非線形コンクリート特論（Nonlinear Behavior of Concrete and Concrete Members）

(1) ひずみ・Strain

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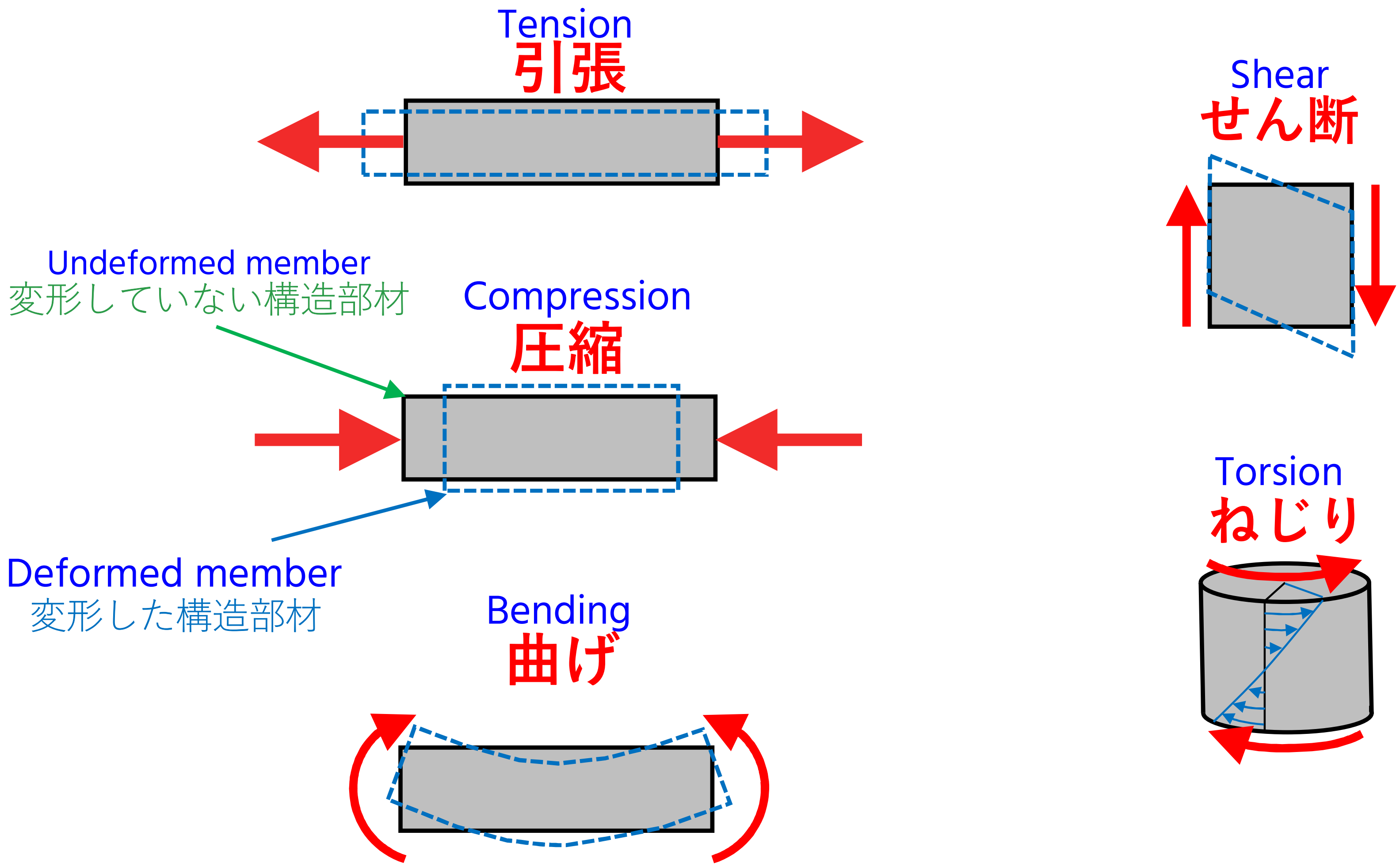
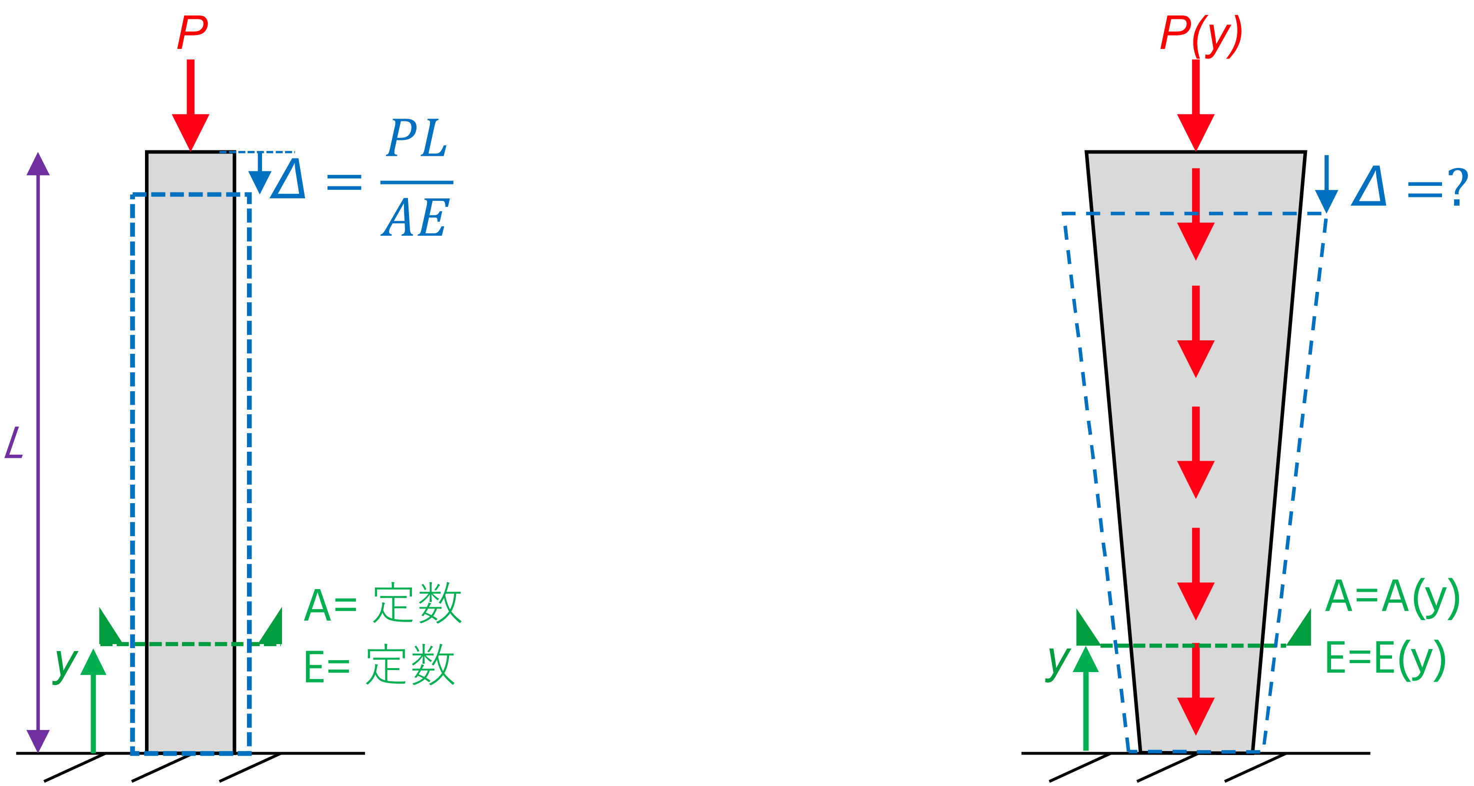
構造部材の応答・Member response



構造部材の応答・Member response



一定の軸力と構造部材特性
Constant axial force and member properties

可変軸力と構造部材特性
Variable axial force and member properties

本物の建物・Real Buildings

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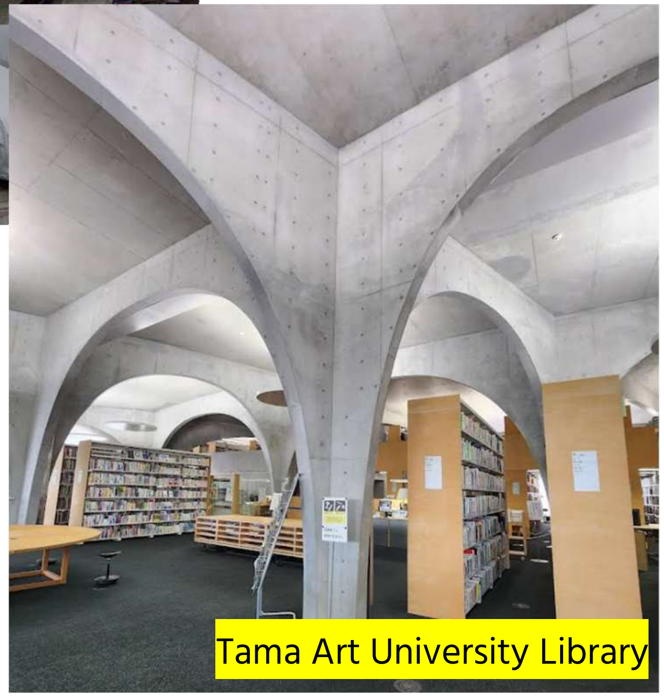
Omotesando Keyaki Building


Breeze Condominium, Setagaya

Taken by Raja Vijayaraghavan, obtained from Google Maps


Yoyogi 1st National Gymnasium


Tama Art University Library

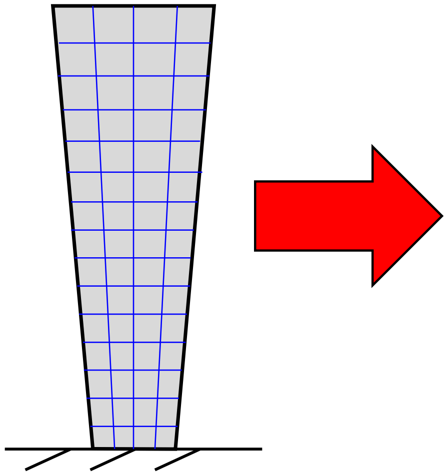
All images obtained from Google Street View unless otherwise stated

構造部材の応答・Member response

- 厳密解だが難しい
  The exact solution may be complicated

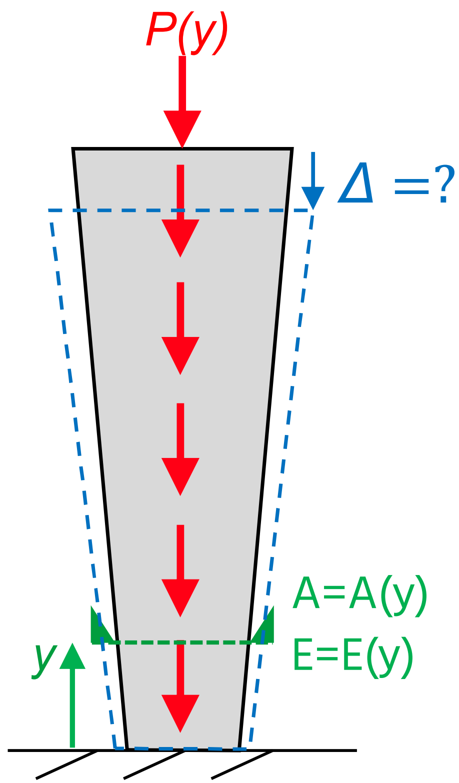
$$\Delta = \int_0^L \frac{P(y)}{A(y)E(y)} dy$$

- 数値解法　　Numerical analysis
  (例：構造部材をメッシュに分解)
  (Example: discretizing member into a mesh)

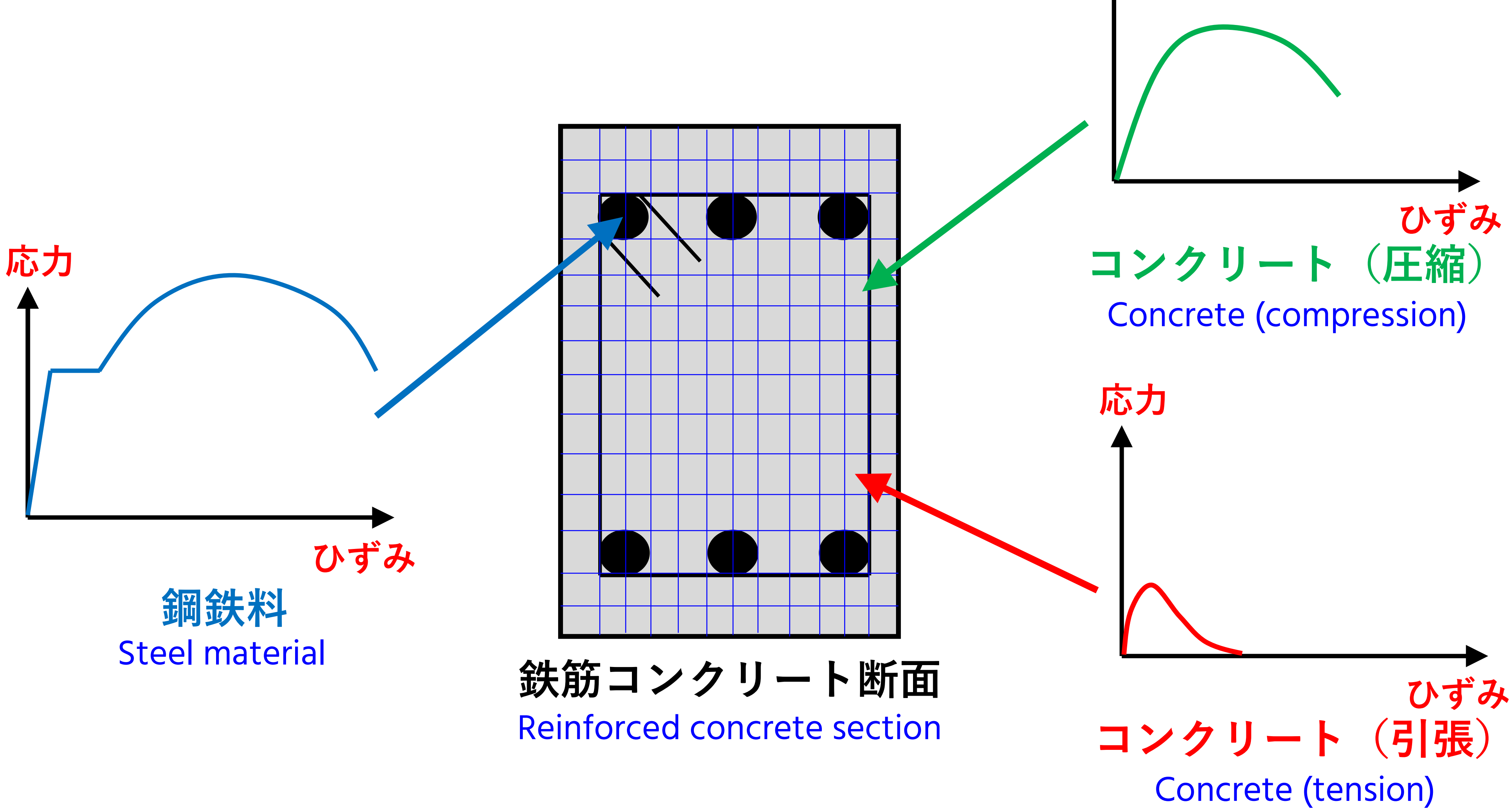


Such analysis methods will be covered in more detail later in the course

このような数値解析手法はコースの後半で詳しく説明する予定です



材料の応答・Material response



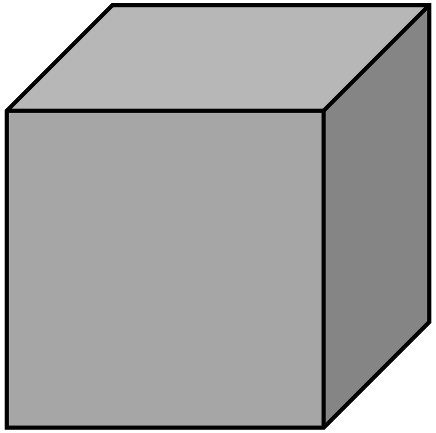
Need to understand stress and strains in order to perform numerical simulations

数値解析手法が行えるために、
応力・ひずみを理解ことが必要である

等方的・異方的材料
Isotropic/Anisoptropic Material

Isotropic
等方的

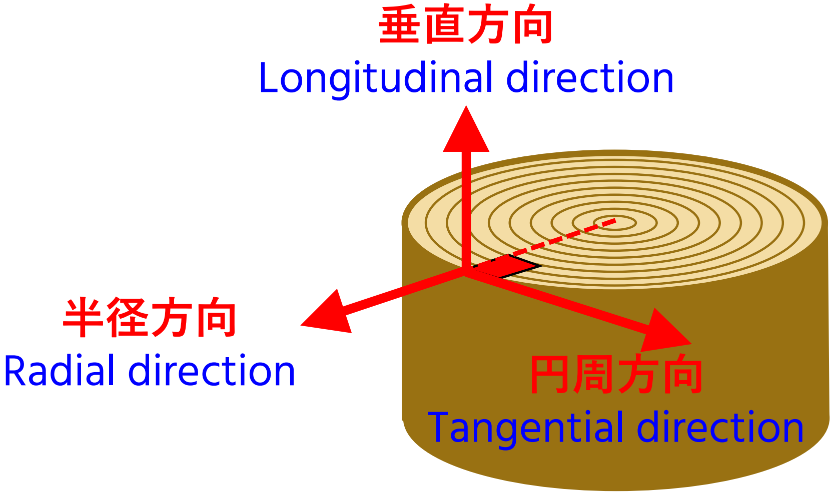
方向によらずに機械的な特性が同じ
Mechanical properties are the same in all directions



鋼鉄材料
Steel

Anisotropic
異方的

方向によらずに機械的な特性が異なる
Mechanical properties depend on direction

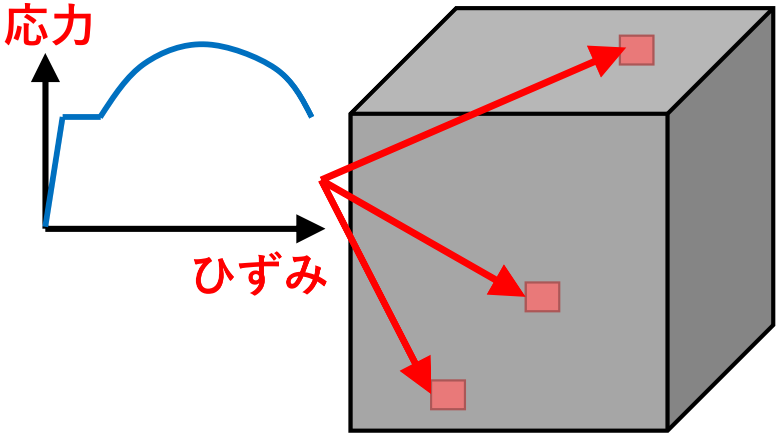


木材料
Timber

均質・非均質材
Homogeneous・Heterogeneous Material

Homogeneous
均質材

材料中のどの場所でも応力－ひずみ関係が同一である
Stress-strain relationship is identical throughout material



鋼鉄材料
Steel

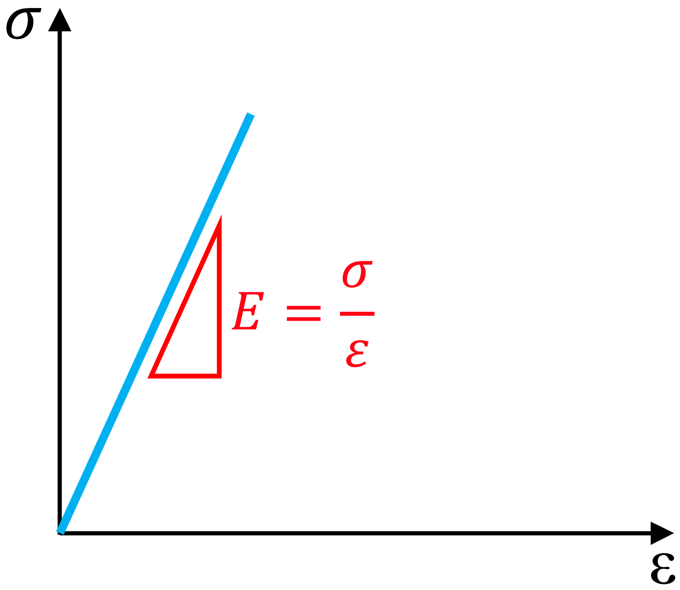
Heterogeneous
非均質材

材料中の場所毎に応力－ひずみ関係が異なる
Nonuniform material composition throughout material

セメントと骨材の特性は異なる
Properties of cement and aggregate are different

コンクリート
Concrete

線型・非線型/弾性・塑性
Linear・Nonlinear/Elastic・Plastic

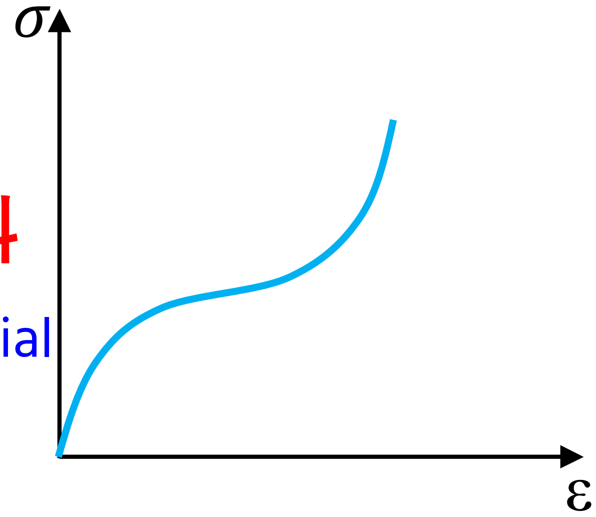


線型弾性材料

Linear elastic material

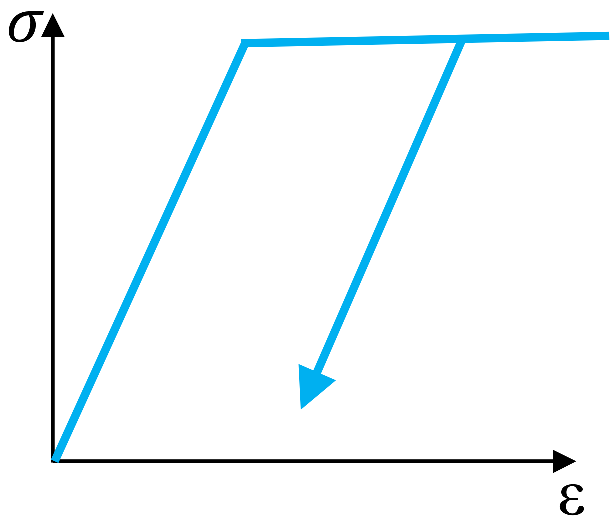
非線型材料

Nonlinear material



塑性材料

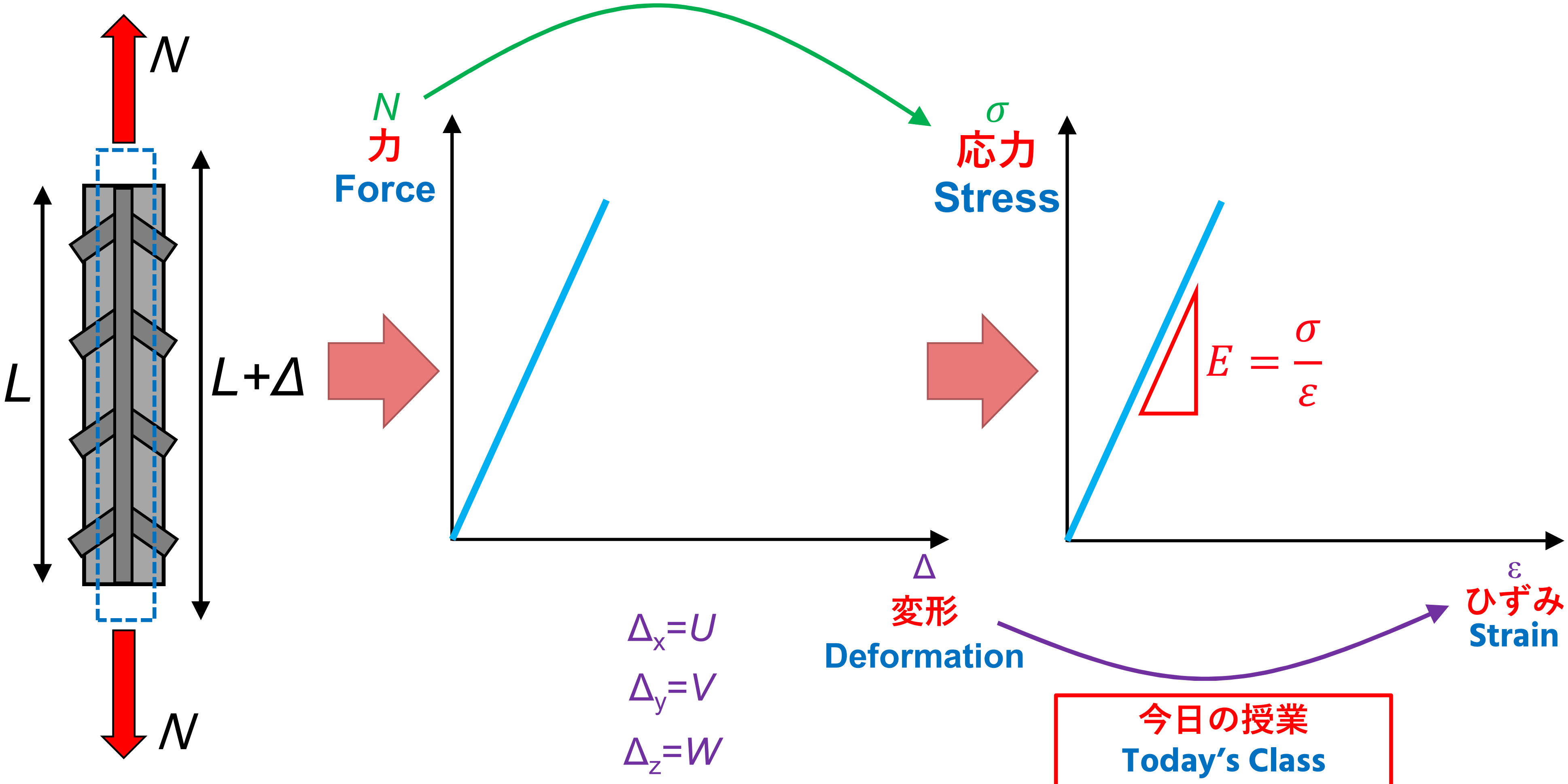
Plastic material



We will focus on ISOTROPIC, HOMOGENEOUS and LINEAR ELASTIC materials

均質等方性線型弾性材料に焦点を当てる

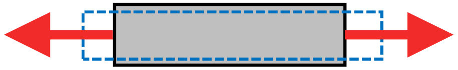
応力ーひずみ・Stress-Strain



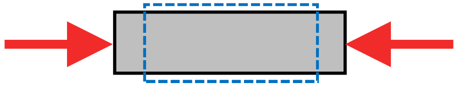
今日の授業
Today's Class

ひずみ・Strain

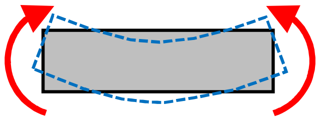
Tension
引張



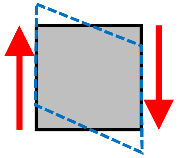
Compression
圧縮

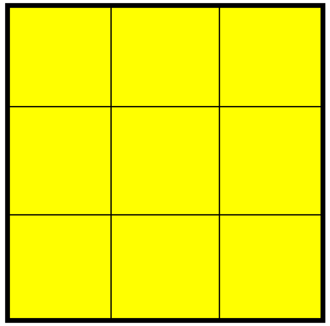


Bending
曲げ

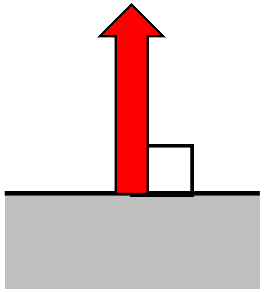


Shear
せん断



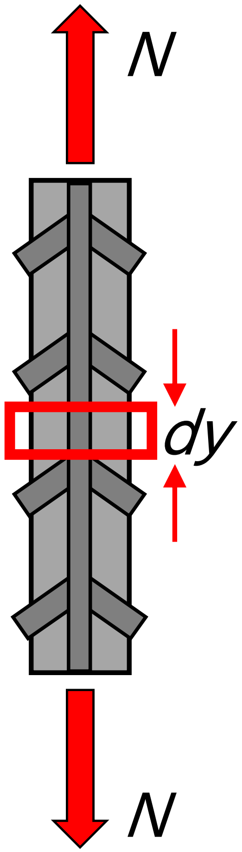


垂直ひずみ・Normal Strain



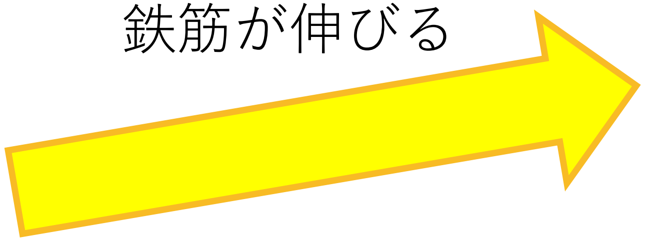
応力は表面に垂直

Stress is perpendicular to surface



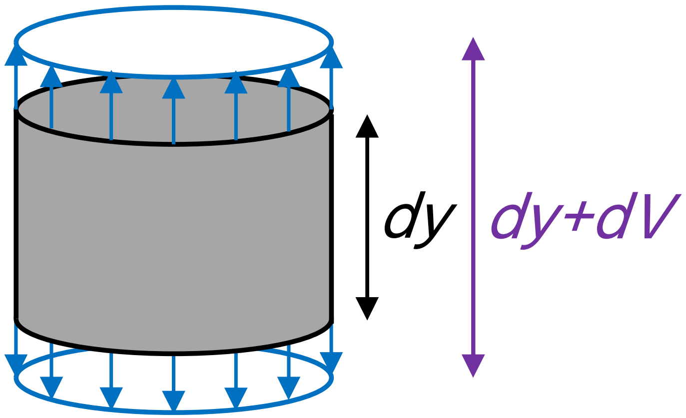
Elongation due to tensile load *N*

引張荷重*N*により、鉄筋が伸びる



Change in length over distance *dy*

dV = *dy*における長さの変化

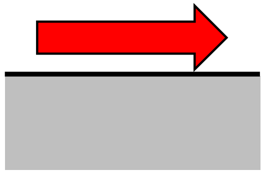


Normal strain is a measure of deformation per unit length

垂直ひずみ(ε): 単位長さ当たりの変形

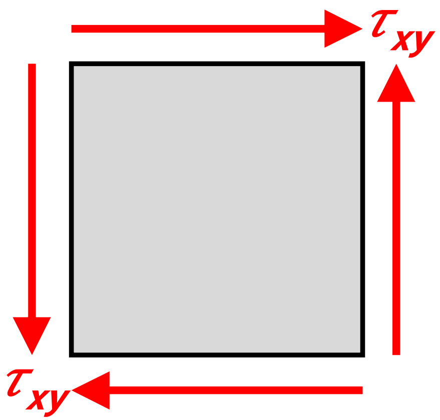
$$\varepsilon_{yy} = \frac{dV}{dy}$$

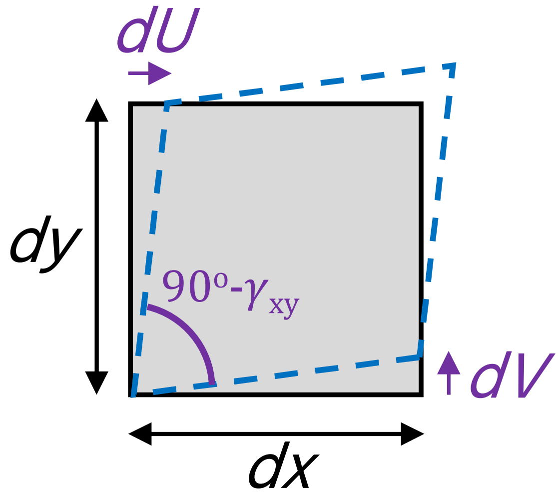
せん断ひずみ・Shear Strain



応力は表面
に平行

Stress is parallel
to surface





Shear strain is the change in angle from a right angle

せん断ひずみ(γ): 直角からの変化量

$$\gamma_{xy} = \frac{dU}{dy} + \frac{dV}{dx}$$

例）引張荷重・Tension load example

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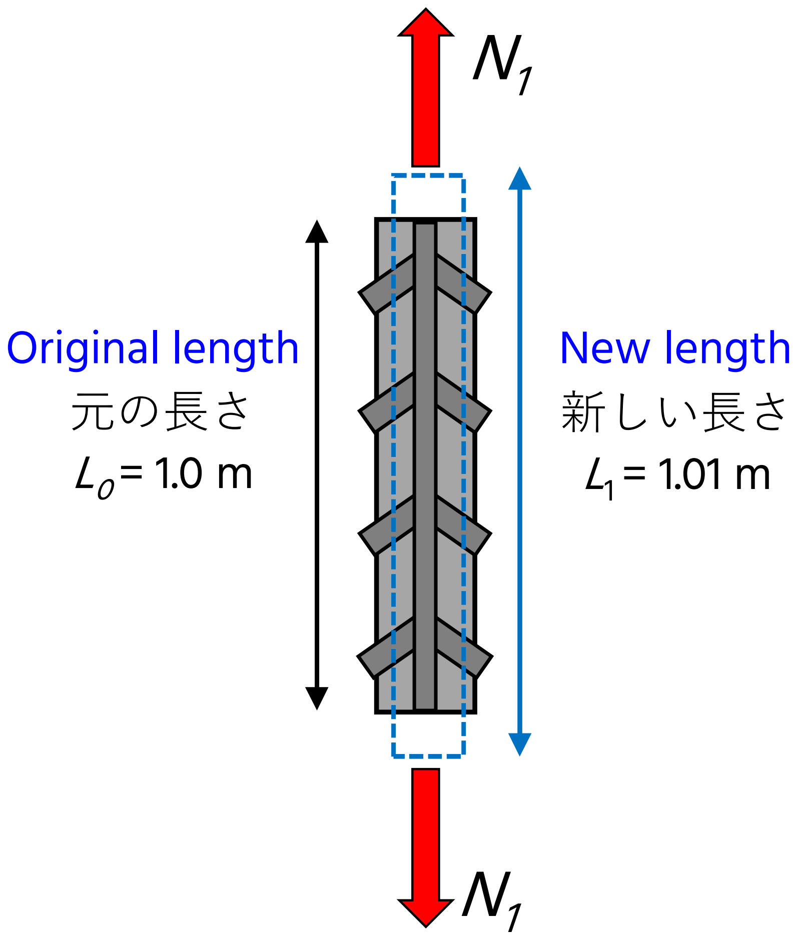

例）引張荷重・Tension load example

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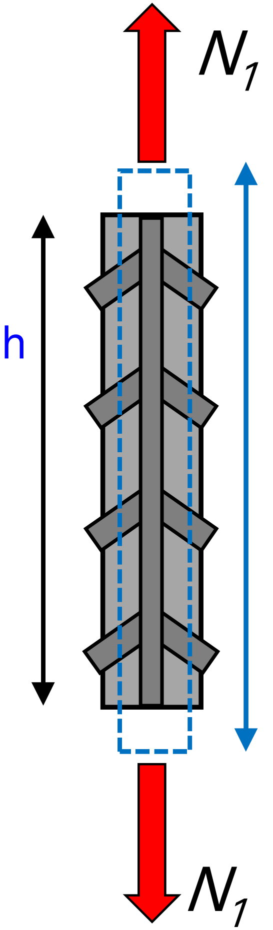
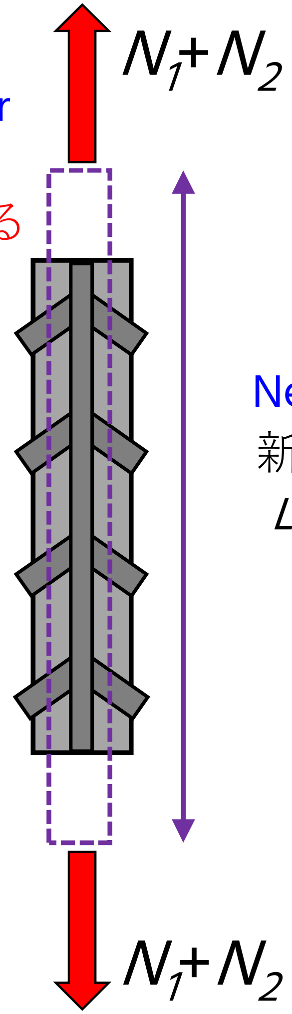


Original length
元の長さ
L_0 = 1.0 m

Length under N_1
N_1による長さ
L_1 = 1.01 m

If additional N_2 is applied, bar elongates further
さらにN_2の引張荷重を加えると、鉄筋が伸びる。

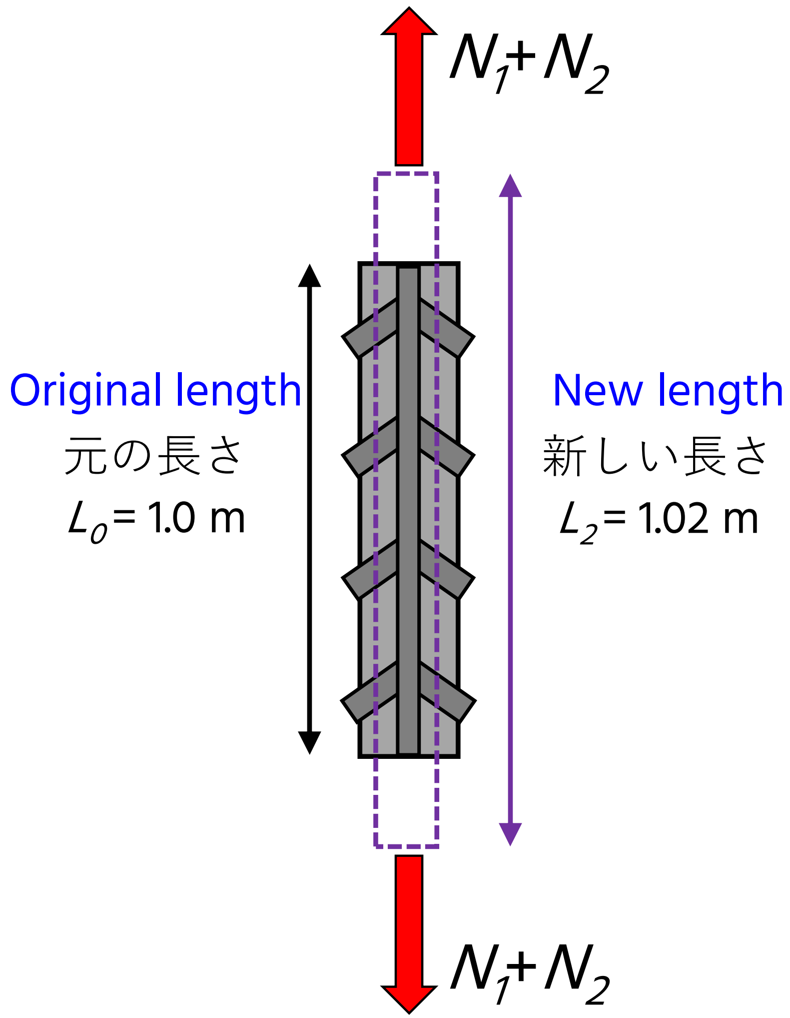


New length
新しい長さ
L_2 = 1.02 m

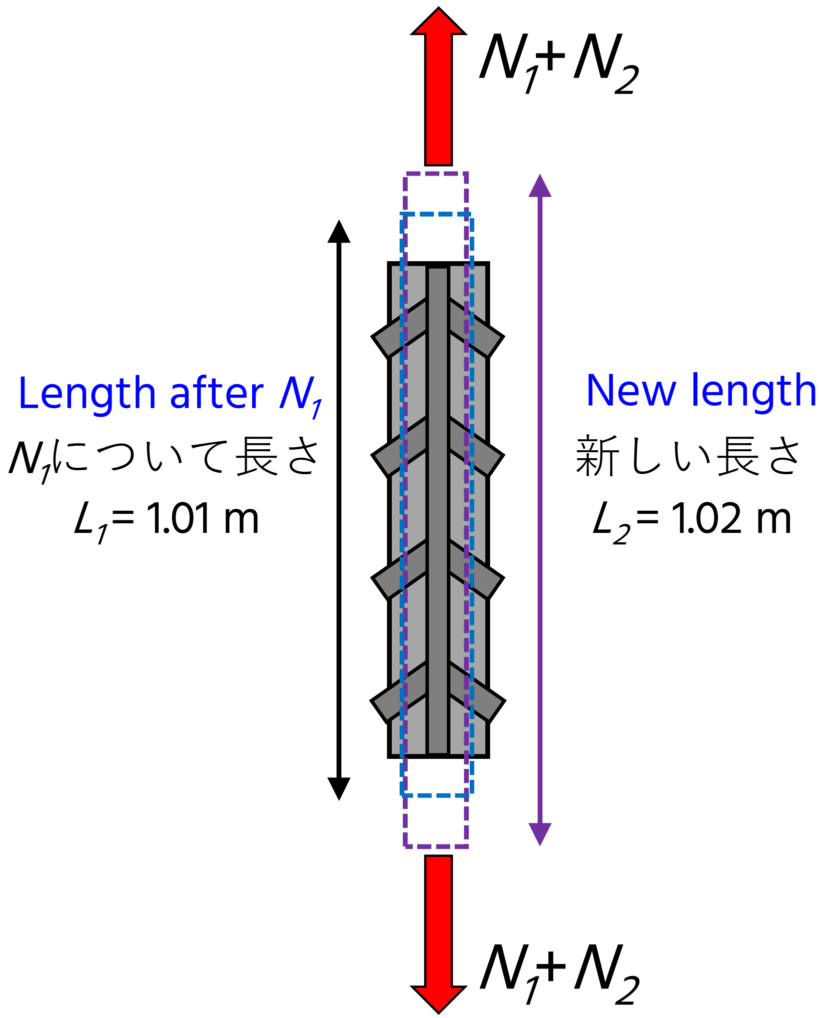
N_1+N_2によるひずみは何？
What is the strain under N_1+N_2?

a) 0.02
b) 0.0198

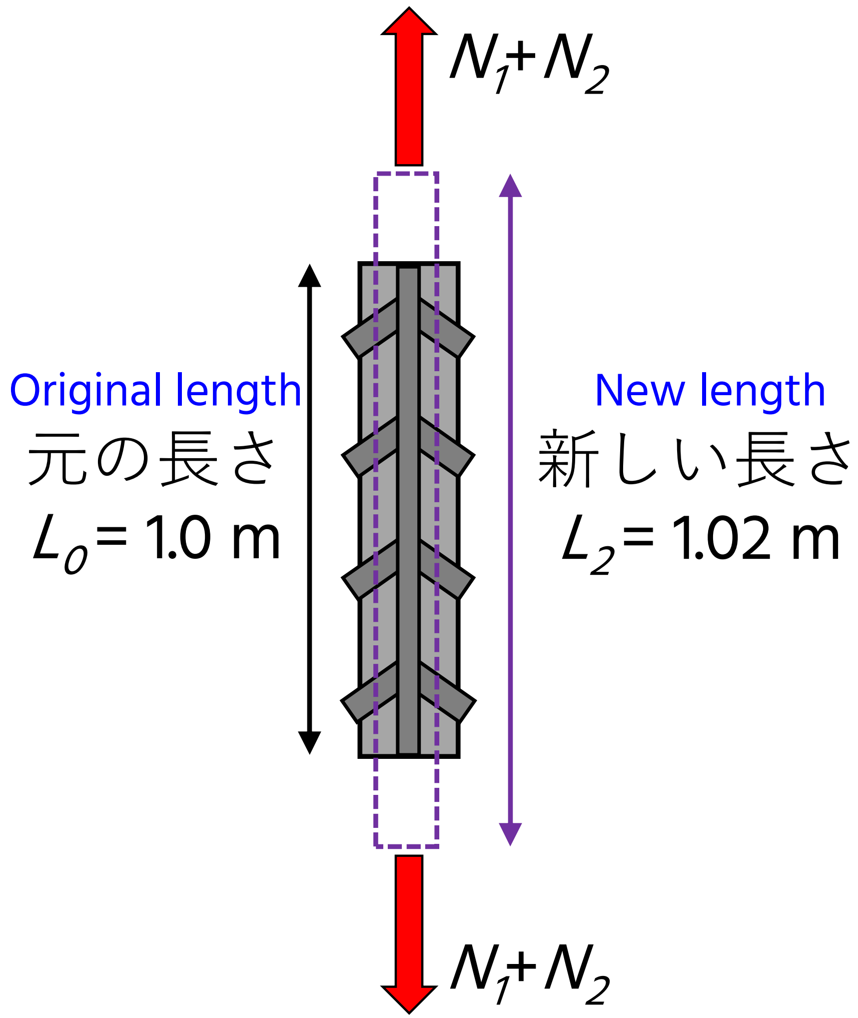
工学ひずみ・Engineering strain



真ひずみ・True strain



真ひずみ・True strain



工学ひずみ・真ひずみ
Engineering and true strain

Engineering Strain

工学ひずみ：

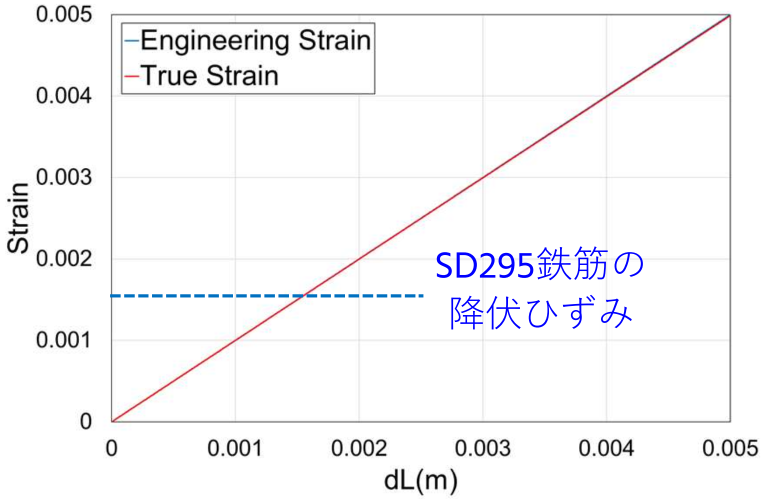
$$\frac{L - L_0}{L_0}$$

True Strain

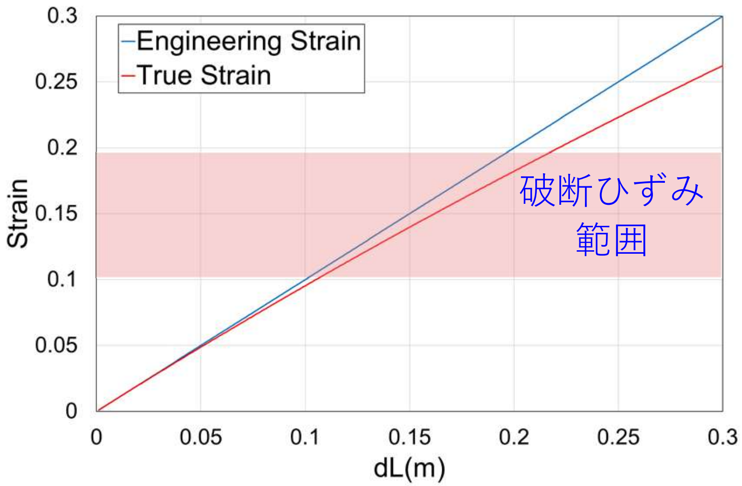
真ひずみ：

$$ln\left(\frac{L}{L_0}\right)$$

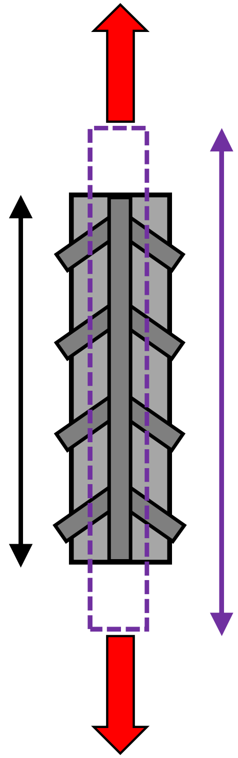
低いひずみ



高いひずみ

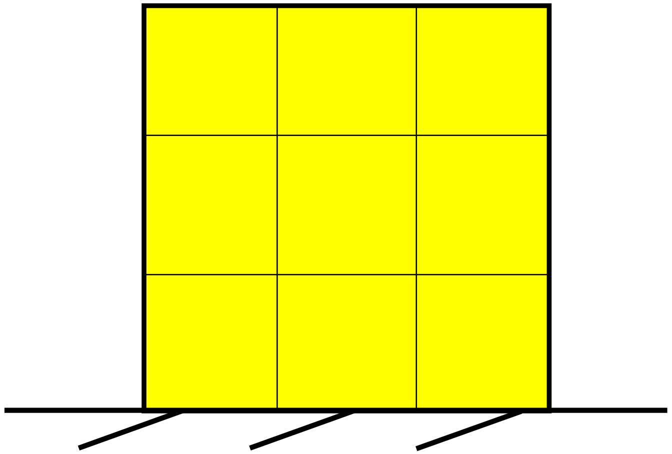


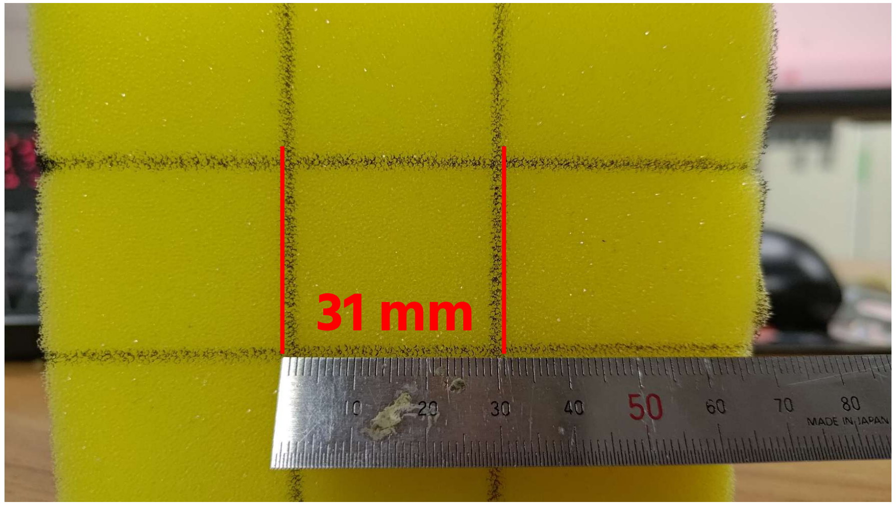
元の長さ
L_0= 1.0 m

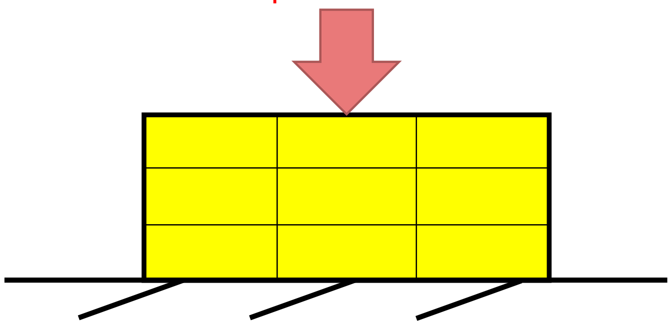


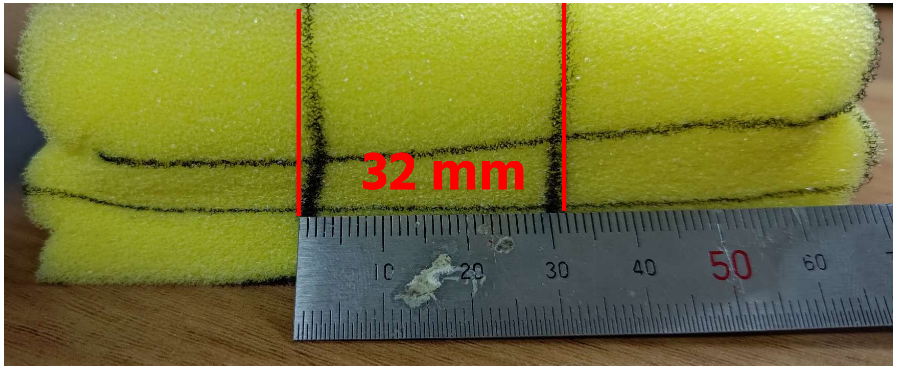
新しい長さ
$L = L_0 + dL$

ポアソン比・Poisson’s Ratio









ポアソン比・Poisson's Ratio

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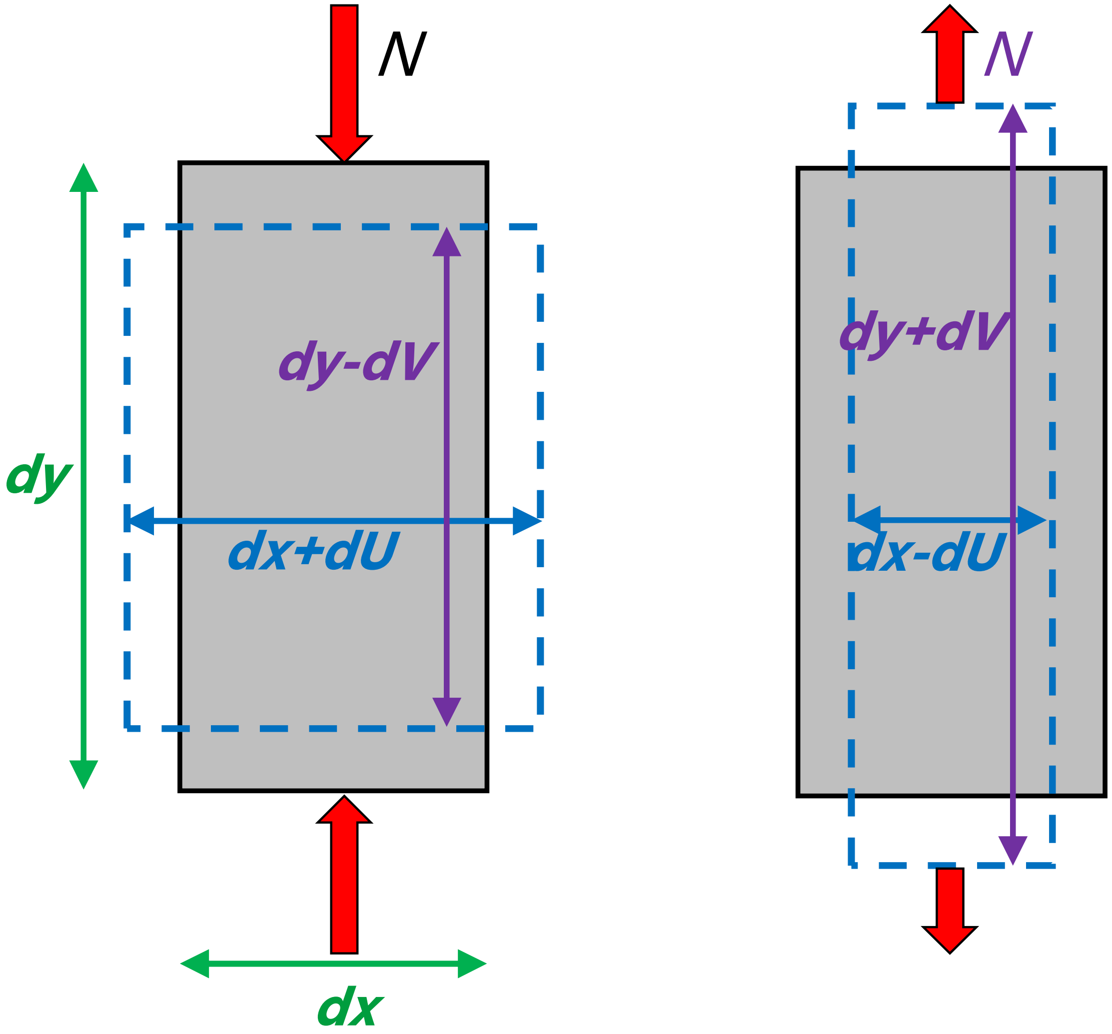


Force N causes longitudinal strain (ε_y) along y axis.

Nは y 方向縦ひずみ(ε_y)を引き起こす

$$\varepsilon_{yy} = \frac{dV}{dy}$$

Deformation will also occur in the sideways direction. (lateral strain of ε_x)

横方向に変形もある(横ひずみ ε_x)

$$\varepsilon_{xx} = \frac{dU}{dx}$$

The strains can be related via Poisson's Ratio, ν (~0.16 for concrete, ~0.3 for steel, ~0 for spong) for isotropic homogeneous linear elastic materials

均質等方生線型弾性材料の横・縦ひずみは、ポアソン比（コンクリートで～0.16、鋼材で～0.3、スポンジ～0）を介して関係づけられる。

$$\nu = -\frac{\varepsilon_{xx}}{\varepsilon_{yy}}$$ (Uniaxial loading case)

ひずみゲージ・Strain Gauge

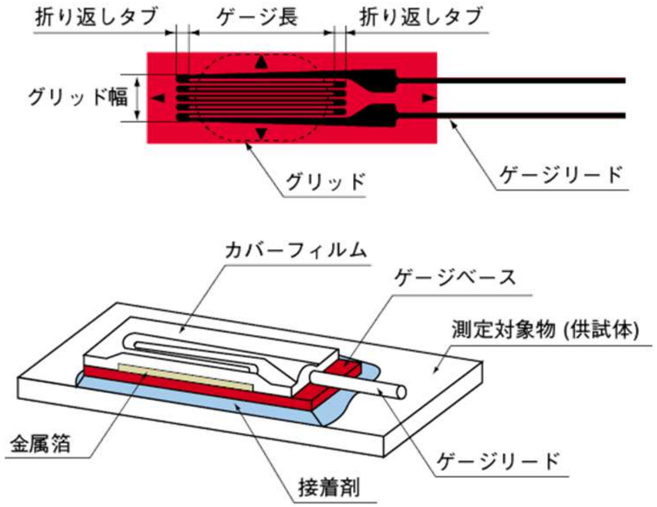
ひずみはひずみゲージを用いて測定することができる
Strains can be measured using strain gauges

ひずみゲージが取り付けられている面が伸びると、ワイヤーの長さは長くなり、せん断席は小さくんる
If surface that strain gauge is attached to elongates, the wire length increases and its cross sectional area decreases.

そのため、ひずみゲージの抵抗を増えている
This causes the resistance of the gauge to increase

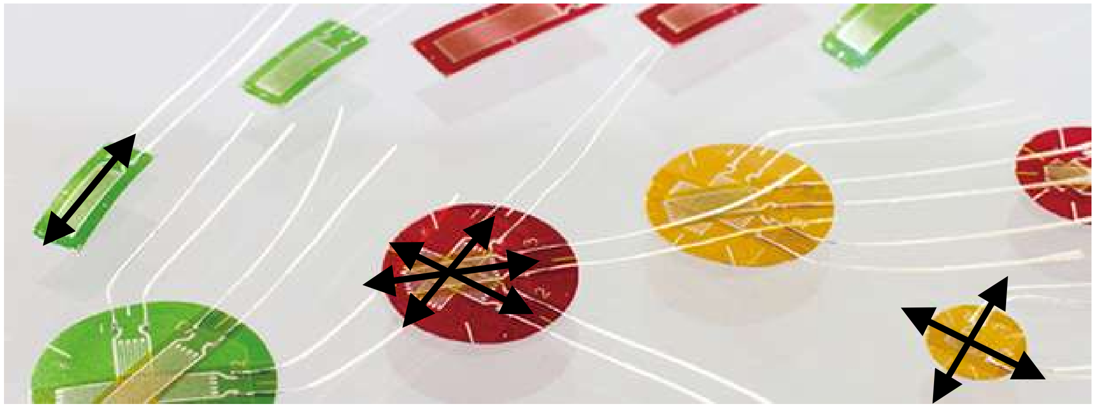
$$\varepsilon = \frac{1}{K}\frac{\Delta R}{R}$$

ΔR –抵抗変化量・Change in resistance
R –最初の抵抗・Initial resistance value
K –ゲージ率(~ 2.0)・gauge factor (~ 2.0)



Gauge components[1]

Use in testing



Various types of strain gauges[1]

[1] 株式会社東京測器研究所・Tokyo Measuring Instruments Laboratory Co., Ltd
https://tml.jp/knowledge/strain_gauge/about.html

ひずみゲージ・Strain Gauge

抵抗の変化は、 Wheatstone Bridge Circuitの入力電圧（*E*）と出力電圧（*e*）を比較することで測定できる：

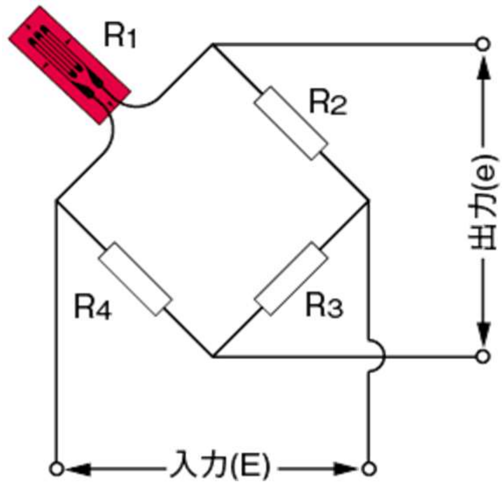
Change in resistance can be measured by comparing the input voltage (E) and output voltage (e) of a Wheatstone Bridge Circuit:

$$e = \frac{R_1R_3 - R_2R_4}{(R_1 + R_2)(R_3 + R_4)}E$$

This is NOT Young's Modulus!!!

R_1 – ひずみゲー時の抵抗値・strain gauge resistance

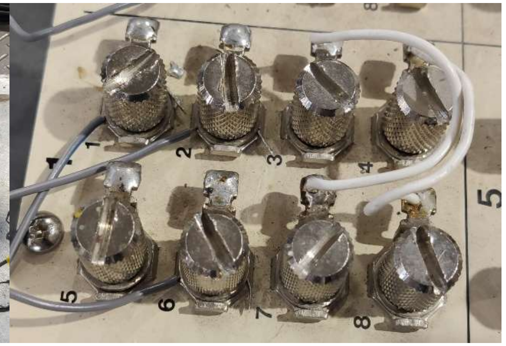
R_2-R_4 – 固定抵抗の抵抗値・resistors resistance



Wheatstone bridge Circuit[1]

R_1~R_4の初期抵抗値をRとし、ひずみゲージの抵抗値変化がΔR発生したとする If the initial resistance of R_1~R_4 is *R*, and a change in resistance of the strain gauge of Δ*R* occurs:

$$\Delta e = \frac{(R+\Delta R)R-R^2}{(2R+\Delta R)(2R)}E = \frac{\Delta R}{4R+2\Delta R}E \approx \frac{E}{4}\frac{\Delta R}{R} \approx \frac{E}{4}K\varepsilon \qquad (R \gg R)$$



ひずみは出力電圧の変化によって決定することができる

Thus, strain can be determined by a change in output voltage

[1] 株式会社東京測器研究所・Tokyo Measuring Instruments Laboratory Co., Ltd
https://tml.jp/knowledge/strain_gauge/about.html