみ分布

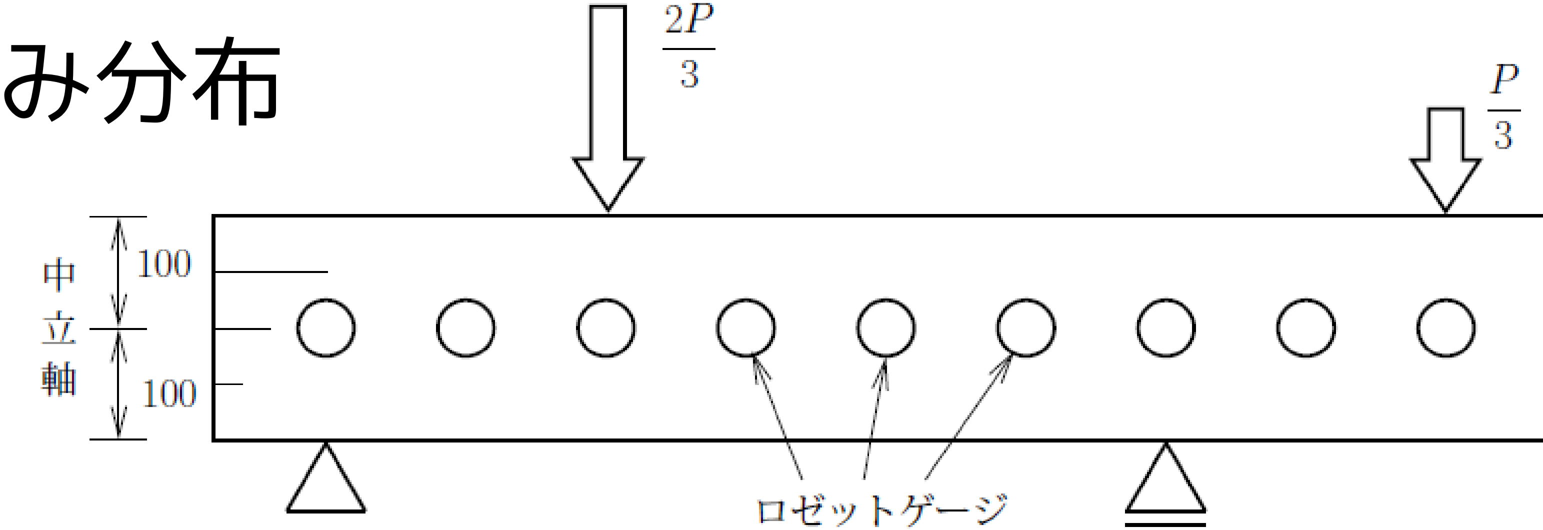


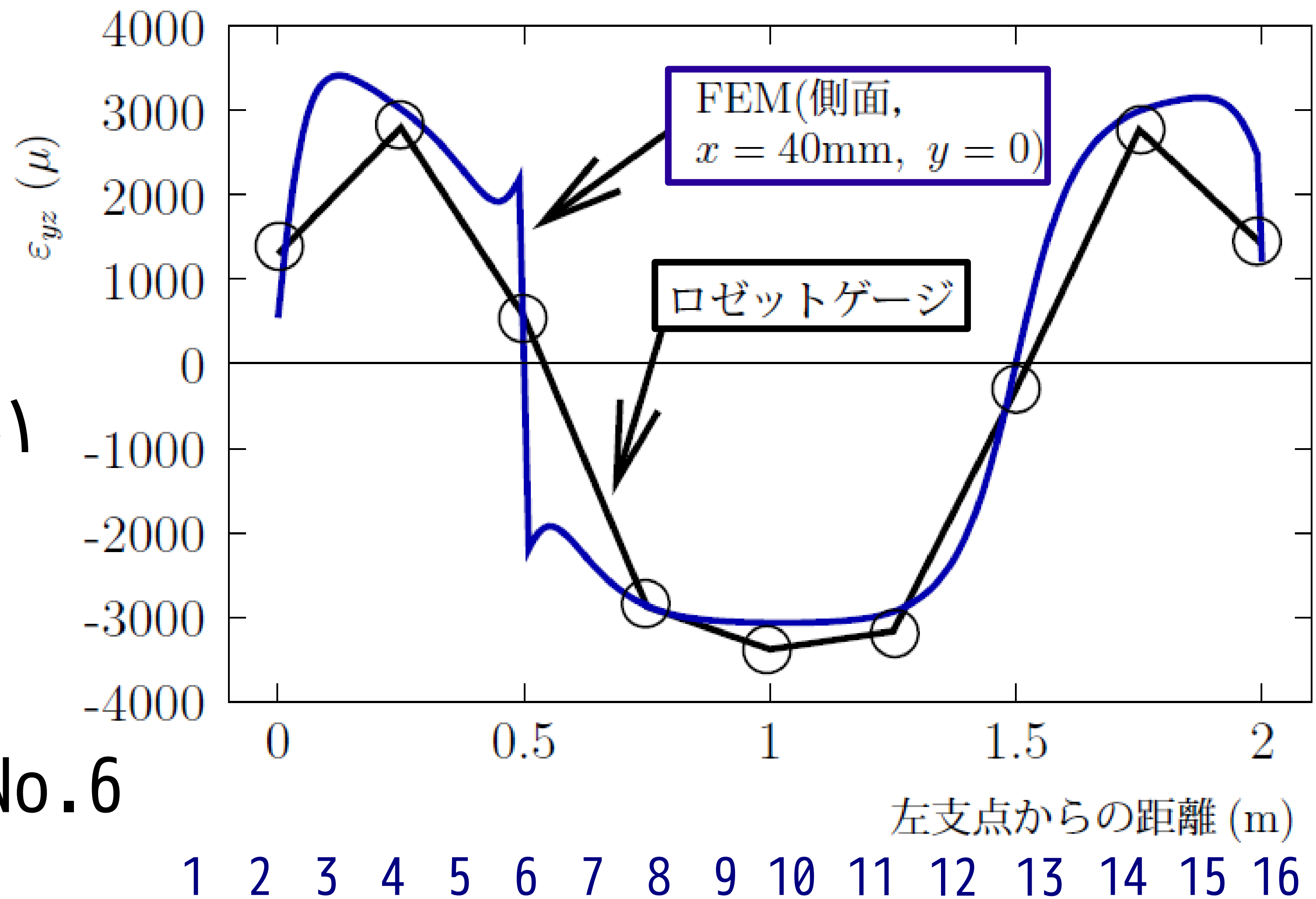


スギ試験体No.6

せん断ひずみ分布







実験値と
FEM値が近い

スギ試験体No.6

破壊時の応力

$$\sigma_{max} = \frac{M_{max}}{\boxed{I_n}} y$$

$$\tau = -\frac{S(z)\boxed{Q(y)}}{b(y)\boxed{I_n}}$$

断面1次関数

換算断面2次モーメント

スギ(E75-F270)

$$F_b = 27[\mathrm{MPa}]$$

$$F_{sx-x} = 3.0[\mathrm{MPa}]$$

No.	深さ [%]	P_{max}[kN]	σ_{max}[MPa]	τ_{max}[MPa]
1	0	115	36.0	3.60
3	15	137	18.4	3.85
4	15	141	22.0	4.47
5	25	170	18.7	5.13
6	25	124	16.2	3.98
7	35	150	17.6	4.68
8	35	135	14.3	3.77

カラマツ(E105-F345)

$$F_b = 34.2[\mathrm{MPa}]$$

$$F_{sx-x} = 3.6[\mathrm{MPa}]$$

No.	深さ [%]	P_{max}[kN]	σ_{max}[MPa]	τ_{max}[MPa]
1	0	98	30.3	3.03
2	0	114	36.1	3.61
3	15	113	23.6	3.48
4	25	163	35.3	5.64
5	25	154	29.8	4.77
6	35	177	25.7	4.75

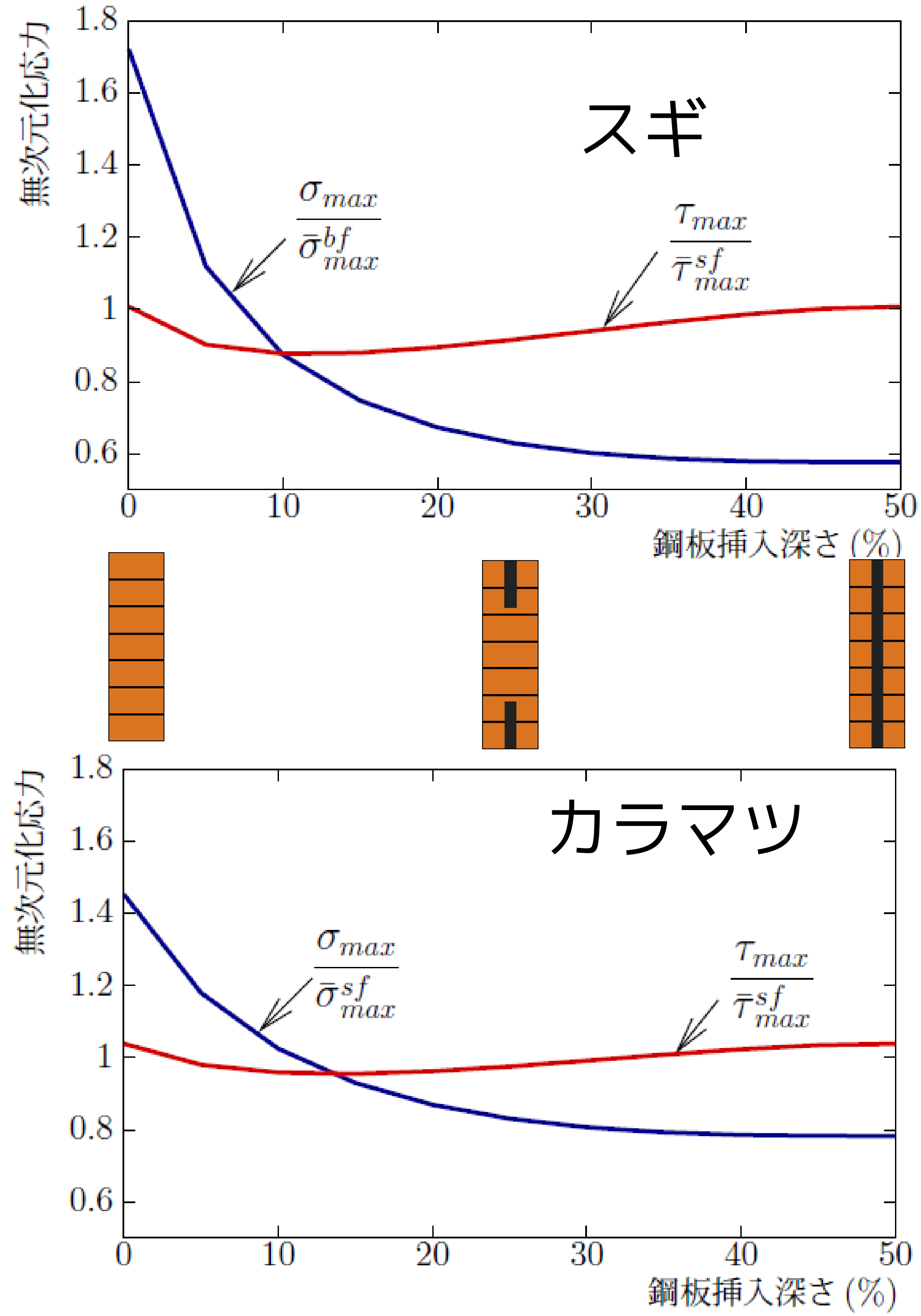
無次元化応力

荷重P=140kN

$$\sigma_{max} = \frac{M_{max}}{I_n} y$$

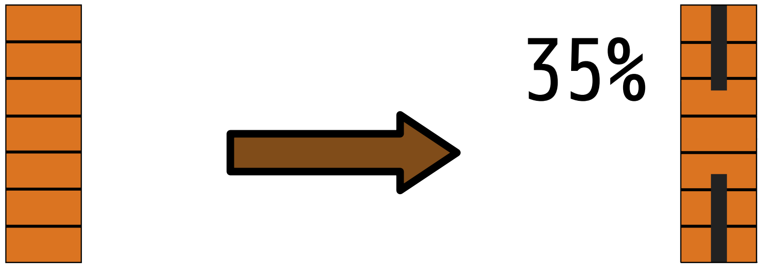
$$\tau = -\frac{S(z)Q(y)}{b(y)I_n}$$

10%前後から
せん断が支配的



まとめ

0%
35%



曲げ剛性 → スギ3倍マツ2倍　深さと相関あり

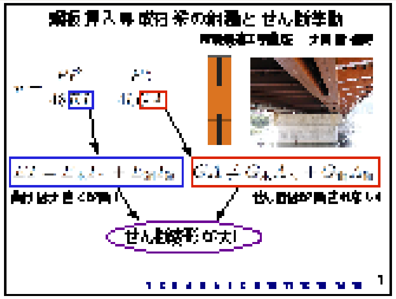
せん断弾性 → スギ・マツ深さと相関なし

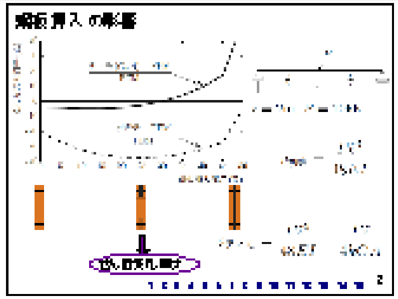
じん性 → スギ・改善無し　マツ・改善

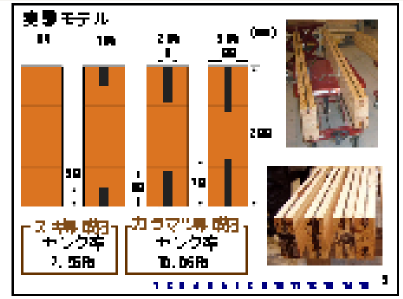
FEMのひずみ ⇔ 一致 ⇔ 実験値のひずみ

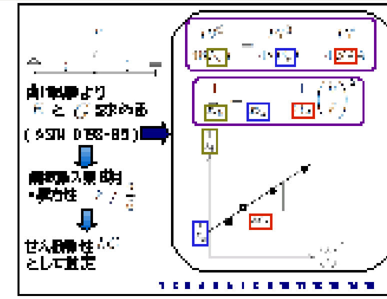
FEMや計算から
ひずみや応力を推測可能

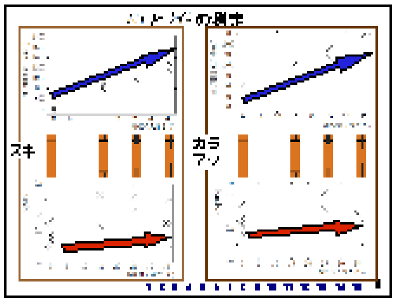
目次

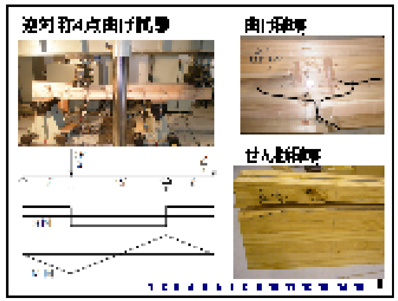
1


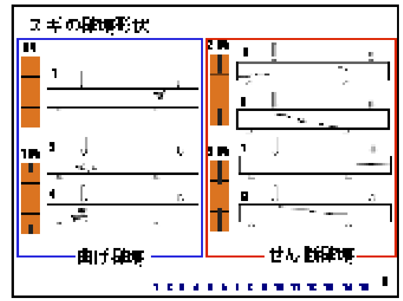
2


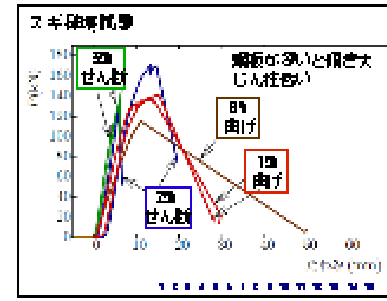
3


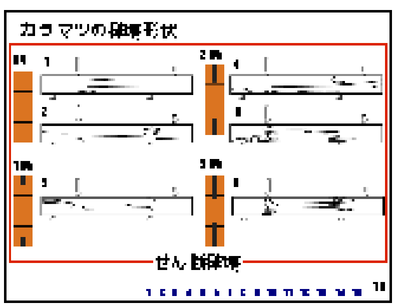
4


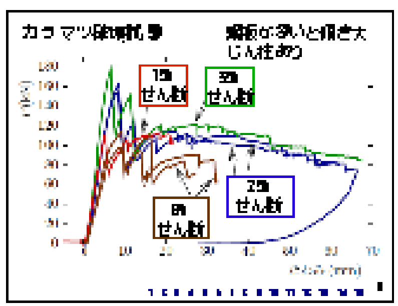
5


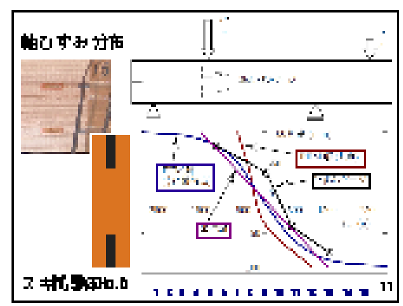
6


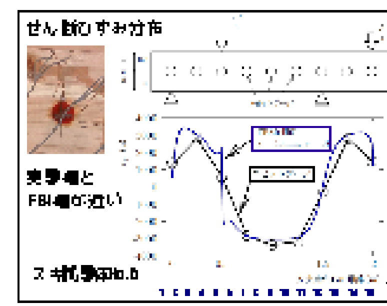
7


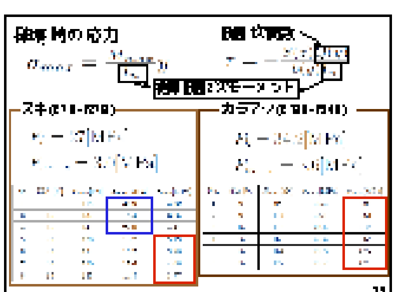
8


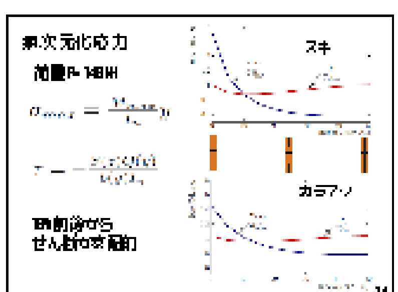
9


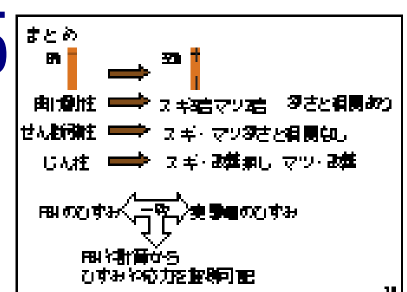
10


11


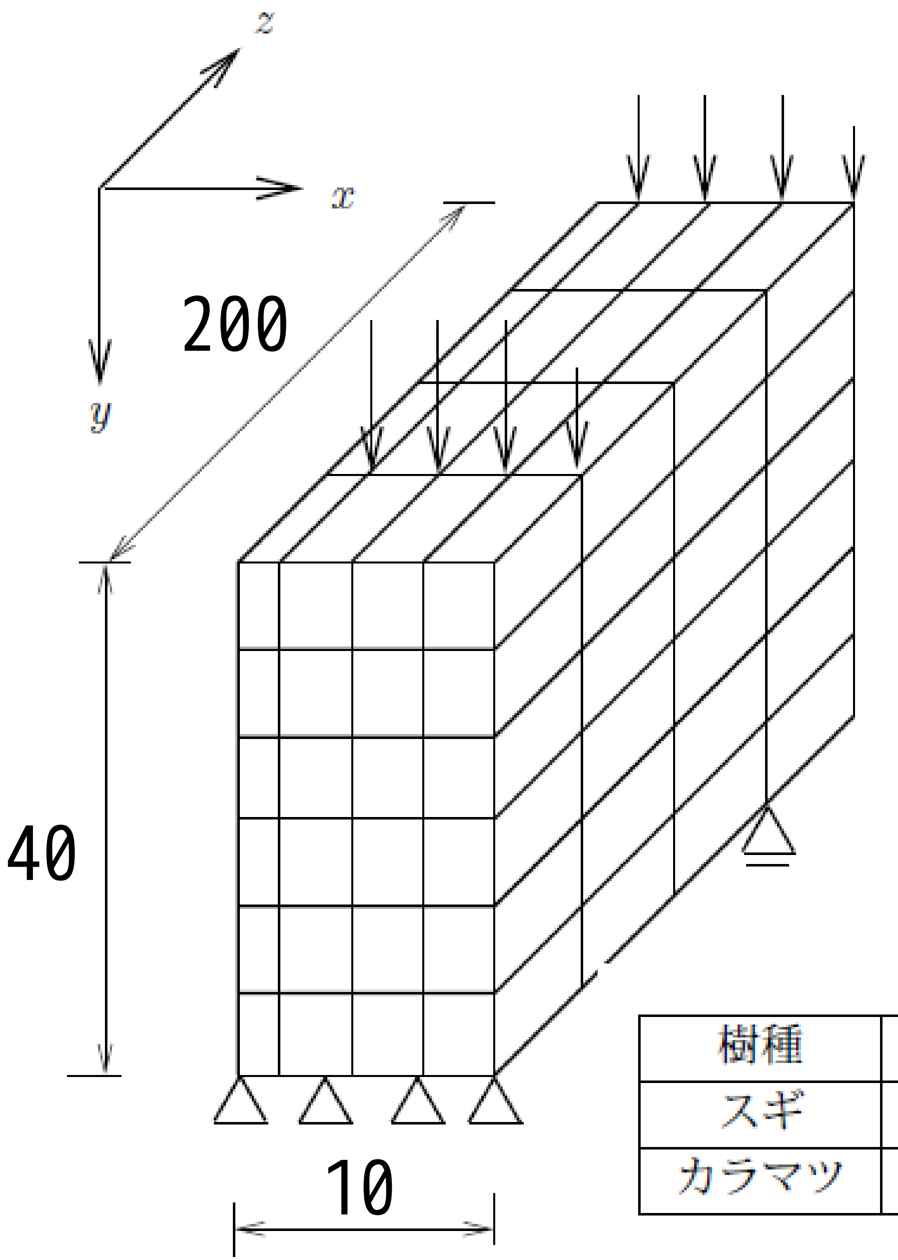
12


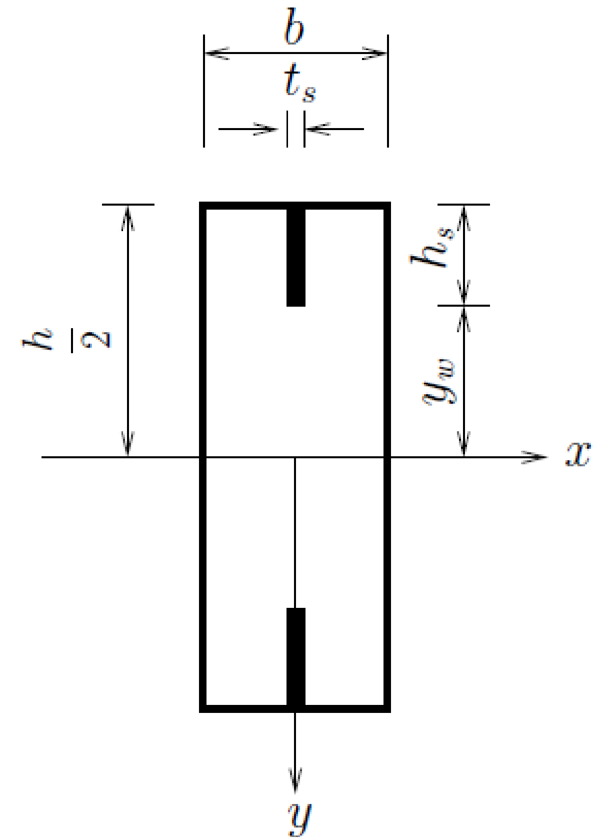
13


14


15


FEM解析モデル





推定したEとGを使用

樹種	E_{zz}[GPa]	E_{xx}, E_{yy}[GPa]	G_{xy}, G_{xz}, G_{yz}[GPa]
スギ	7.49	0.30	0.442
カラマツ	16.6	0.66	0.538

$$I_n = \frac{E_{木} I_{木} + E_{鋼} I_{鋼}}{E_{木}}$$

$$b_n = (b - t_{鋼}) + \frac{E_{鋼}}{E_{木}} t_{鋼}$$

$$\tau_{max} = -\frac{E_{木} S(z)}{b(E_{木} I_{木} + E_{鋼} I_{鋼})} \left\{ \frac{b_n}{2} (y_{木}^2 - \frac{h^2}{4}) - \frac{b}{2} y_{木}^2 \right\}$$

$$\begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{xz} \\ \gamma_{yz} \end{pmatrix} = \begin{bmatrix} \frac{1}{E_x} & \frac{-\nu_{xy}}{E_x} & \frac{-\nu_{xz}}{E_x} & 0 & 0 & 0 \\ \frac{\nu_{yx}}{E_y} & \frac{1}{E_y} & \frac{-\nu_{yz}}{E_y} & 0 & 0 & 0 \\ \frac{-\nu_{zx}}{E_z} & \frac{-\nu_{zy}}{E_z} & \frac{1}{E_x} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{xy}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{xz}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{yz}} \end{bmatrix} \begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{xz} \\ \tau_{yz} \end{pmatrix}$$

EI と kG の推定

スギ

試験体 No.	挿入深さ [%]	$E_w I_w$[kNm^2]	合成 EI[kNm^2]
1	0	419	419
2	0	386	386
3	15	374	868
4	15	392	786
5	25	344	975
6	25	410	977
7	35	433	1154
8	35	440	1297

試験体	鋼板深さ [%]	kG_w[GPa]	合成 kG[GPa]
1	0	0.38	0.38
2	0	0.47	0.47
3	15	0.33	0.43
4	15	0.30	0.63
5	25	0.45	0.53
6	25	0.37	0.62
7	35	0.33	0.59
8	35	0.31	0.45

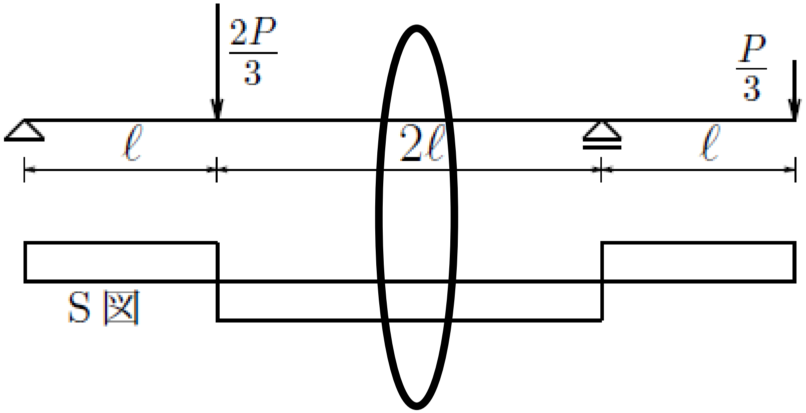
カラマツ

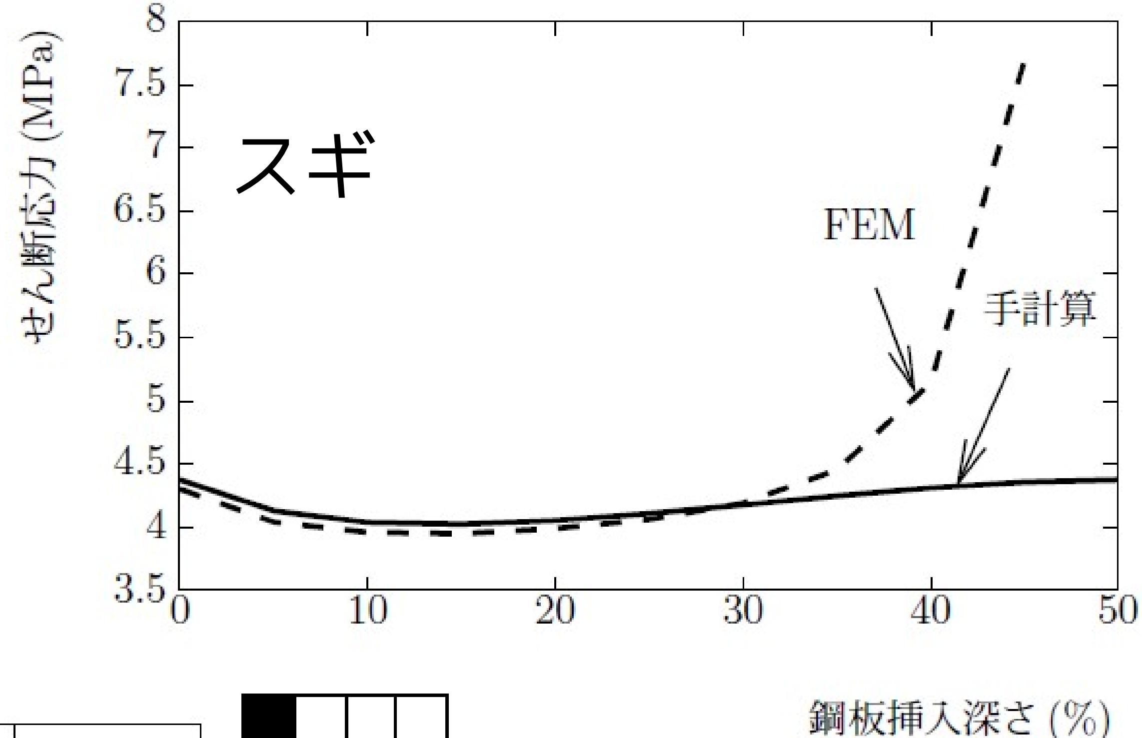
試験体 No.	挿入深さ [%]	$E_w I_w$[kNm^2]	合成 EI[kNm^2]
1	0	906	906
2	0	894	894
3	15	822	1228
4	25	938	1362
5	25	941	1518
6	35	819	1766

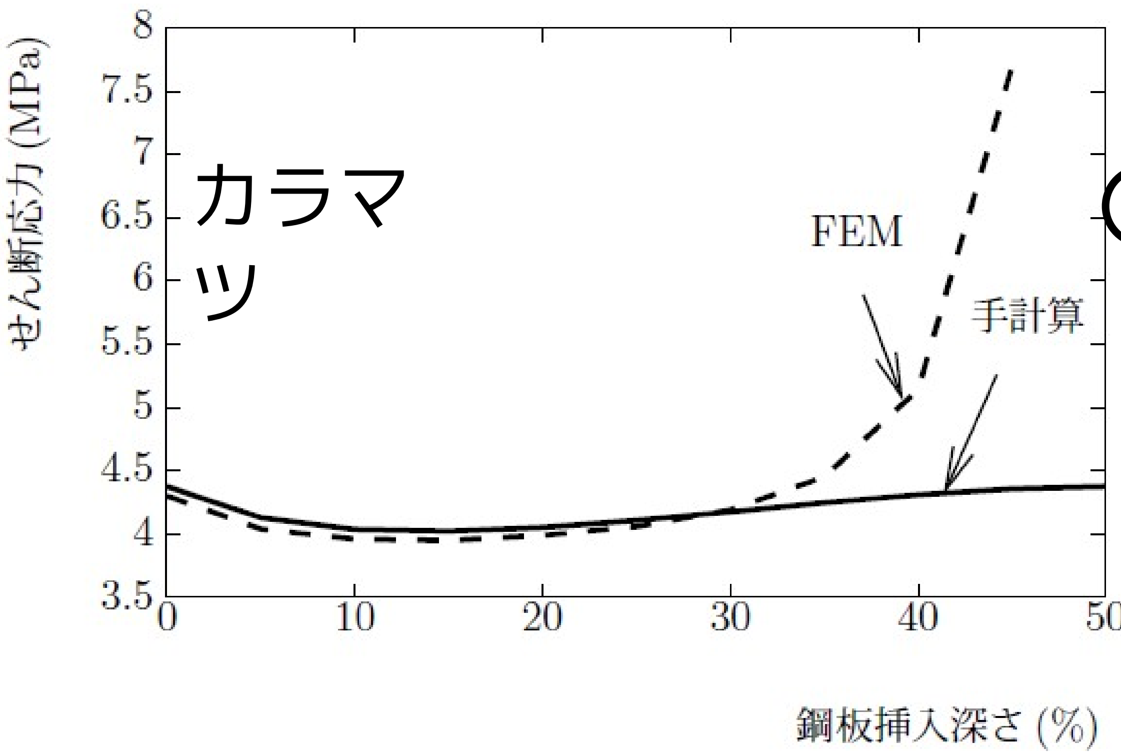
試験体	鋼板深さ [%]	kG_w[GPa]	合成 kG[GPa]
1	0	0.42	0.42
2	0	0.37	0.37
3	15	0.44	0.55
4	25	0.47	0.63
5	25	0.43	0.53
6	35	0.56	0.50

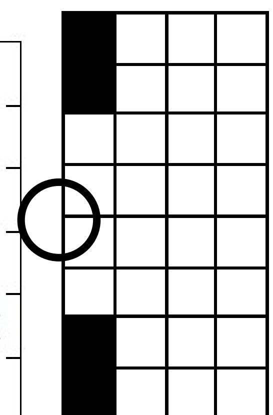
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

支間中央
せん断応力





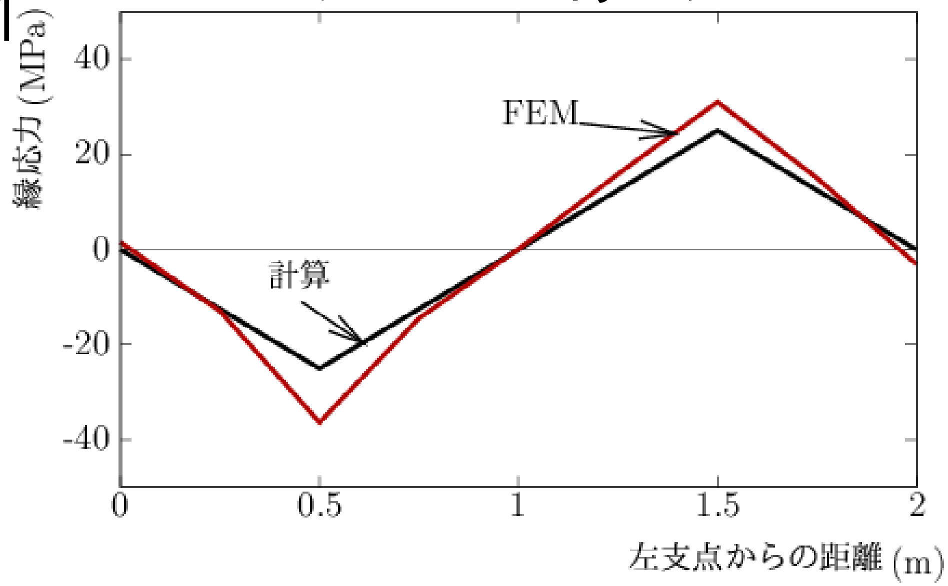




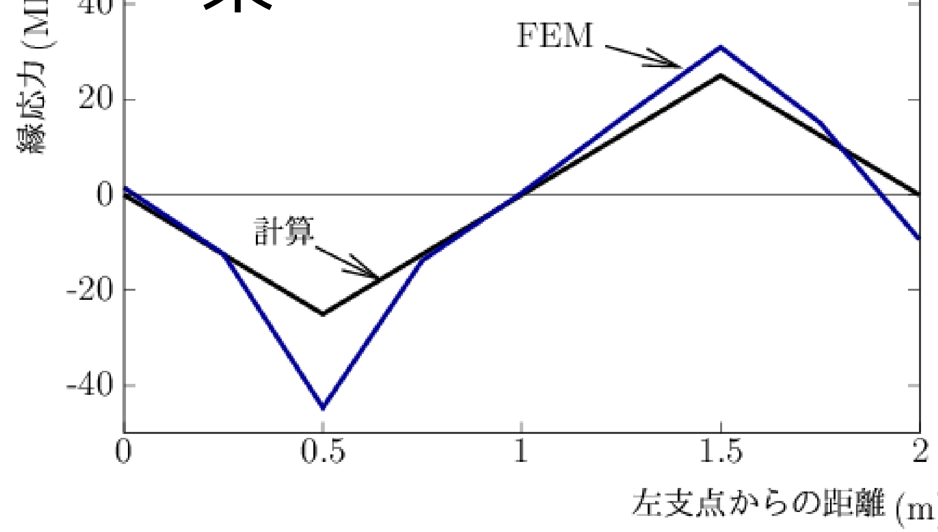
- 35%位から合わない
- 鋼板の影響?
  応力集中?

載荷・拘束条件

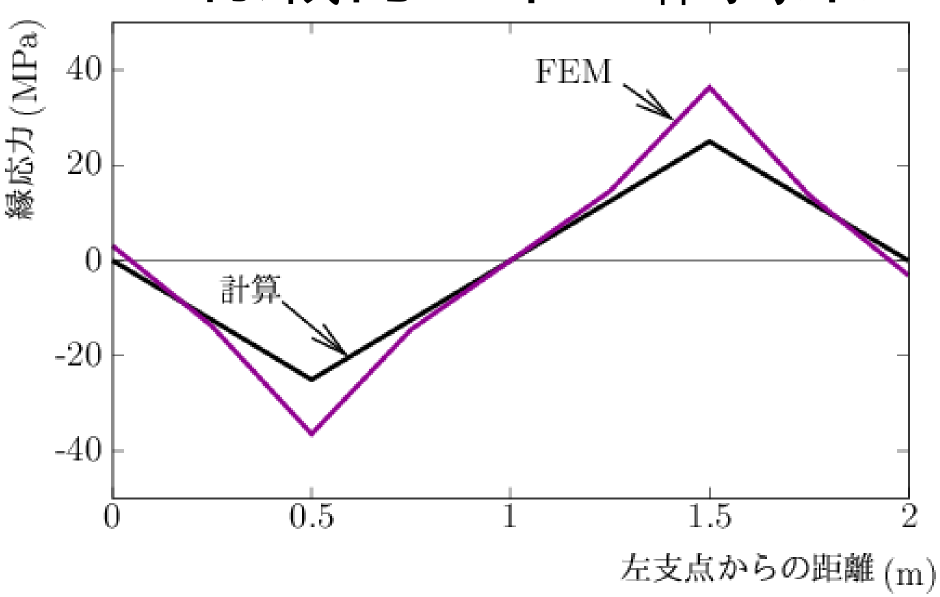
線載荷・下縁拘束



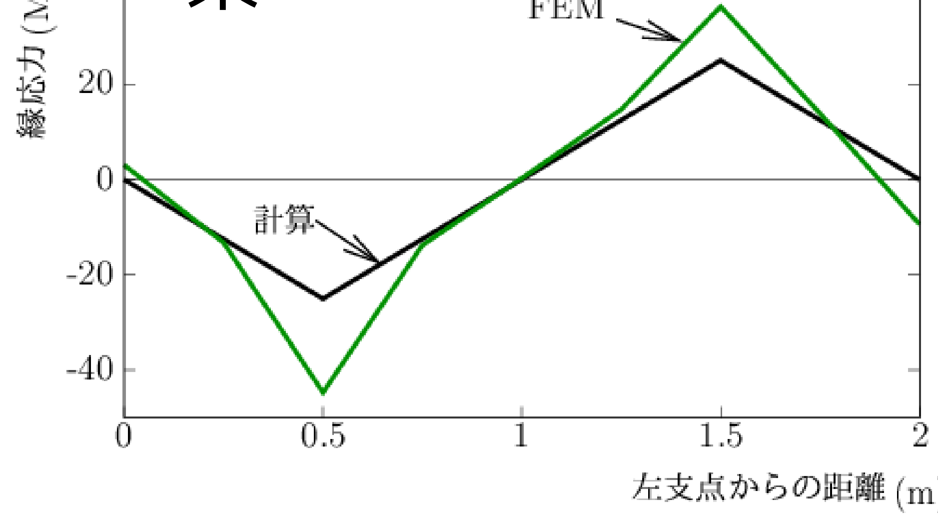
面積載荷・下縁拘束



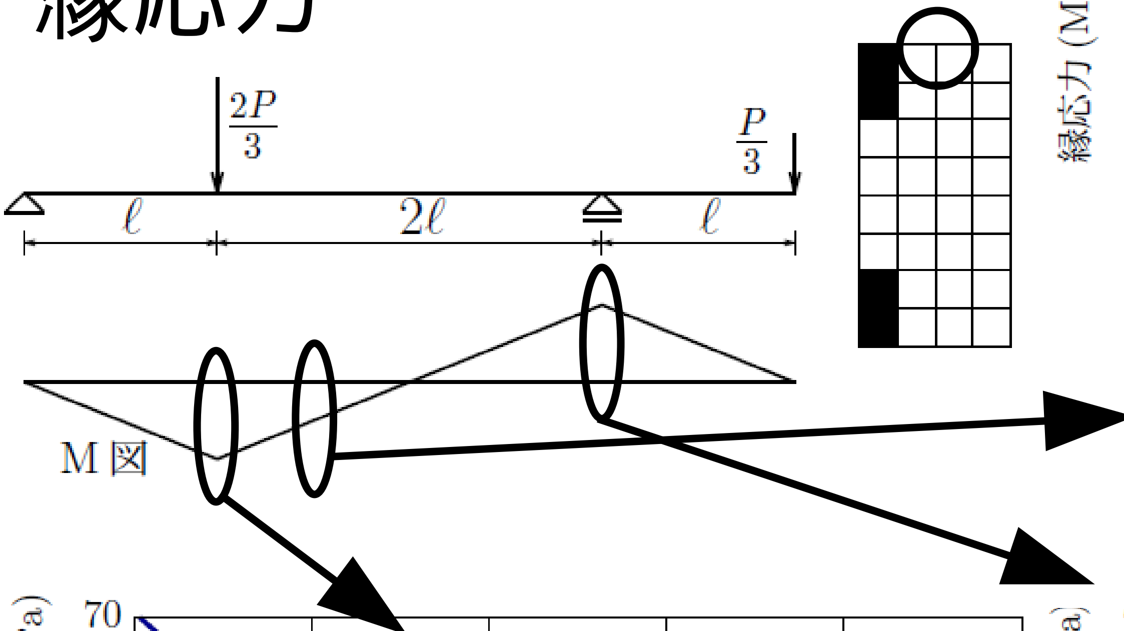
線載荷・中立軸拘束

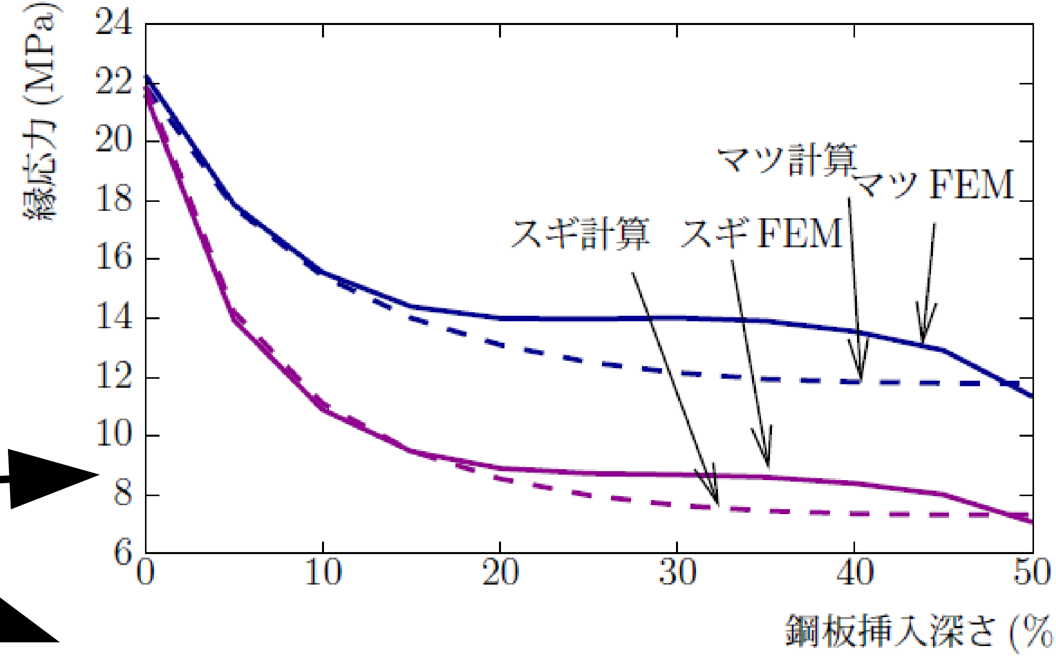


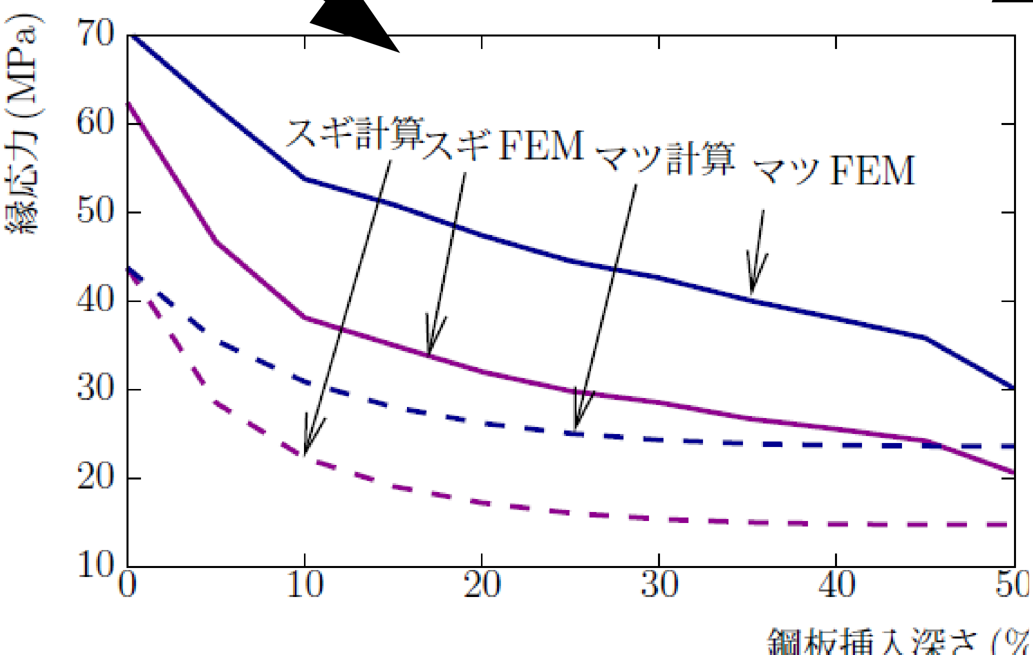
面積載荷・中立軸拘束

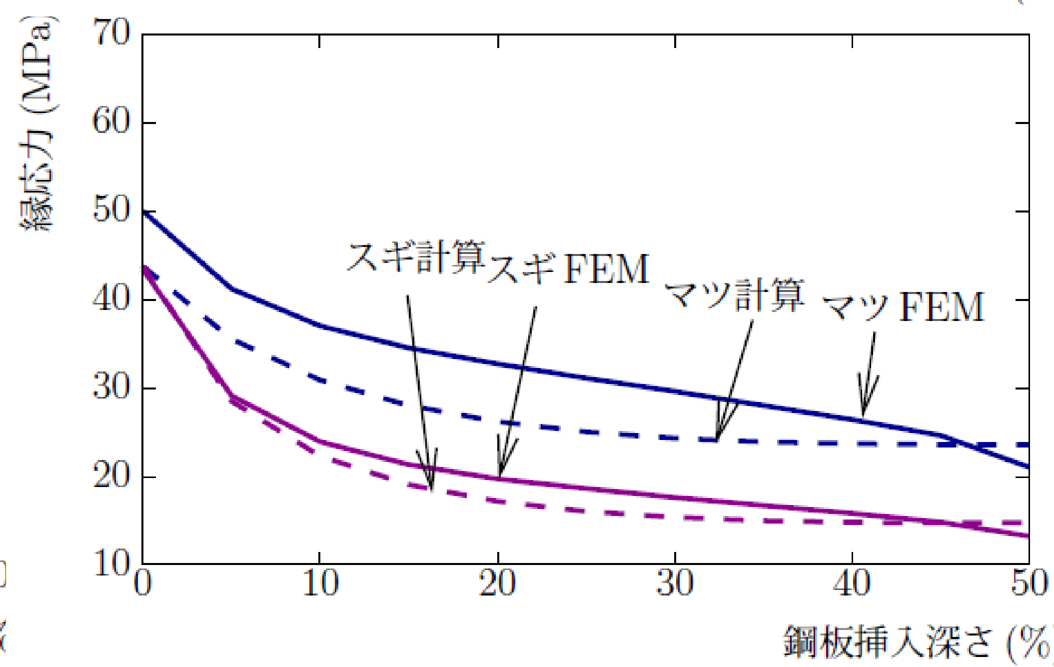


縁応力









- 載荷部、支点部には載荷や拘束の影響