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# *IMPORTANCE OF MODULUS OF ELASTICITY IN SURFACE REPAIR MATERIALS*

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# *TECHNOTE*

B. Bissonnette, ing., *Ph.D.*, FACI

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Not so fast...

# Cleveland already got Fred G!

# Fred's new life?

# Fred's new life?

# Coming up?

ACI 364.5T-10 TechNote

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# Importance of Modulus of Elasticity in Surface Repair Materials—TechNote

**Keywords: compatibility; cracking; creep; modulus of elasticity; nonstructural repair; strain; stress; structural repair; tensile strain capacity; tension.**

## Question

How important is the modulus of elasticity as a property of surface repair materials?

## Answer

Modulus of elasticity is an important physical property of surface repair materials. For structural repairs, the modulus of elasticity of the repair materials should be similar to that of the substrate concrete, whereas in the case of nonstructural repairs, a lower modulus of elasticity may be beneficial.

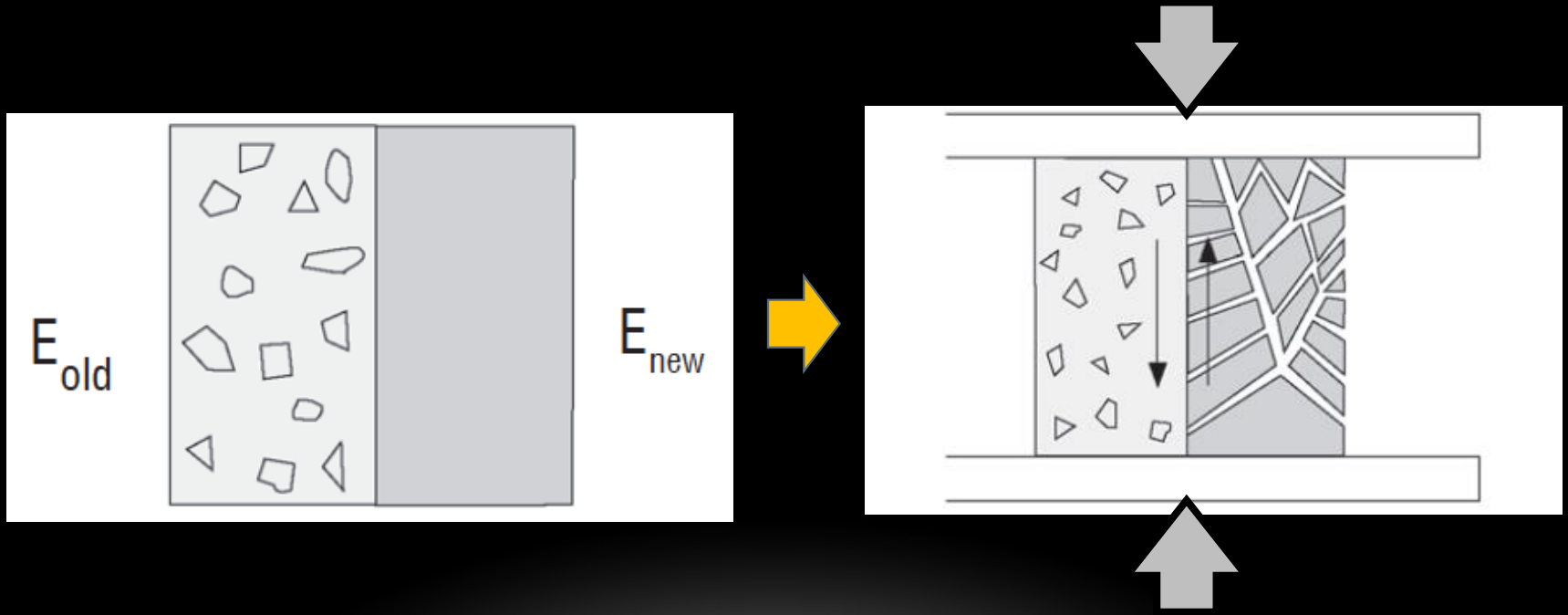
## Discussion

Concrete repairs may be broadly classified as structural (load-carrying) and nonstructural (protective and/or cosmetic). Examples of the latter are repairs in the tensile half of a beam or on the edge of a slab. Load-carrying capacity and stress distribution should be considered in the case of structural repairs where replacement of deteriorated load-bearing concrete is required. The repair materials may be subjected to tension, compression, shear forces, or a combination of these. These forces arise primarily from the superimposed loads, as dead loads will not be shared initially unless the structure is unloaded prior to repair. The repairs may become engaged over time as a result of creep in the substrate concrete, if the member is overloaded, or both. In nonstructural repairs, one of the primary design considerations is the ability of the repair materials to resist cracking for adequate protection and aesthetics. It must be emphasized, however, that a structural repair should also protect the underlying concrete from deterioration and reinforcing steel from corrosion.

The modulus of elasticity is the constant of proportionality between the applied stress and the strain within the linear stress-strain range of the material (refer to Fig. 1). It corresponds to the slope of the straight-line portion of a graph of stress versus strain. The property, also commonly referred to as the elastic modulus or Young's modulus, is a measure of the stiffness of a material (Beer et al. 2014; Mehta and Monteiro 2014). A material with a higher modulus of elasticity is less flexible than a material with a lower modulus of elasticity. The term "elasticity" refers to the reversible character of the dimensional change (as a spring would recover if compressed or stretched). The modulus of elasticity of repair materials is typically measured using ASTM C469/C469M or ASTM C580 test methods. Additional information regarding the modulus of elasticity testing and its significance is included in ACI 546.3R.

# Question

- *How important is the modulus of elasticity as a property of surface repair materials?*



# Discussion

# Type of repairs and loading considerations

- Concrete repairs may be broadly classified as:
  - non-structural (protective and/or cosmetic)
  - structural (load-carrying)


# Type of repairs and loading considerations

- Replacement of deteriorated load-bearing concrete
  - Load-carrying capacity
  - Stress distribution

(tcsdivisions.com)

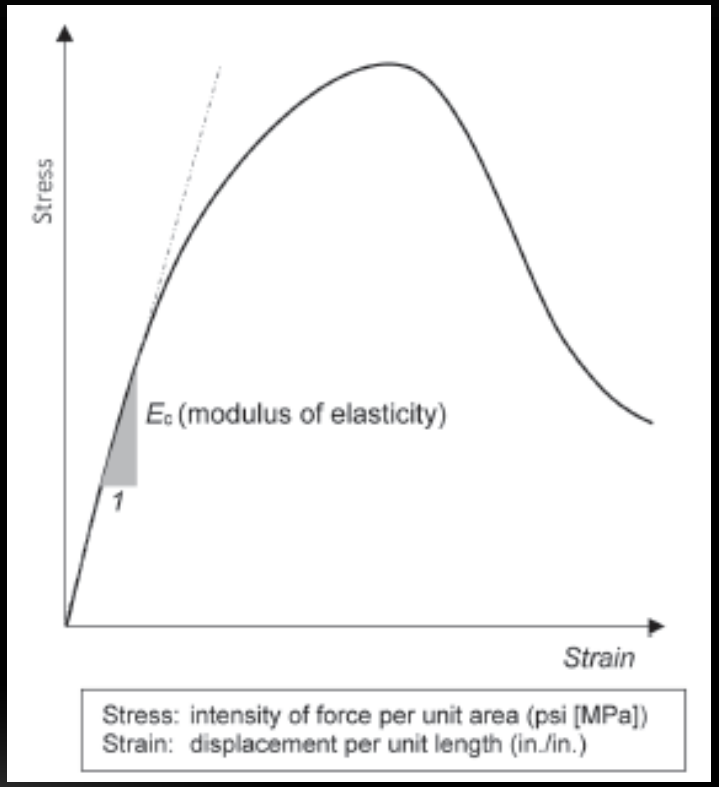
# Loading in structural repairs

- The repair material may be subjected to various types of loading
  - Tension
  - Compression
  - Shear
- Irrespective of the repair material's modulus, permanent loads will not be shared unless the existing member is unloaded prior to repair
  - Different approaches may be required for the design and analysis of such repairs
  - A structural repair must still protect the underlying concrete and reinforcing steel from deterioration and corrosion

# Elastic modulus of concrete

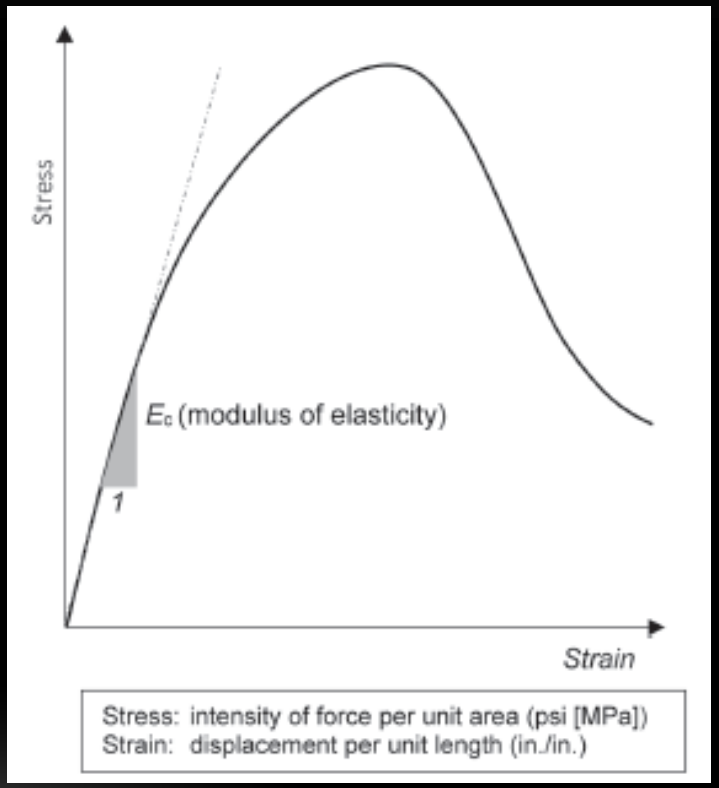
- Evaluation of the material's stiffness (ASTM C469 / ASTM C580)


(Dinehart, 2016)



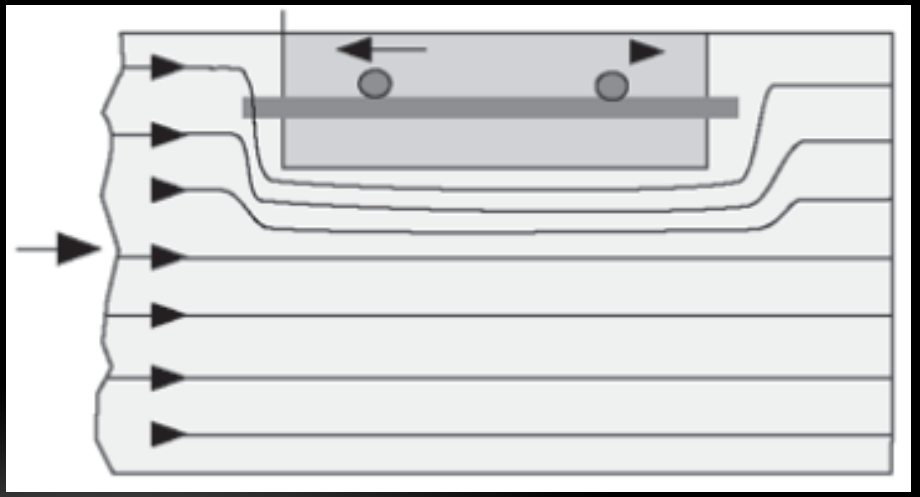
# Elastic modulus of concrete

- Typical repair materials
  - OPC: 25-35 GPa
  - Proprietary repair materials: 18-35 GPa (wide range)



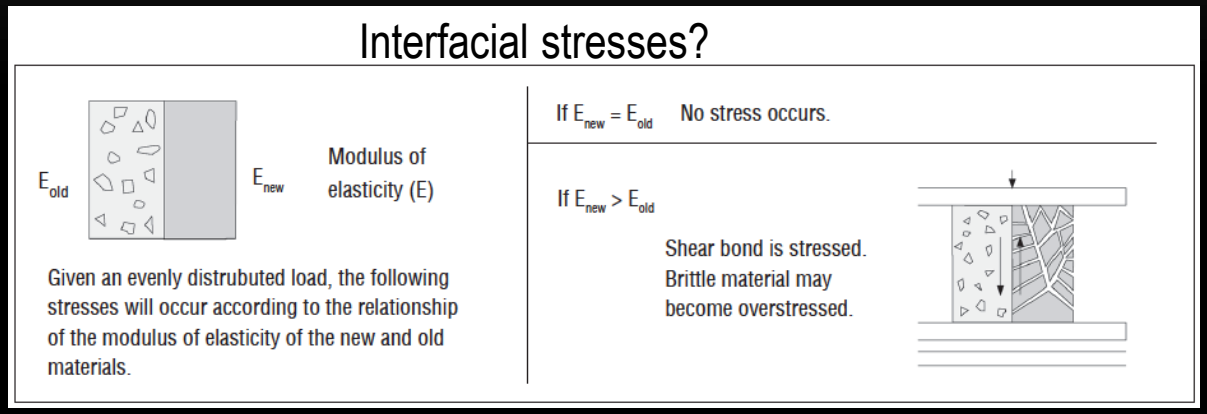
# Mechanical compatibility *vs.* load distribution

- Requirement in a structural repair: load sharing
  - A repair with an elastic modulus lower that that of the existing concrete will not carry as much load as intended
  - A repair with an elastic modulus higher that that of the existing concrete will carry more load

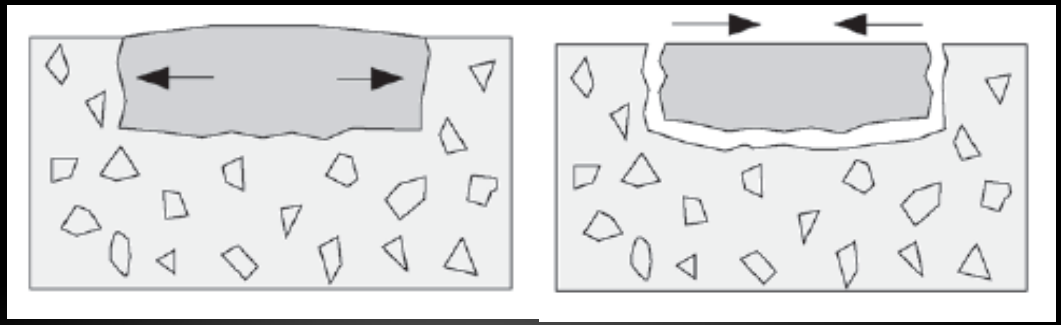


# Mechanical compatibility *vs.* load distribution

- Gravity loads (LL)

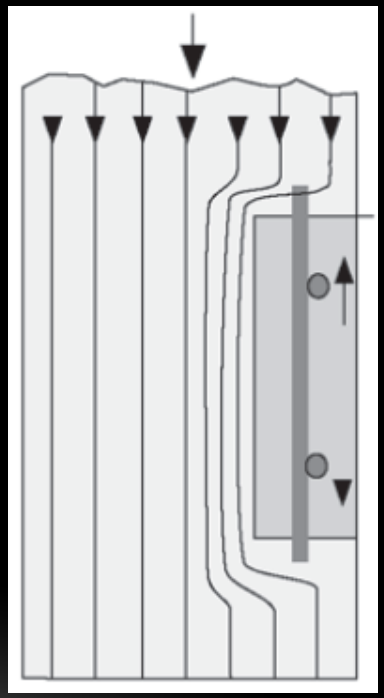



- Thermal and shrinkage-induced stresses



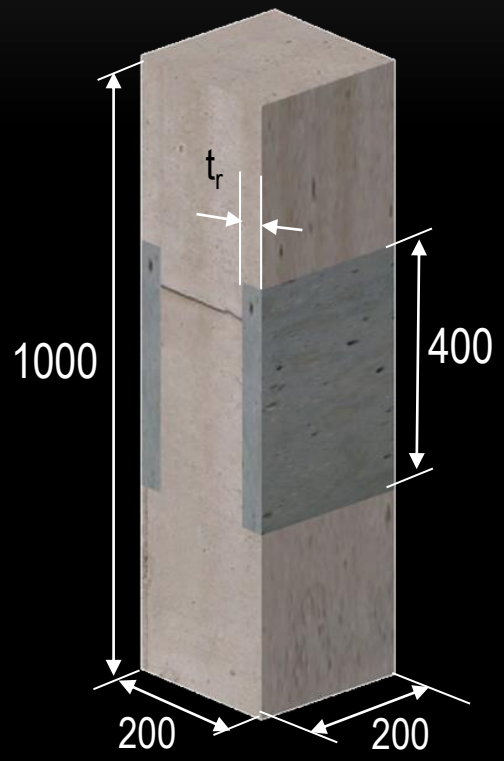
# Mechanical compatibility *vs.* load distribution

- Significant difference in stiffness may lead to distress under externally applied loads, depending on the induced stress field with respect to the structure layout
  - The stiffer material draws more stresses



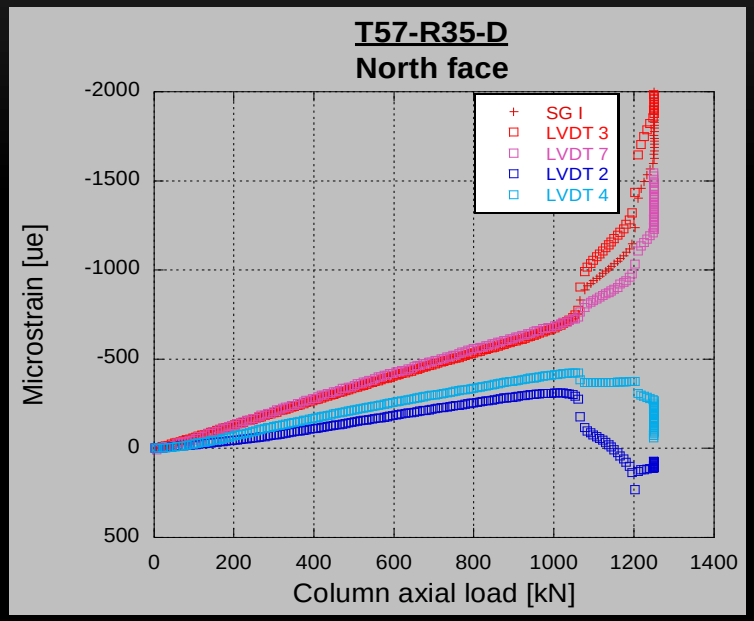
$E_{repair} < E_{substrate}$

# Mechanical compatibility *vs.* load distribution




(Thomassin, 2010)

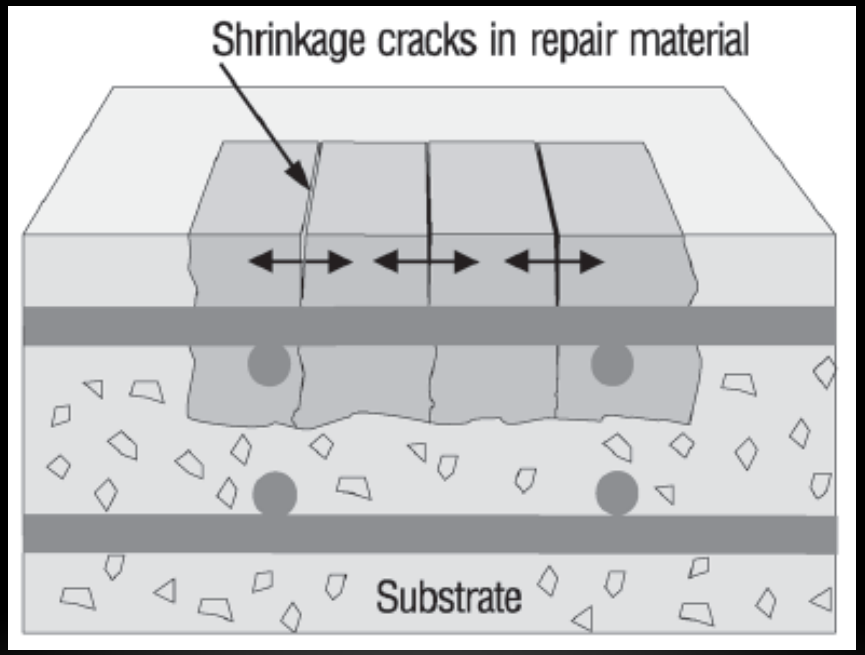
# Mechanical compatibility *vs.* load distribution




(Thomassin, 2010)

# Dimensional compatibility *vs.* cracking

- For increased resistance to cracking, the materials selected for protective repairs should be more *extensible* to accommodate temperature and shrinkage strains



# Dimensional compatibility *vs.* cracking

- Notion of *extensibility* ?
  - Tensile strain capacity = elastic strain ($\varepsilon_{elastic}$) + creep strain ($\varepsilon_{creep}$)

- Dimensional compatibility requires a balance between mechanical and environmentally induced strains:

$$\alpha_r \left( \varepsilon_{shrinkage} + \varepsilon_{thermal} \right) \leq \left( \varepsilon_{elastic} + \varepsilon_{creep} \right)$$

where $\alpha_r$ is the degree of restriction

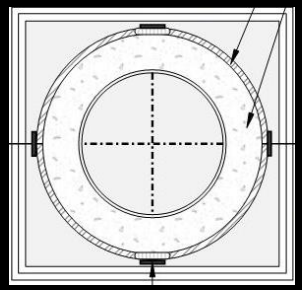
# Dimensional compatibility *vs.* cracking

- Achieving dimensional compatibility of the repair material to prevent cracking
  - Low shrinkage
  - Low elastic modulus
  - High creep

- Example of performance criteria for repair materials (REMR Experimental program, USACoE 1999)
  - $\varepsilon_{sh\ 7\text{-}d} \leq 400$ µstrains
  - $f_{t\ 28\text{-}d} \geq 2{,}8$ MPa
  - $E_{t\ 28\text{-}d} \leq 24$ GPa

# Dimensional compatibility *vs.* cracking

- Design or selection of the material for protective repair
  - Some mix design variables have similar effects on shrinkage and *extensibility*
    - w/cm
    - $E_{agg}$
    - etc.
  - At least one exception: increasing the **aggregate volume fraction** in the repair material generally reduces shrinkage, while increasing the material's *extensibility*
    - Overall net gain
    - Reduced shrinkage cracking sensitivity



# Summary

- Surface repairs must be mechanically and dimensionally compatible with the existing concrete substrate
  - to achieve load-sharing (as required)
  - to minimize cracking
  - to ensure that the repair and existing structure act monolithically
- To achieve repairs that comply with these requirements, the magnitude of the repair material modulus of elasticity with respect to that of the substrate needs to be taken into account in the design process

# Answer

- The modulus of elasticity is a very important property
  - For structural repairs, the elastic modulus should be close to that of the substrate concrete
  - In the case of non-structural (protective) repairs, a lower elastic modulus is generally desirable

# Useful references

- *American Concrete Institute*
  - 546.3R Guide for the Selection of Materials for the Repair of Concrete
  - ACI 364 FAQ's (2004) Concrete International, V. 26, No. 12, pp. 90-92.
- *ASTM International*
  - C469 Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression
  - C580 Standard Test Method for Flexural Strength and Modulus of Elasticity of Chemical-Resistant Mortars, Grouts, Monolithic Surfacings, and Polymer Concretes

# Thanks Fred, all the best in your new life!

# THANKS FOR YOUR ATTENTION!