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Advanced Topics in Civil Engineering

Dimensional Stability of Concrete

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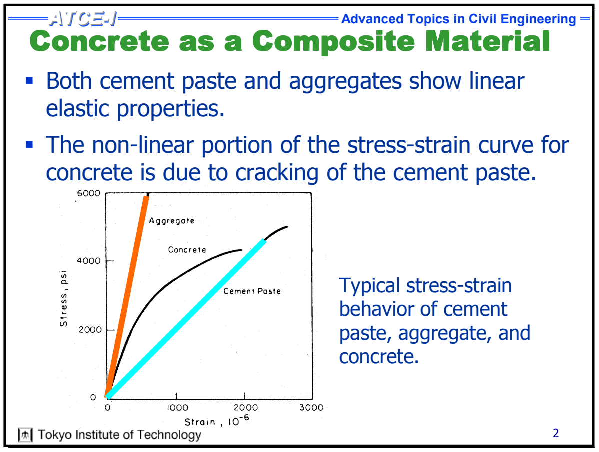

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Concrete as a Composite Material

- Both cement paste and aggregates show linear elastic properties.
- The non-linear portion of the stress-strain curve for concrete is due to cracking of the cement paste.

Typical stress-strain behavior of cement paste, aggregate, and concrete.

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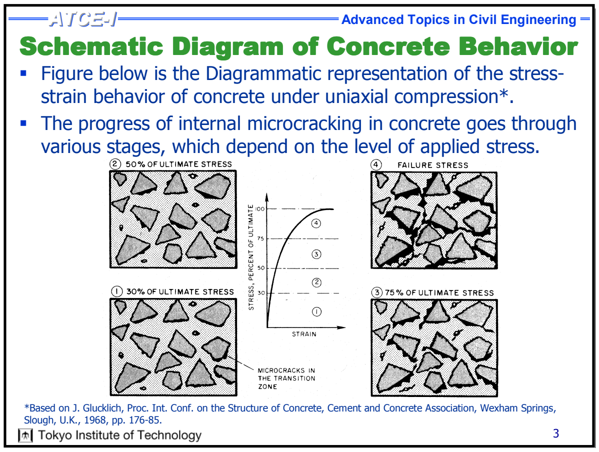

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Schematic Diagram of Concrete Behavior

- Figure below is the Diagrammatic representation of the stress-strain behavior of concrete under uniaxial compression*.
- The progress of internal microcracking in concrete goes through various stages, which depend on the level of applied stress.

*Based on J. Glucklich, Proc. Int. Conf. on the Structure of Concrete, Cement and Concrete Association, Wexham Springs, Slough, U.K., 1968, pp. 176-85.

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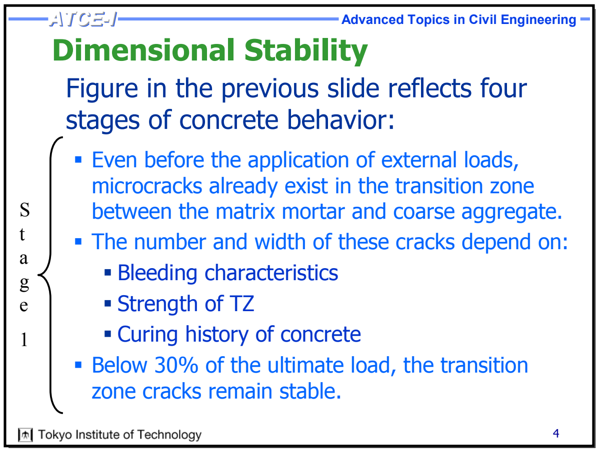
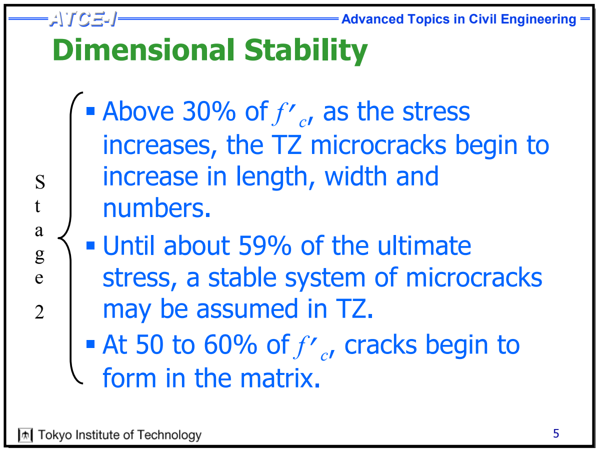


Dimensional Stability

Figure in the previous slide reflects four stages of concrete behavior:

Stage 1

- Even before the application of external loads, microcracks already exist in the transition zone between the matrix mortar and coarse aggregate.
- The number and width of these cracks depend on:
  - Bleeding characteristics
  - Strength of TZ
  - Curing history of concrete
- Below 30% of the ultimate load, the transition zone cracks remain stable.



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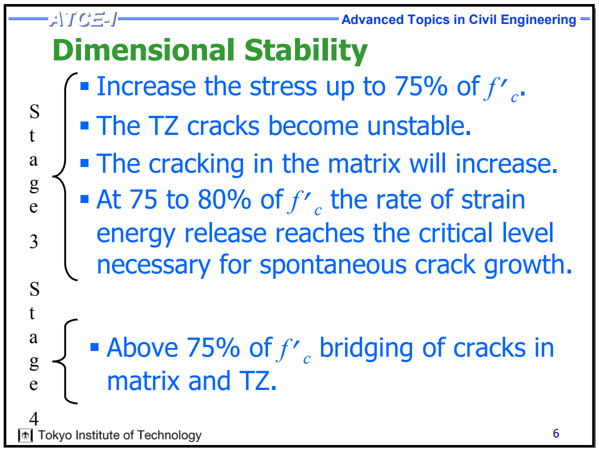
Stage 2

- Above 30% of f'_c, as the stress increases, the TZ microcracks begin to increase in length, width and numbers.
- Until about 59% of the ultimate stress, a stable system of microcracks may be assumed in TZ.
- At 50 to 60% of f'_c, cracks begin to form in the matrix.



Dimensional Stability

Stage 3

- Increase the stress up to 75% of f'_c.
- The TZ cracks become unstable.
- The cracking in the matrix will increase.
- At 75 to 80% of f'_c the rate of strain energy release reaches the critical level necessary for spontaneous crack growth.

Stage 4

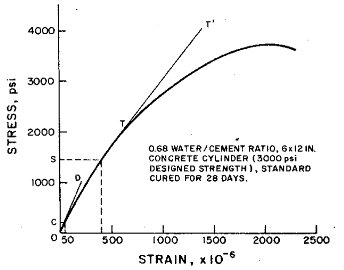
- Above 75% of f'_c bridging of cracks in matrix and TZ.

Elastic Modulus of Concrete

- Types of Elastic Modulus (E) — Static / Dynamic
- E is given by the shape of $\sigma - \varepsilon$ curve for concrete under uniaxial loading (since the curve for concrete is nonlinear, three methods for computing moduli are used).
  - **Tangent Modulus** (slope of a line drawn tangent to the $\sigma - \varepsilon$ curve at any point on the curve)
  - **Secant Modulus** (slope of the line drawn from the origin to a point on the curve corresponding to a 40% f'_c)
  - **Chord Modulus** (slope of a line drawn between two points on the $\sigma - \varepsilon$ curve)

Elastic Modulus of Concrete

Different types of elastic moduli and the method by which these are determined.



CALCULATING THE ELASTIC MODULI

σ_{ULT} = 3600 psi
40% σ_{ULT} = 1440 psi = SO

Secant Modulus: Slope of the line corresponding to stress SO = 1440/400 × 10^{-6} = 3.6 × 10^6 psi

Chord Modulus: Slope of the line corresponding to stress SC = (1440-200)/(400-50) × 10^{-6} = 3.5 × 10^6 psi

Tangent Modulus: Slope of the line TT' drawn tangent to any point on the σ-ε curve = 2.5 × 10^6 psi

Dynamic Modulus (Initial Tangent Modulus): Slope of the OD from the origin = 1000/200 × 10^{-6} = 5 × 10^6 psi

Elastic Modulus of Concrete

- According to ACI Building Code 318, with a concrete unit weight between 90 and 155 lb/ft^3, the modulus of elasticity can be determined from: $E = \mathrm{f}(w_c, f'_c)$

$$E_c = W_c^{1.5} \times 33 f'^{1/2}_c$$

Where:
E_c = elastic modulus
W_c = unit weight of concrete (lb/ft^3)
f'_c = the 28-day compressive strength of standard cylinders

Factors Controlling Elastic Modulus

- In single phase solids (homogeneous materials) a direct relationship exists between density and modulus of elasticity.
- In heterogeneous, multi-phase materials, i.e., concrete, the volume fraction, density, and modulus of elasticity of each phase, and the characteristics of TZ determine the elastic behavior of the composite.

Factors Controlling Elastic Modulus

- **Aggregate:**
  - Porosity of aggregate (determines stiffness) is the most important factor that affects E of concrete. Dense aggregates have a high E.
  - In general, the larger the amount of coarse aggregate with a high elastic modulus in a concrete mixture, the greater would be the modulus of elasticity of concrete.
  - Elastic Mismatch:

	E_a
Granite	20×10^6 psi
Sandstone (porous)	3-7 × 10^6 psi
Lightweight expanded shale	1-3 × 10^6 psi

Will develop more cracks in the TZ due to elastic mismatch

≈HCP

Factors Controlling Elastic Modulus

- **Hydrated Cement Paste (HCP):**
  - The elastic modulus of the cement paste matrix (E_p) is determined by its porosity.
  - The factors controlling the porosity of the cement paste are: *w/c*, air content, mineral admixtures, and degree of cement hydration.

$$E_c = E_a \underset{\text{Volume fraction of aggregate}}{g} + E_p \underbrace{(1-g)}_{\text{Volume of cement paste}}$$

- **Transition zone (TZ):**
  - Void space, microcracks, and orientation of CH crystals are more common in TZ than in bulk cement paste; therefore they play a very important role in determining the stress-strain relationship in concrete.

Poisson's Ratio

For a material subjected to simple axial load, the ratio of the lateral strain to axial strain ***within the elastic range*** is called **Poisson's ratio**.

$$\text{Poisson's Ratio} = \frac{\text{Lateral Strain}}{\text{Axial Strain}} = \nu$$

With concrete the values of Poisson's ratio generally vary between 0.15 and 0.20.

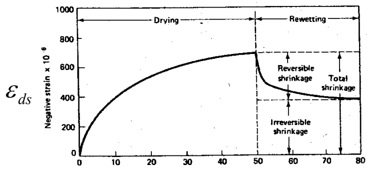
Drying Shrinkage and Creep

Causes

- **Drying Shrinkage:**
  - Loss of surface adsorbed water from C-S-H + loss of hydrostatic tension in small capillaries (<50 nm). (low RH)
- **Creep:**
  - (1) Loss of adsorbed water under mechanical pressure
  - (2) Delayed elastic response of aggregate
  - (3) Transition zone crack propagation.

(cement paste deforms first, then aggregate particles become more stresses, then aggregate will have elastic deformation - that's why its delayed) - (Elastic deformation of aggregate particles).

Drying Shrinkage and Creep



(time under drying)

$\varepsilon_{ds} \approx 400$ - 1200×10^{-6} in/in

(depending on aggregate type and cement)

- Factors affecting drying shrinkage:
  - material and mix proportions
  - Aggregate type and content
  - Cement type and content

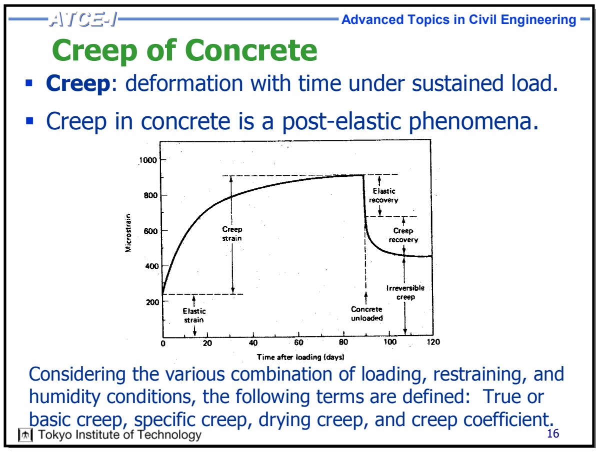
Shrinkage of cement paste

n Related to aggregate *n*≈1.2 to 1.7

$$S_c = \mathrm{f}\left(S_p, V_p, n\right)$$

$$S_c = S_p \underbrace{\left(1-g\right)}_{\text{Volume of cement paste}}^{n}$$

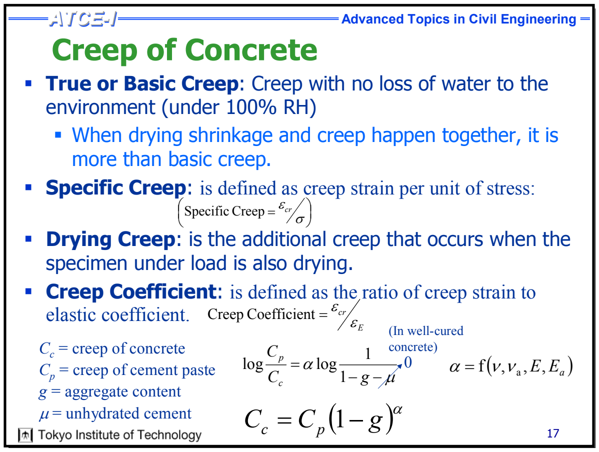
Shrinkage of concrete



Creep of Concrete

- **Creep**: deformation with time under sustained load.
- Creep in concrete is a post-elastic phenomena.

Considering the various combination of loading, restraining, and humidity conditions, the following terms are defined: True or basic creep, specific creep, drying creep, and creep coefficient.



Creep of Concrete

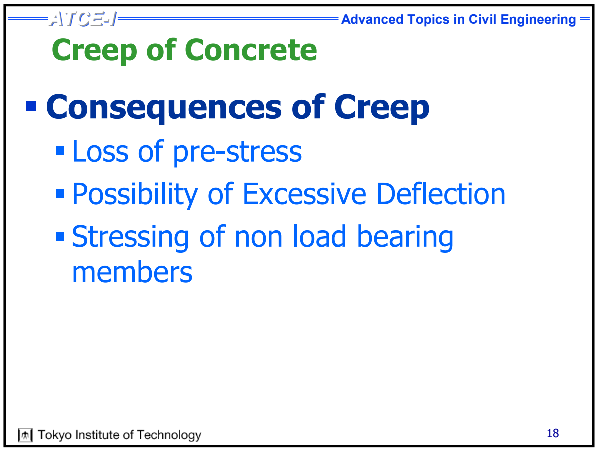
- **True or Basic Creep**: Creep with no loss of water to the environment (under 100% RH)
  - When drying shrinkage and creep happen together, it is more than basic creep.
- **Specific Creep**: is defined as creep strain per unit of stress: $\left(\text{Specific Creep} = \varepsilon_{cr}/\sigma\right)$
- **Drying Creep**: is the additional creep that occurs when the specimen under load is also drying.
- **Creep Coefficient**: is defined as the ratio of creep strain to elastic coefficient. $\text{Creep Coefficient} = \varepsilon_{cr}/\varepsilon_E$

C_c = creep of concrete
C_p = creep of cement paste
g = aggregate content
μ = unhydrated cement

$$\log \frac{C_p}{C_c} = \alpha \log \frac{1}{1 - g - \mu} \qquad \alpha = \mathrm{f}(\nu, \nu_a, E, E_a)$$

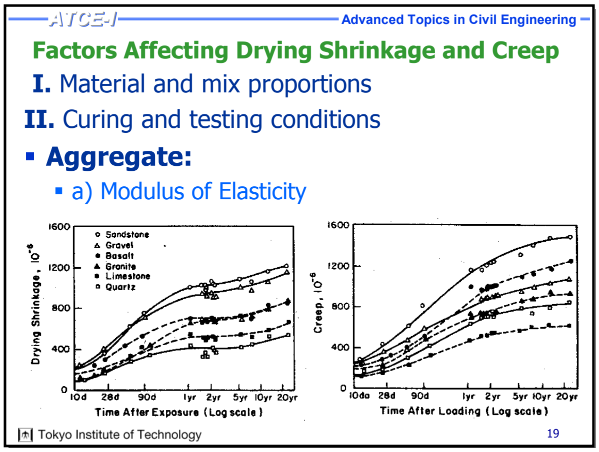
(In well-cured concrete) $\mu \rightarrow 0$

$$C_c = C_p (1 - g)^{\alpha}$$



Creep of Concrete

- **Consequences of Creep**
  - Loss of pre-stress
  - Possibility of Excessive Deflection
  - Stressing of non load bearing members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Factors Affecting Drying Shrinkage and Creep

I. Material and mix proportions

II. Curing and testing conditions

- **Aggregate:**
  - a) Modulus of Elasticity

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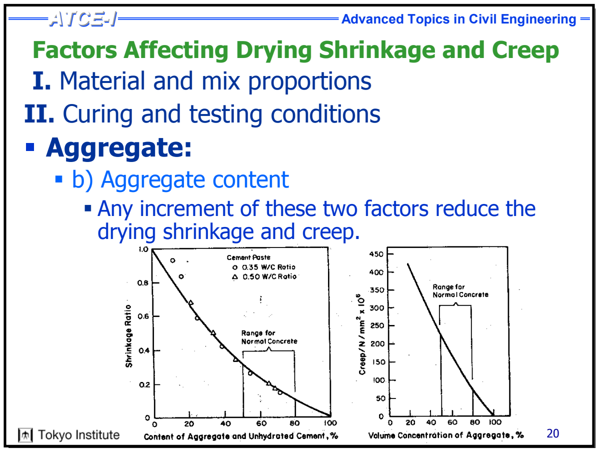
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Factors Affecting Drying Shrinkage and Creep

I. Material and mix proportions

II. Curing and testing conditions

- **Aggregate:**
  - b) Aggregate content
    - Any increment of these two factors reduce the drying shrinkage and creep.

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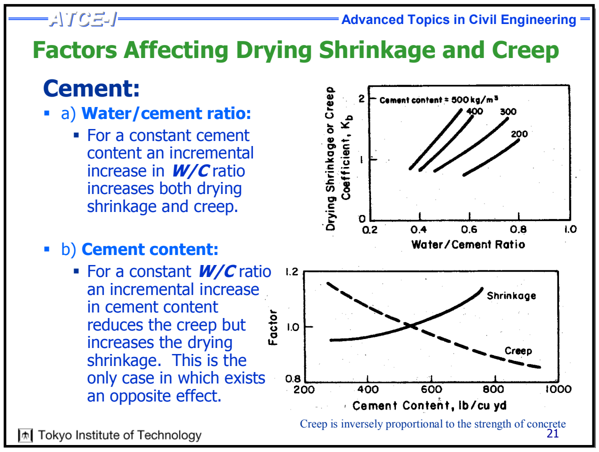
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Factors Affecting Drying Shrinkage and Creep

Cement:

- a) **Water/cement ratio:**
  - For a constant cement content an incremental increase in ***W/C*** ratio increases both drying shrinkage and creep.
- b) **Cement content:**
  - For a constant ***W/C*** ratio an incremental increase in cement content reduces the creep but increases the drying shrinkage. This is the only case in which exists an opposite effect.

Creep is inversely proportional to the strength of concrete

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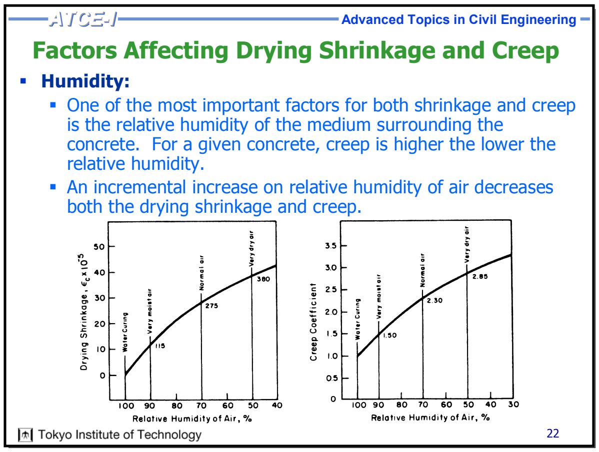

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Factors Affecting Drying Shrinkage and Creep

- **Humidity:**
  - One of the most important factors for both shrinkage and creep is the relative humidity of the medium surrounding the concrete. For a given concrete, creep is higher the lower the relative humidity.
  - An incremental increase on relative humidity of air decreases both the drying shrinkage and creep.

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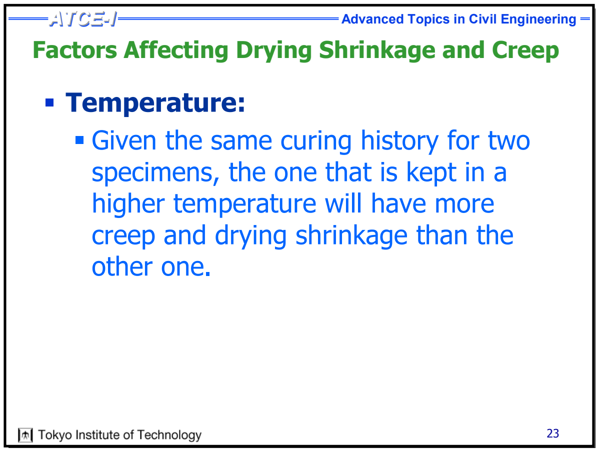

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Factors Affecting Drying Shrinkage and Creep

- **Temperature:**
  - Given the same curing history for two specimens, the one that is kept in a higher temperature will have more creep and drying shrinkage than the other one.

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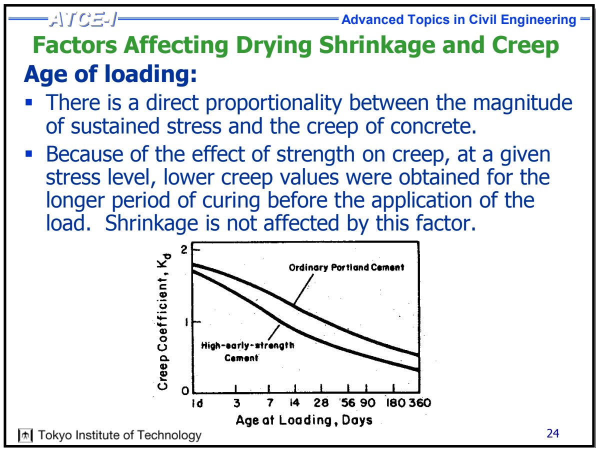

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Factors Affecting Drying Shrinkage and Creep

Age of loading:

- There is a direct proportionality between the magnitude of sustained stress and the creep of concrete.
- Because of the effect of strength on creep, at a given stress level, lower creep values were obtained for the longer period of curing before the application of the load. Shrinkage is not affected by this factor.

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