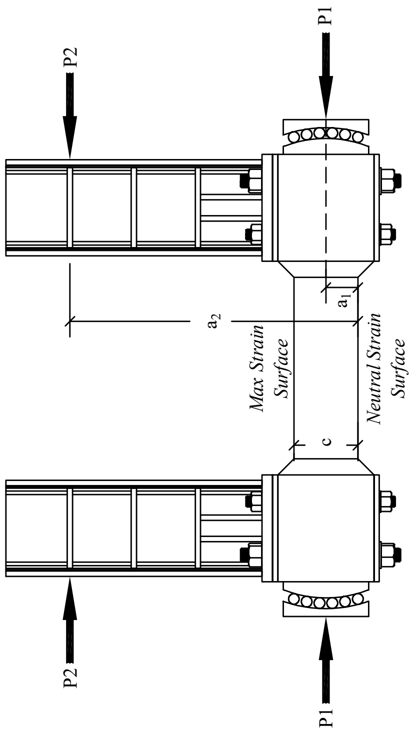
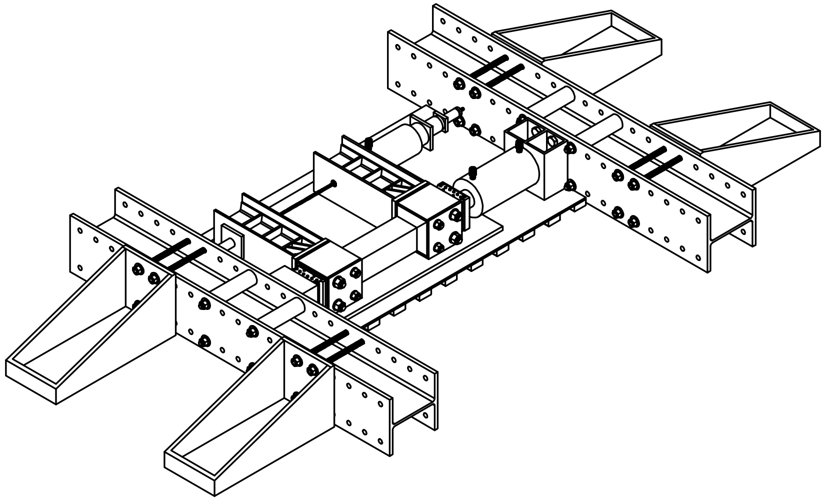


Stress-Strain Analysis of Belite Calcium Sulfoaluminate Cement Concrete for Structural Applications



Gabriel Johnson, PhD Student
Elizabeth Poblete, PhD Candidate
Dr. Cameron Murray, Project Advisor

ACI New Orleans Open Topic Session
Part 1 of 2
Tuesday, March 26, 2024

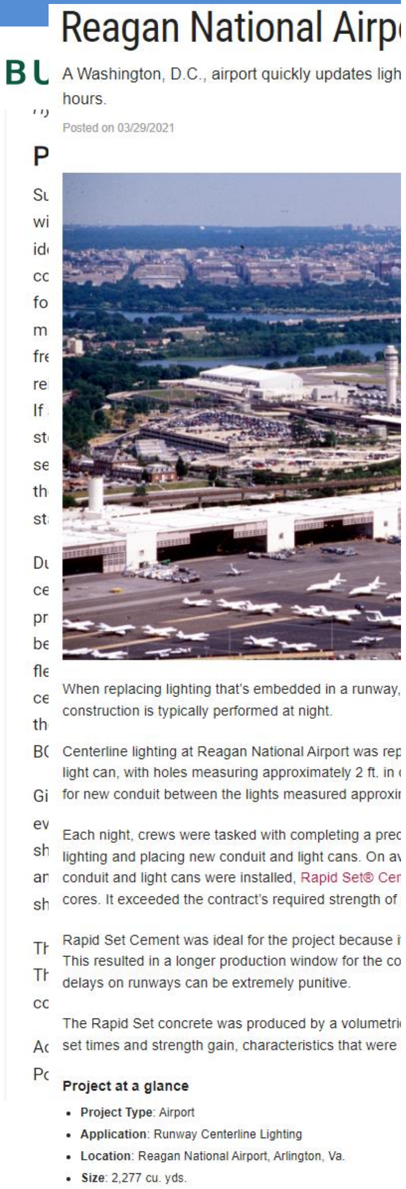
University of Arkansas | College of Engineering, Civil Engineering

aci Foundation — Building the Future

THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

aci CONCRETE CONVENTION

# of BCSA Concrete


Reagan National Airp

A Washington, D.C., airport quickly updates ligh
hours.

Posted on 03/29/2021

When replacing lighting that's embedded in a runway,
construction is typically performed at night.

Centerline lighting at Reagan National Airport was rep
light can, with holes measuring approximately 2 ft. in
for new conduit between the lights measured approxi

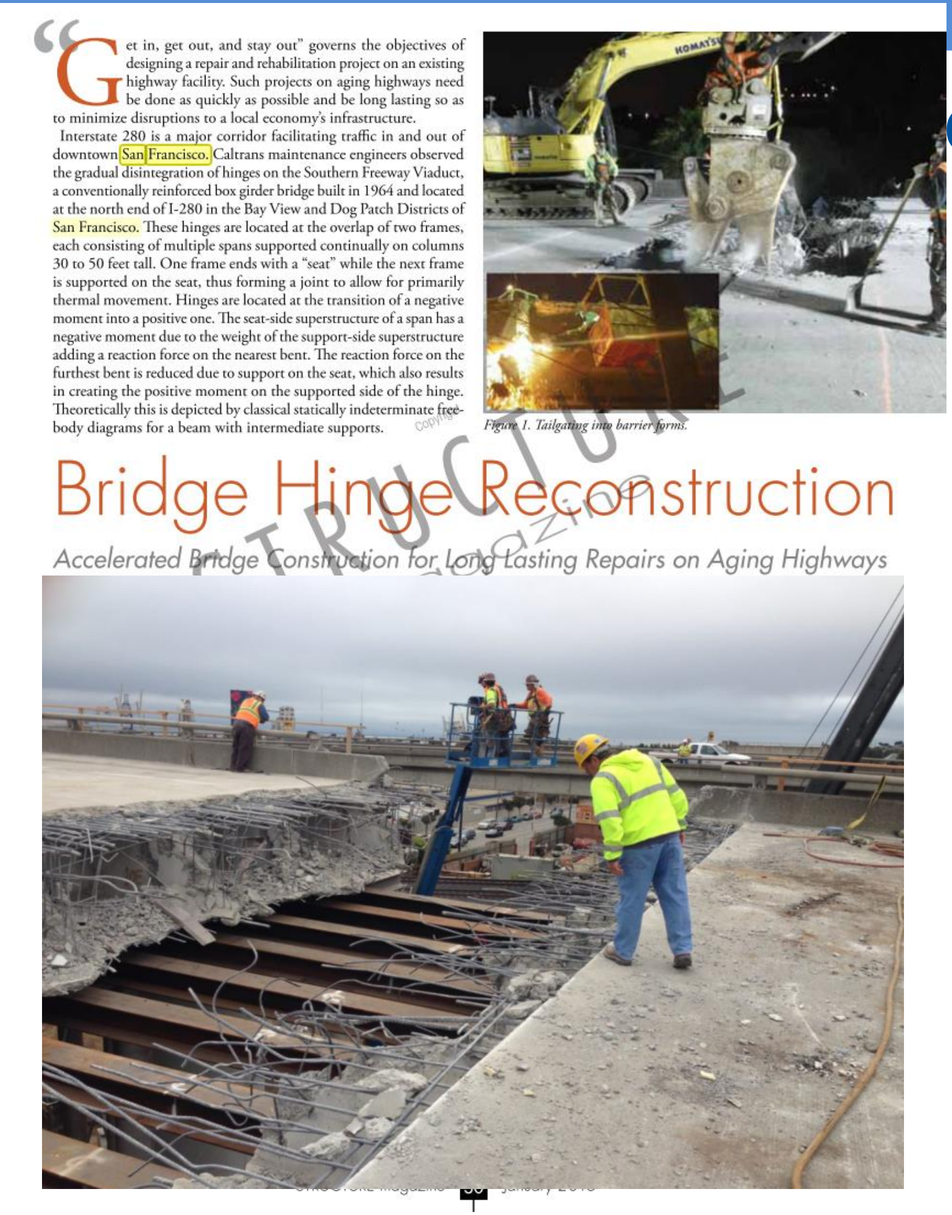
Each night, crews were tasked with completing a prec
lighting and placing new conduit and light cans. On av
conduit and light cans were installed, Rapid Set® Cer
cores. It exceeded the contract's required strength of

Rapid Set Cement was ideal for the project because i
This resulted in a longer production window for the co
delays on runways can be extremely punitive.

The Rapid Set concrete was produced by a volumetri
set times and strength gain, characteristics that were

Project at a glance

- **Project Type**: Airport
- **Application**: Runway Centerline Lighting
- **Location**: Reagan National Airport, Arlington, Va.
- **Size**: 2,277 cu. yds.


"Get in, get out, and stay out" governs the objectives of designing a repair and rehabilitation project on an existing highway facility. Such projects on aging highways need be done as quickly as possible and be long lasting so as to minimize disruptions to a local economy's infrastructure.

Interstate 280 is a major corridor facilitating traffic in and out of downtown San Francisco. Caltrans maintenance engineers observed the gradual disintegration of hinges on the Southern Freeway Viaduct, a conventionally reinforced box girder bridge built in 1964 and located at the north end of I-280 in the Bay View and Dog Patch Districts of San Francisco. These hinges are located at the overlap of two frames, each consisting of multiple spans supported continually on columns 30 to 50 feet tall. One frame ends with a "seat" while the next frame is supported on the seat, thus forming a joint to allow for primarily thermal movement. Hinges are located at the transition of a negative moment into a positive one. The seat-side superstructure of a span has a negative moment due to the weight of the support-side superstructure adding a reaction force on the nearest bent. The reaction force on the furthest bent is reduced due to support on the seat, which also results in creating the positive moment on the supported side of the hinge. Theoretically this is depicted by classical statically indeterminate free-body diagrams for a beam with intermediate supports.

Figure 1. Tailgating into barrier forms.

Bridge Hinge Reconstruction

Accelerated Bridge Construction for Long Lasting Repairs on Aging Highways

Why BCSA

- High early strength
- Lower setting times
- 30% lower carbon emissions compared with portland cement [4-7]
- Lower drying shrinkage [6]
- Higher sulfate resistance [8]

Stress-Strain Analysis of BCSA Concrete

- ACI 318-19 allows use of alternative cements (26.4.1.1).
- Do these materials conform to code provisions?
- Major consideration is flexural behavior.

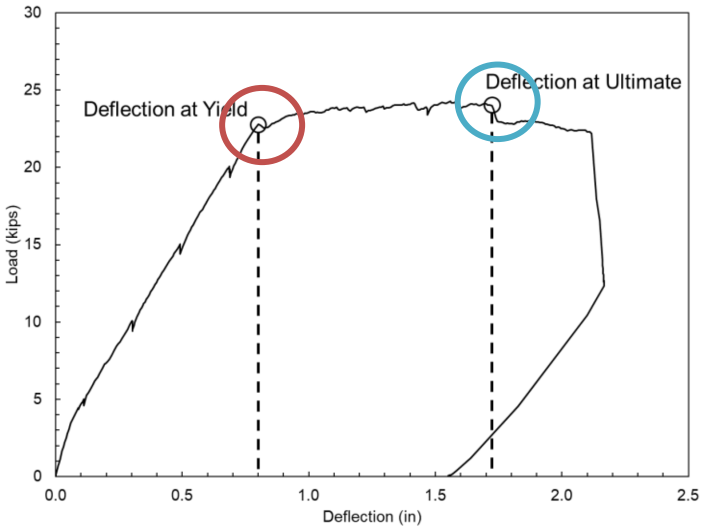
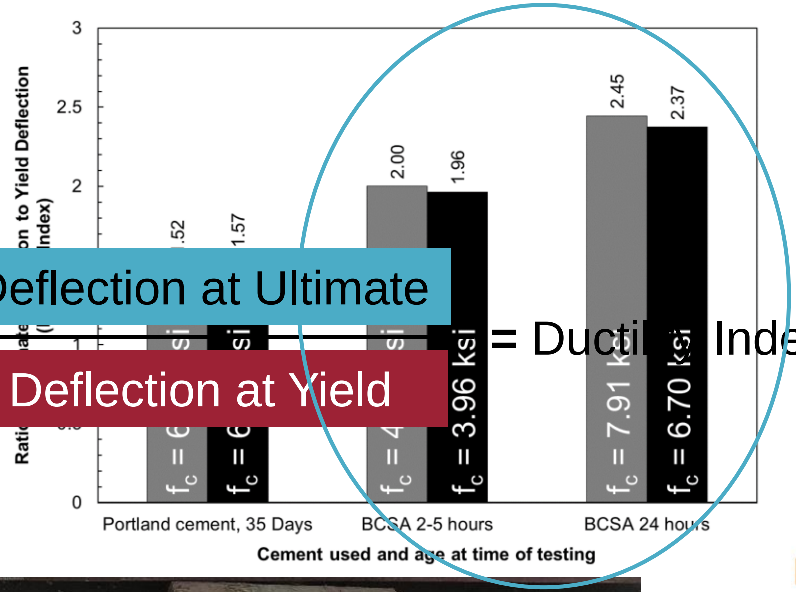


Fig. 3. Beam Load-Strain

Fig. 2. Flexural beam test



$$\frac{\text{Deflection at Ultimate}}{\text{Deflection at Yield}} = \text{Ductility Index}$$

Fig. 4. Beam Ductility

Stress-Strain Analysis of BCSA Concrete

Flexural compression specimen test

- Strength design strain, stress, and force at failure at section AA

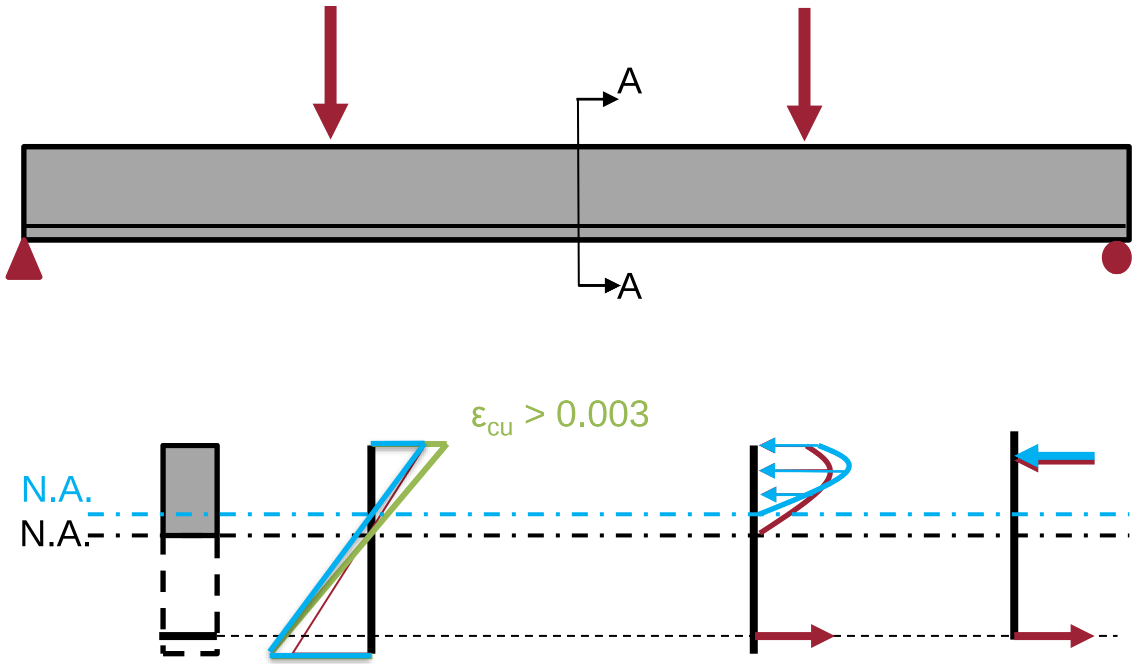


Fig. 5. Strain and stress distribution in reinforced concrete members

Stress-Strain Analysis of BCSA Concrete

Flexural compression specimen test

- Strength design strain, stress, and force at failure at section AA

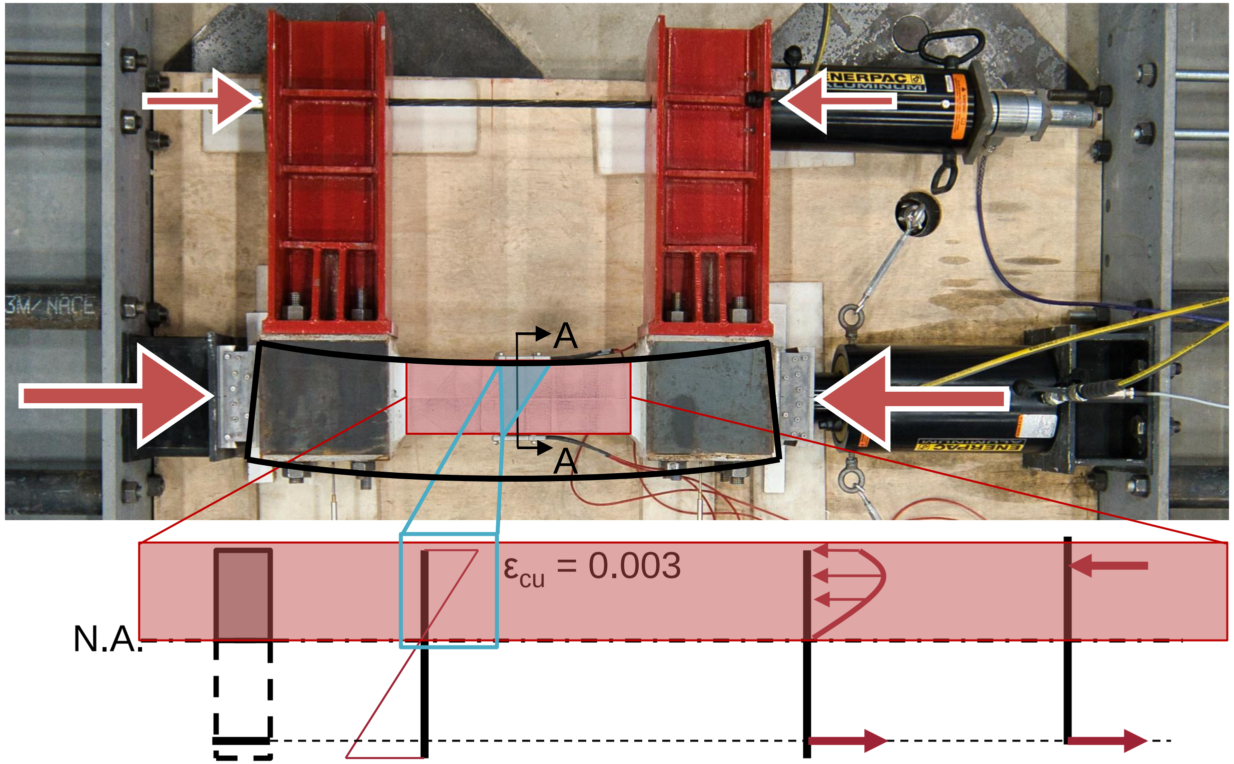


Fig. 6. Strain and stress distribution in specimen

Stress-Strain Analysis of BCSA Concrete

Strain Distribution and load Balancing

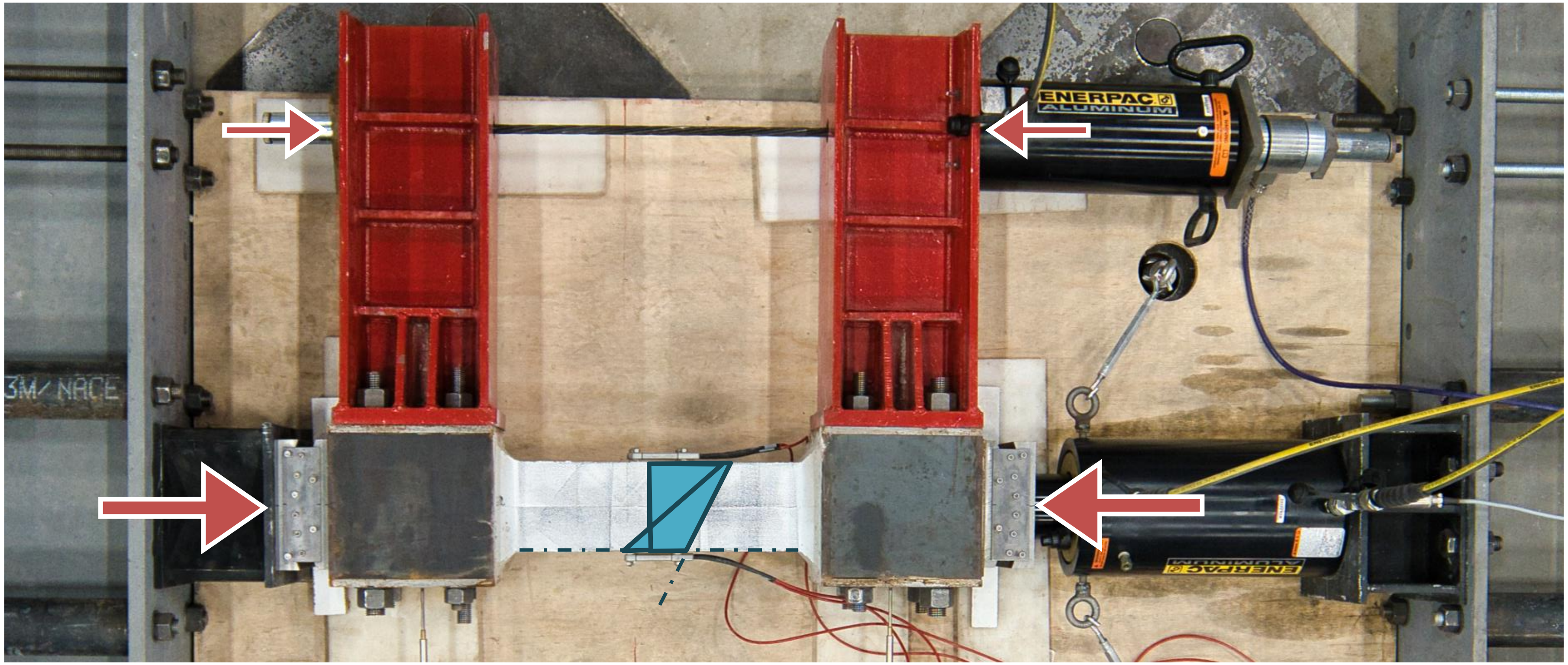


Fig. 7. Load Balancing

Stress-Strain Analysis of BCSA Concrete

DIC strain cameras being used in lieu of strain gauges on top of specimen.

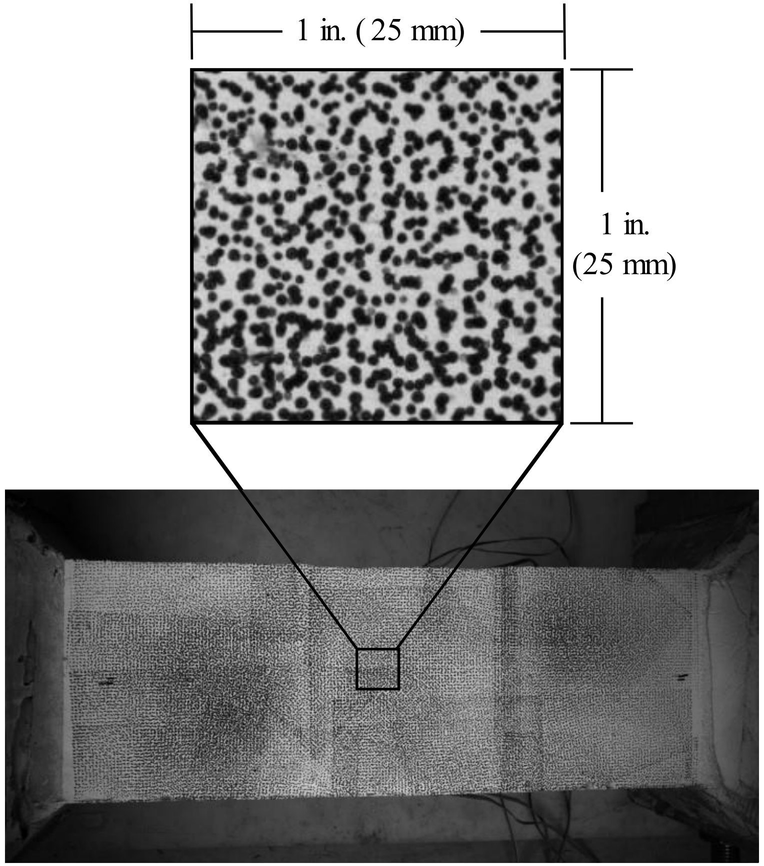


Fig. 9. Speckle pattern and density for flexural compression specimen.

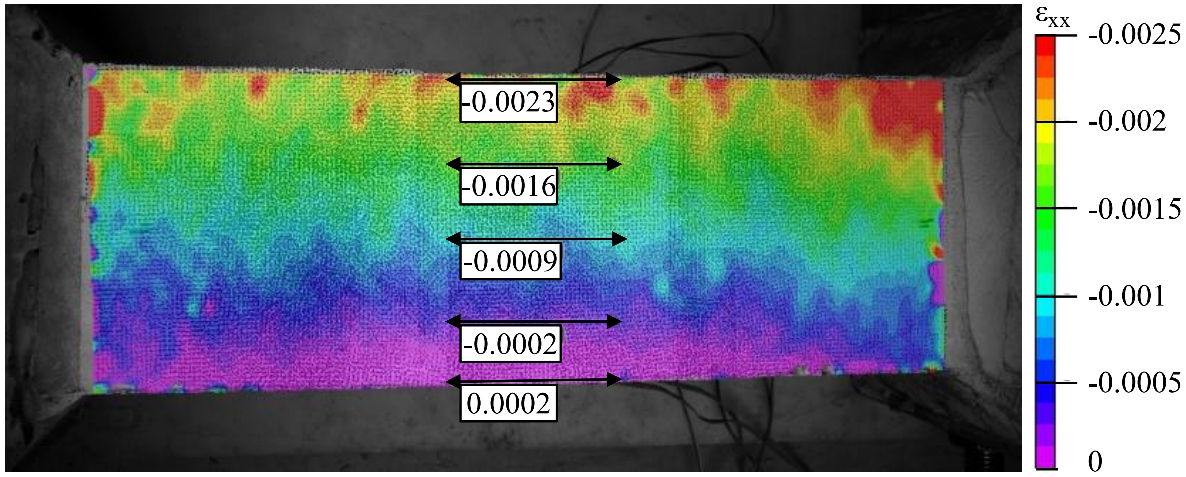


Fig. 10. DIC virtual strain measurement on top face.

Stress-Strain Analysis of BCSA Concrete

Linear strain distribution throughout testing

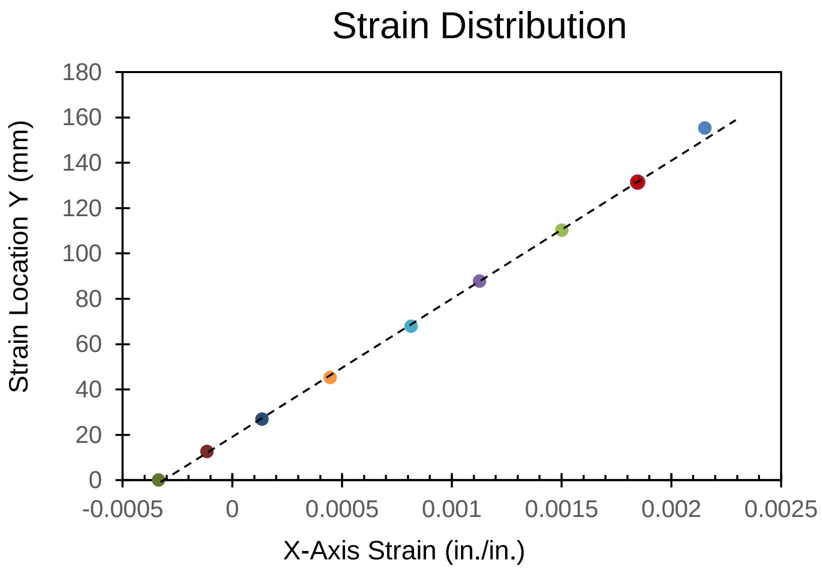


Fig. 11. Strain distribution 2 seconds prior to failure

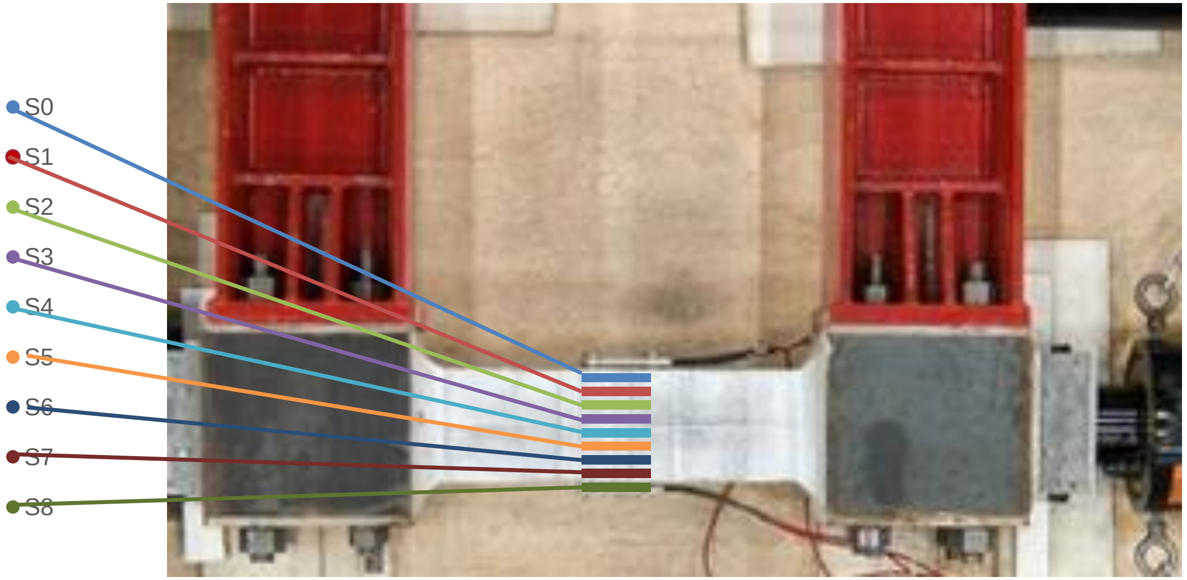


Fig. 12. Virtual strain gauge locations

Stress-Strain Analysis of BCSA Concrete

Fig. 13. Plan View Video

Stress-Strain Analysis of BCSA Concrete

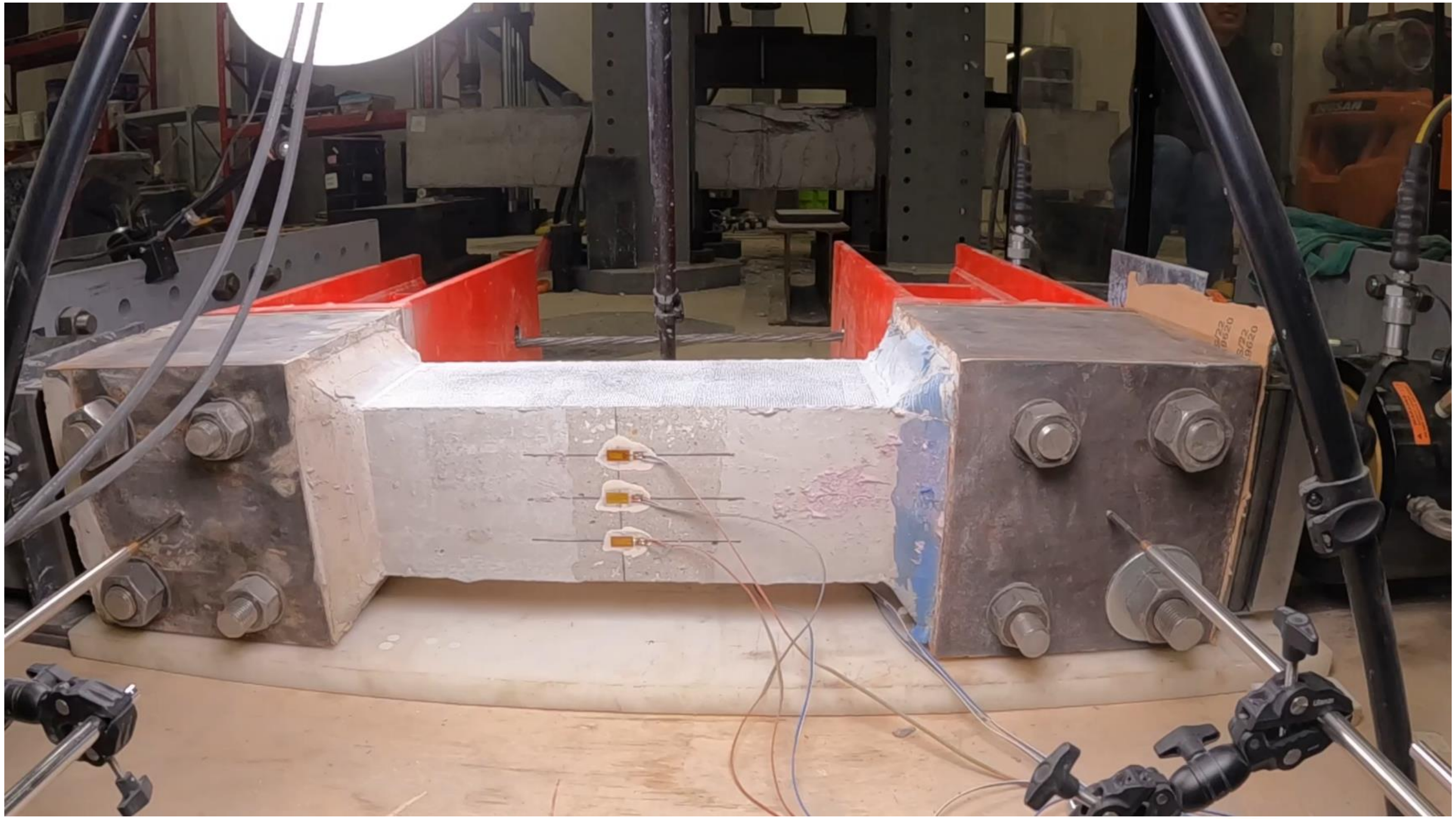
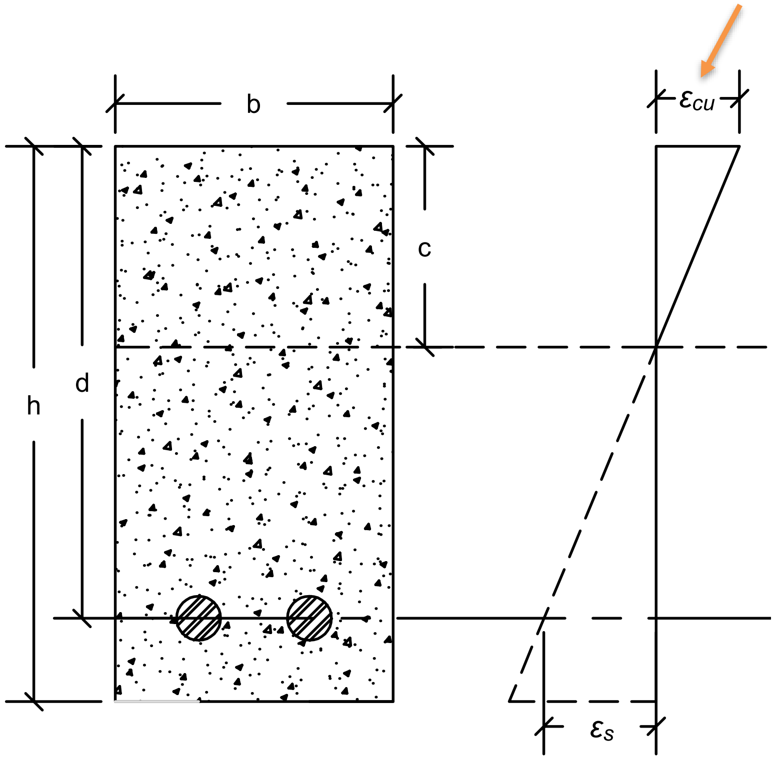


Fig. 14. Neutral Strain Face Video

Stress-Strain Analysis of BCSA Concrete

Design parameter results: ε_{cu}



Reinforced Concrete Beam Section

Strain Distribution

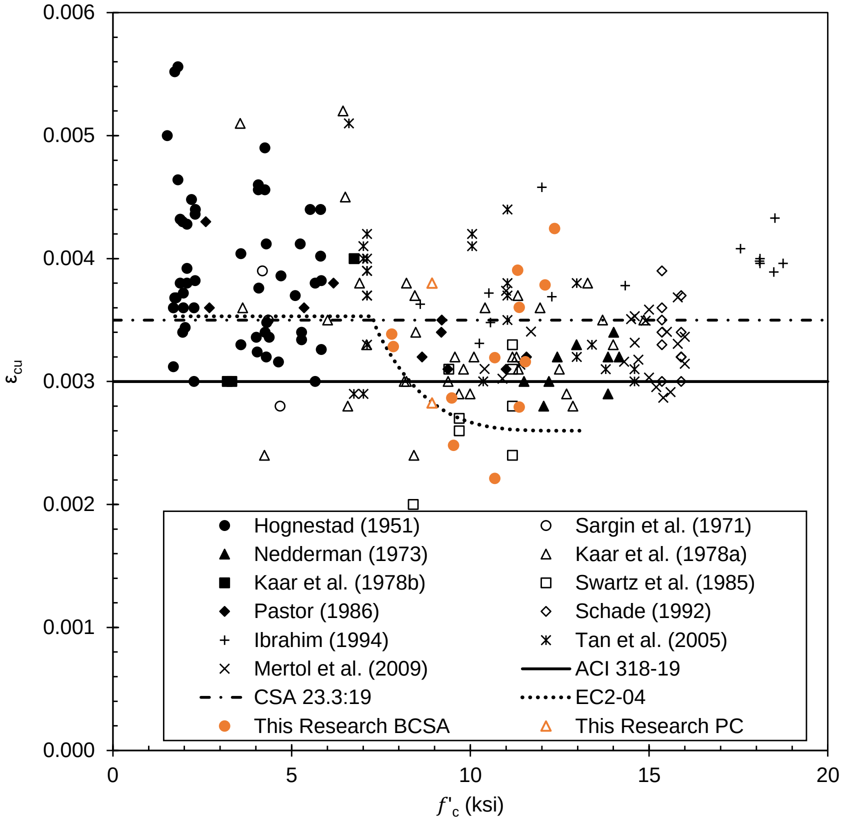
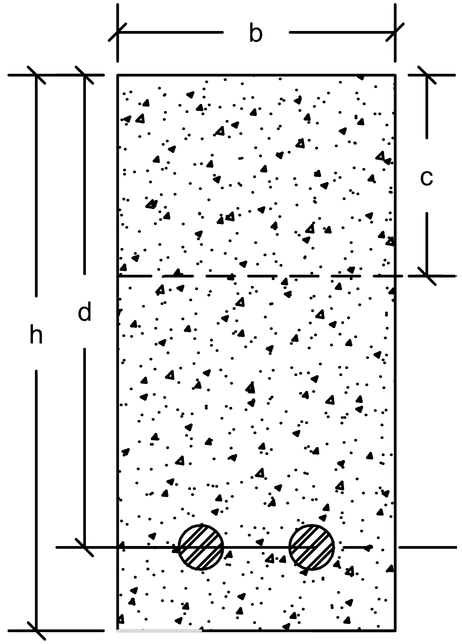


Fig. 15. Design parameter results: εcu

Stress-Strain Analysis of BCSA Concrete

Design parameter results: α_1



Reinforced Concrete
Beam Section

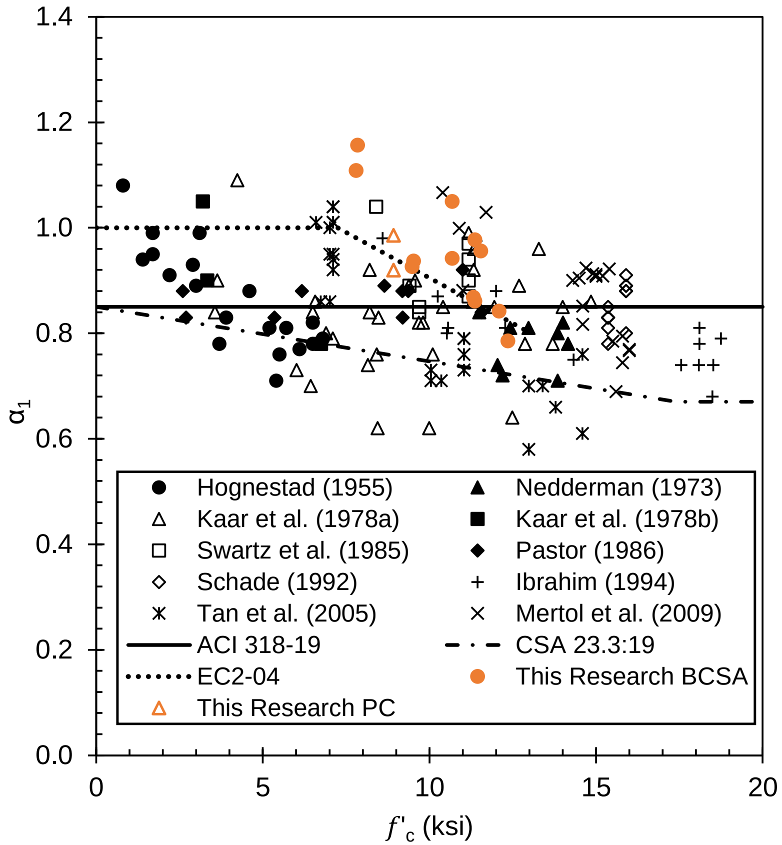
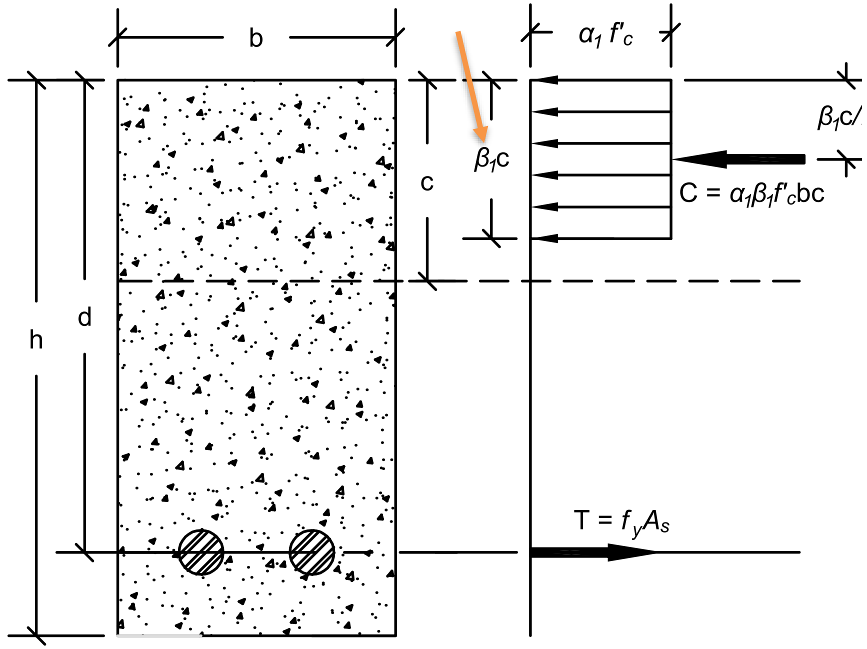


Fig. 16. Design parameter results: α_1

Stress-Strain Analysis of BCSA Concrete

Design parameter results: β_1



Reinforced Concrete
Beam Section

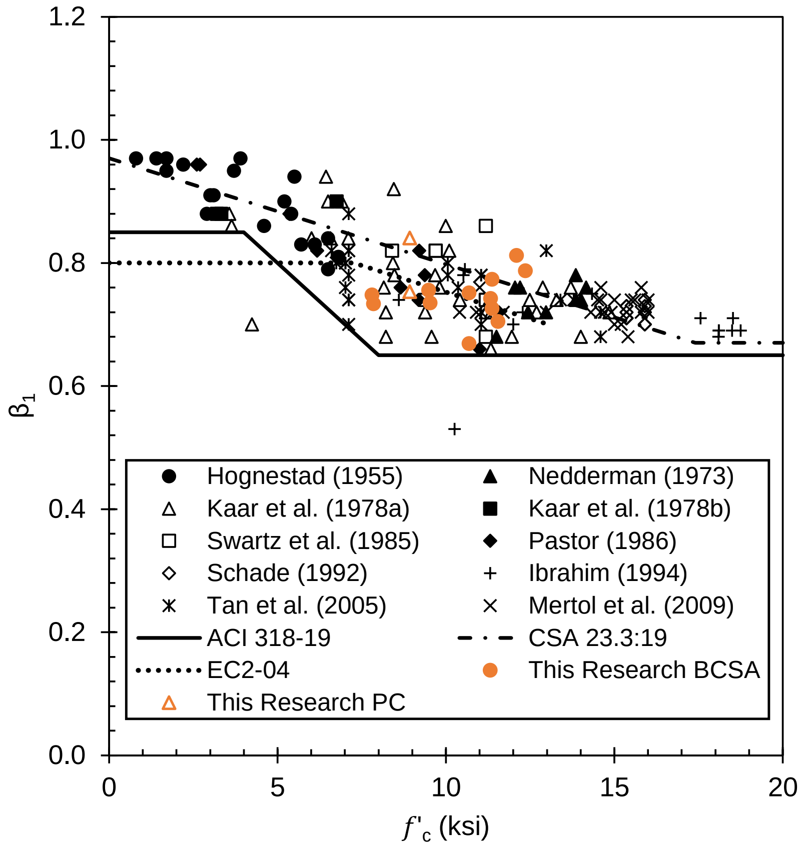


Fig. 17. Design parameter results: β_1

Stress-Strain Analysis of BCSA Concrete

Results: Stress-strain relationship

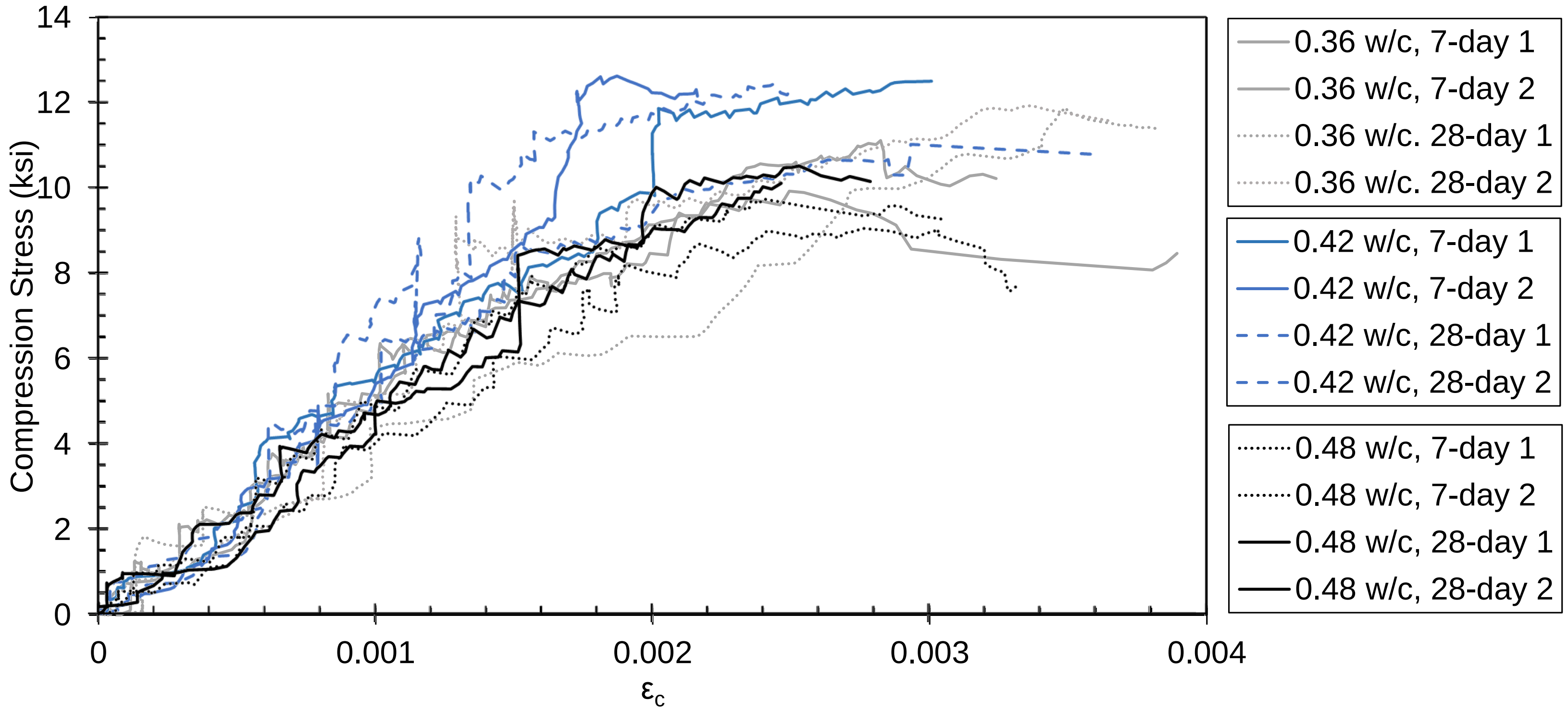


Fig. 18. Stress-strain results

Stress-Strain Analysis of BCSA Concrete

Digital image correlation (DIC) background

- Uses two cameras to calculate relative and absolute movements of dots painted on the surface of specimen to calculate deflection and strain between pictures.
- Advantage: reusable way to measure strain until specimen failure.

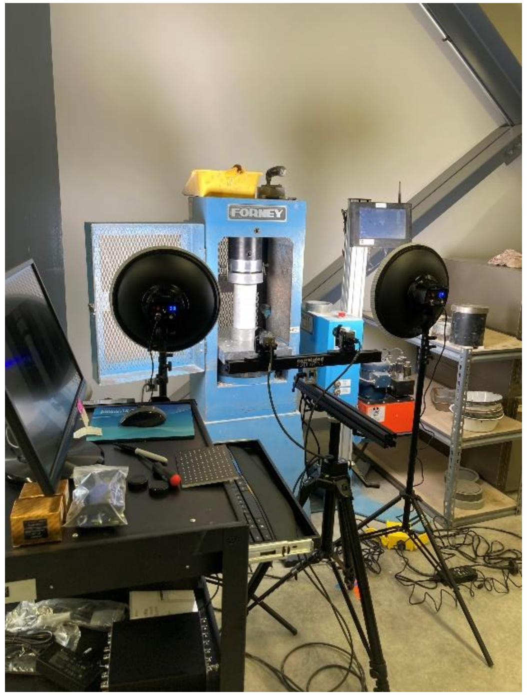


Fig. 19. DIC axial strain setup

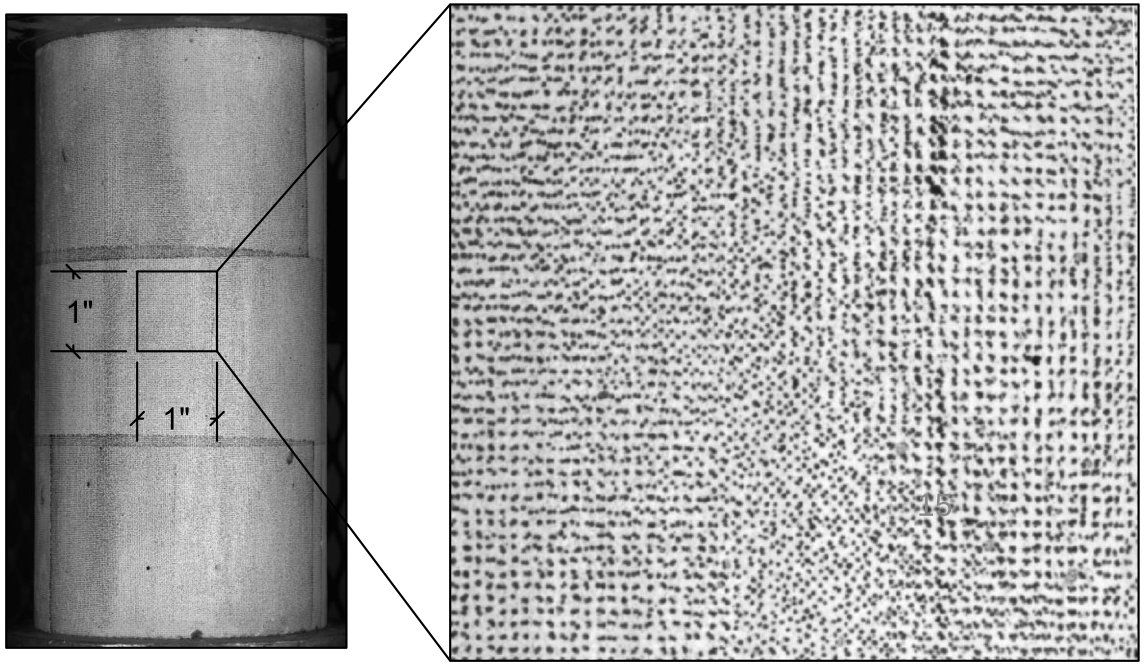


Fig. 20. DIC Speckle Pattern

Stress-Strain Analysis of BCSA Concrete

Uniaxial compression strain results

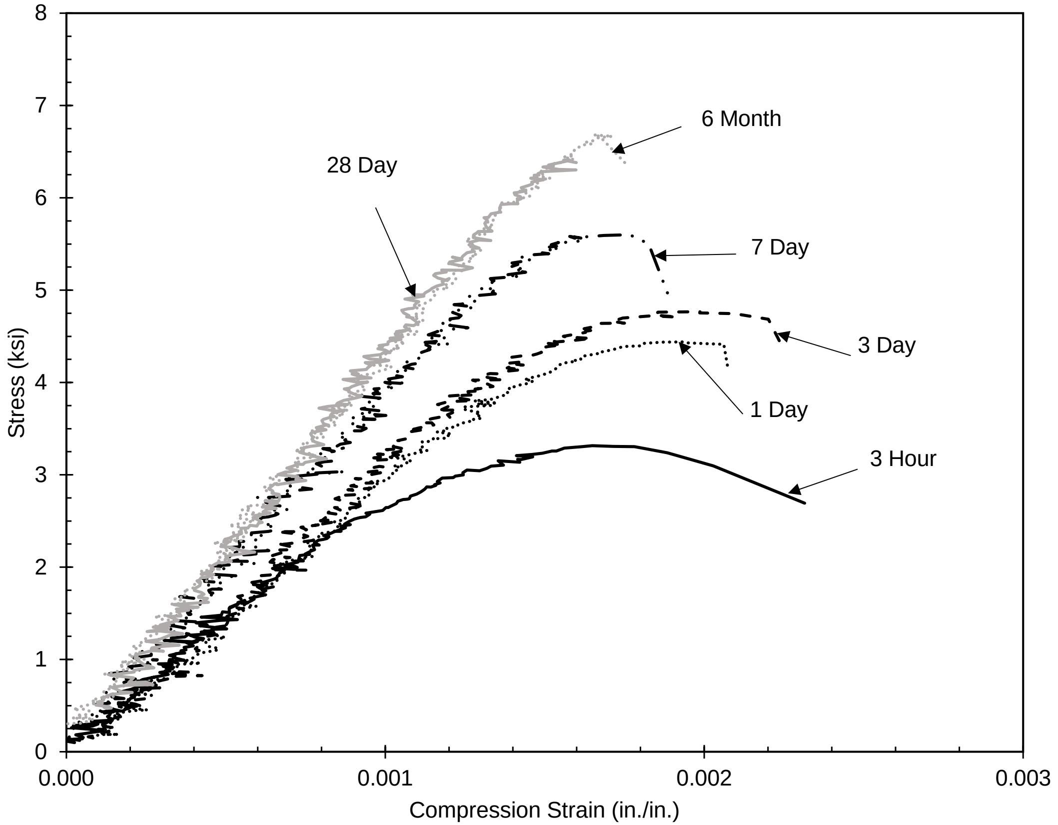


Fig. 21. 0.48 w/c uniaxial stress-strain

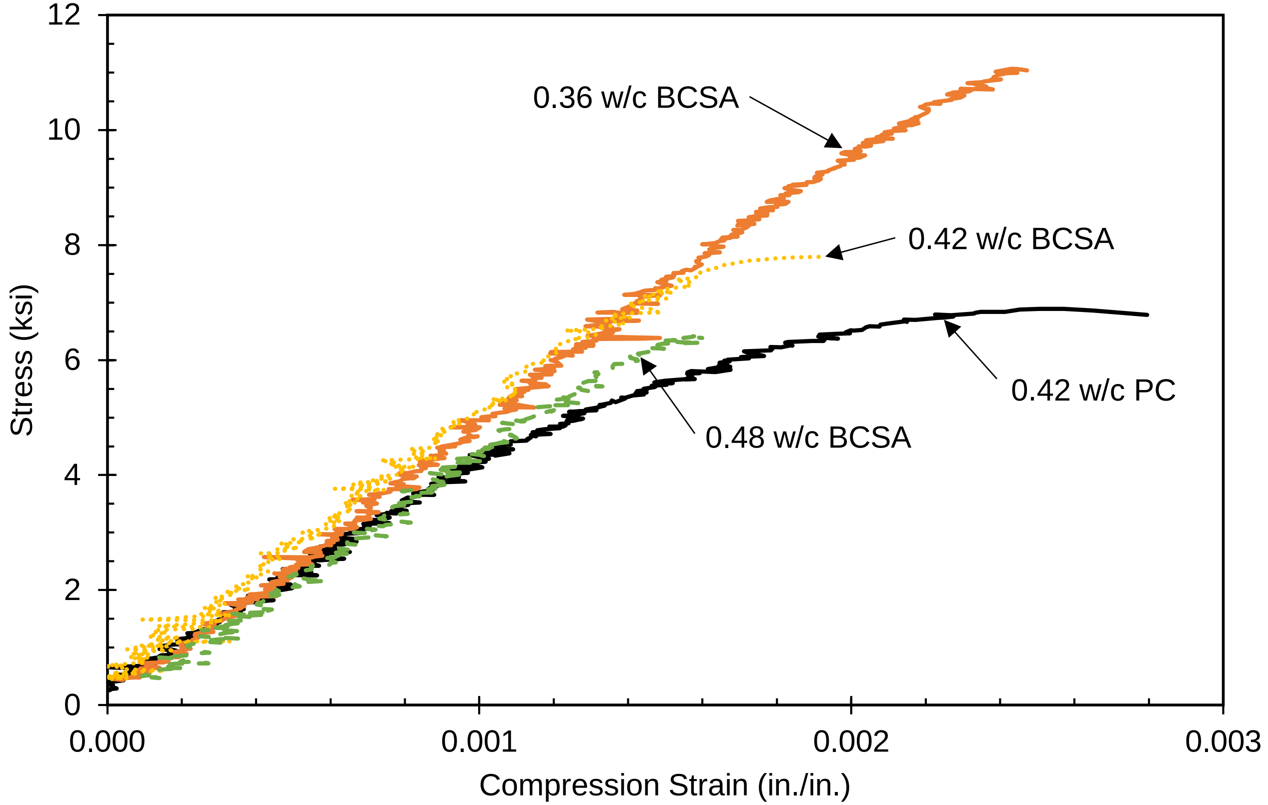


Fig. 22. All w/c at 28 days

Stress-Strain Analysis of BCSA Concrete

Uniaxial compression strain results: MOE & Uniaxial Strain

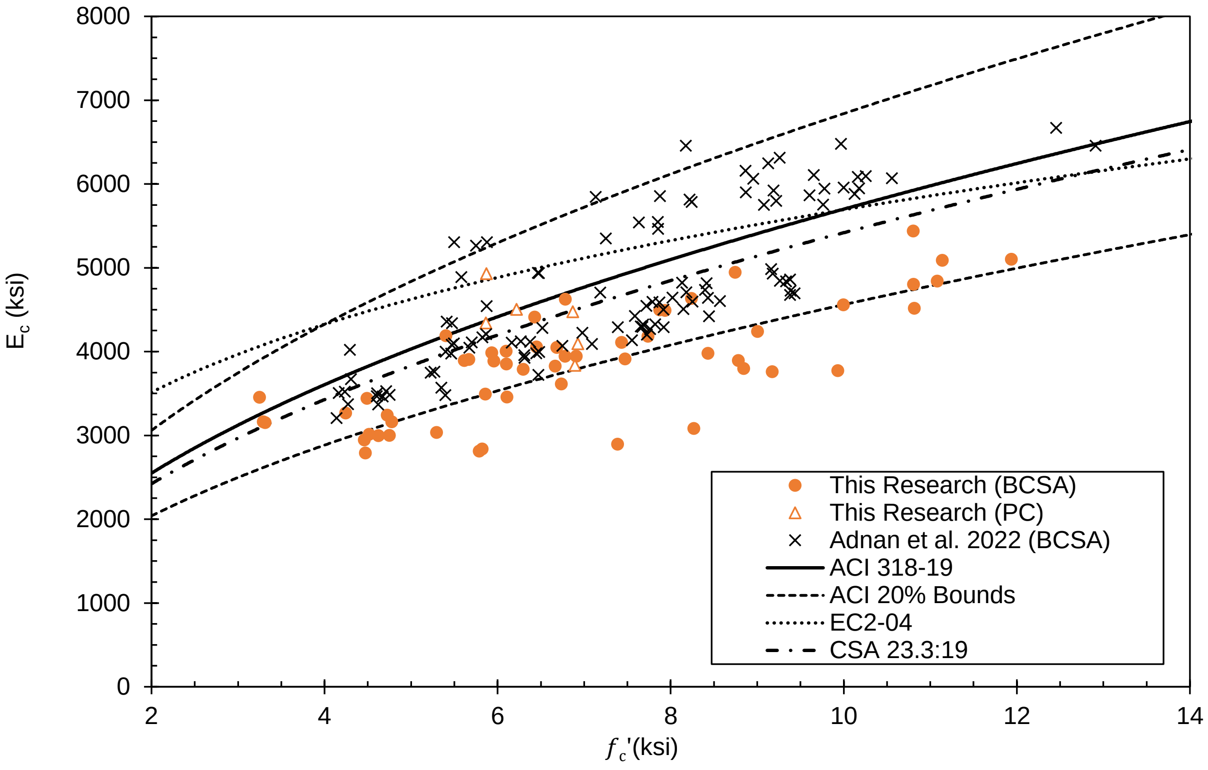


Fig. 23. MOE BCSA

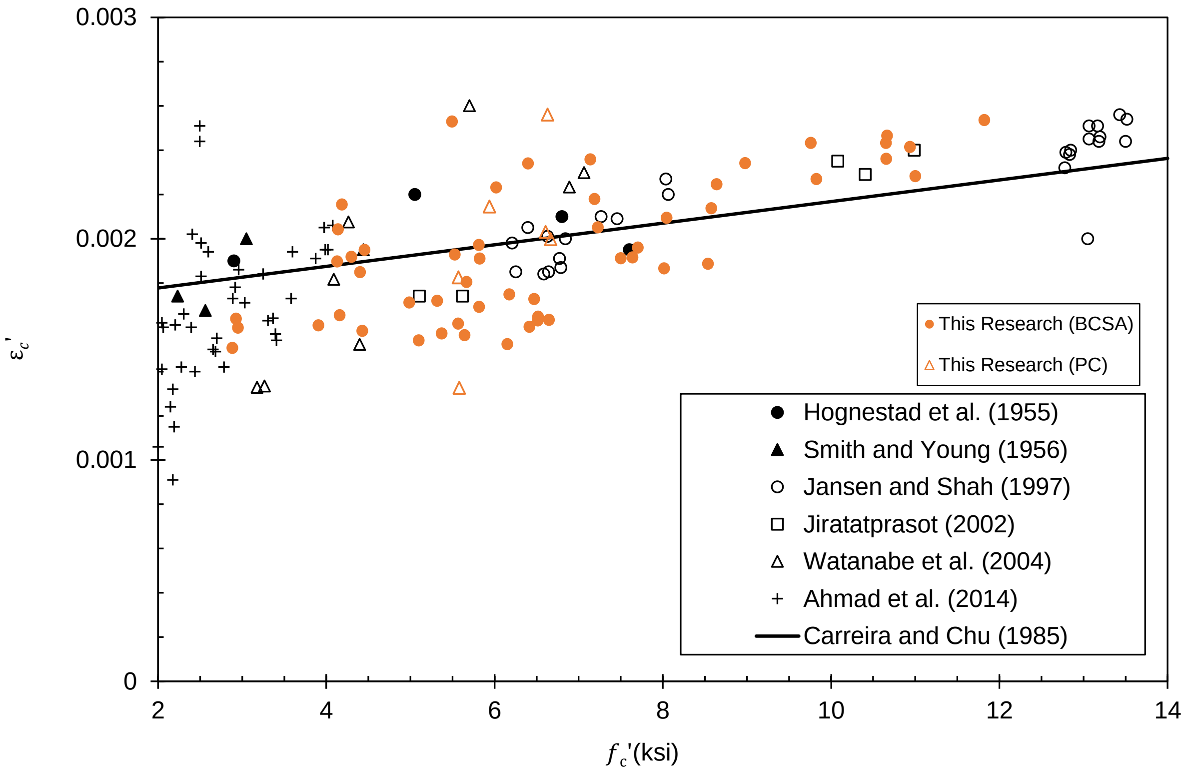
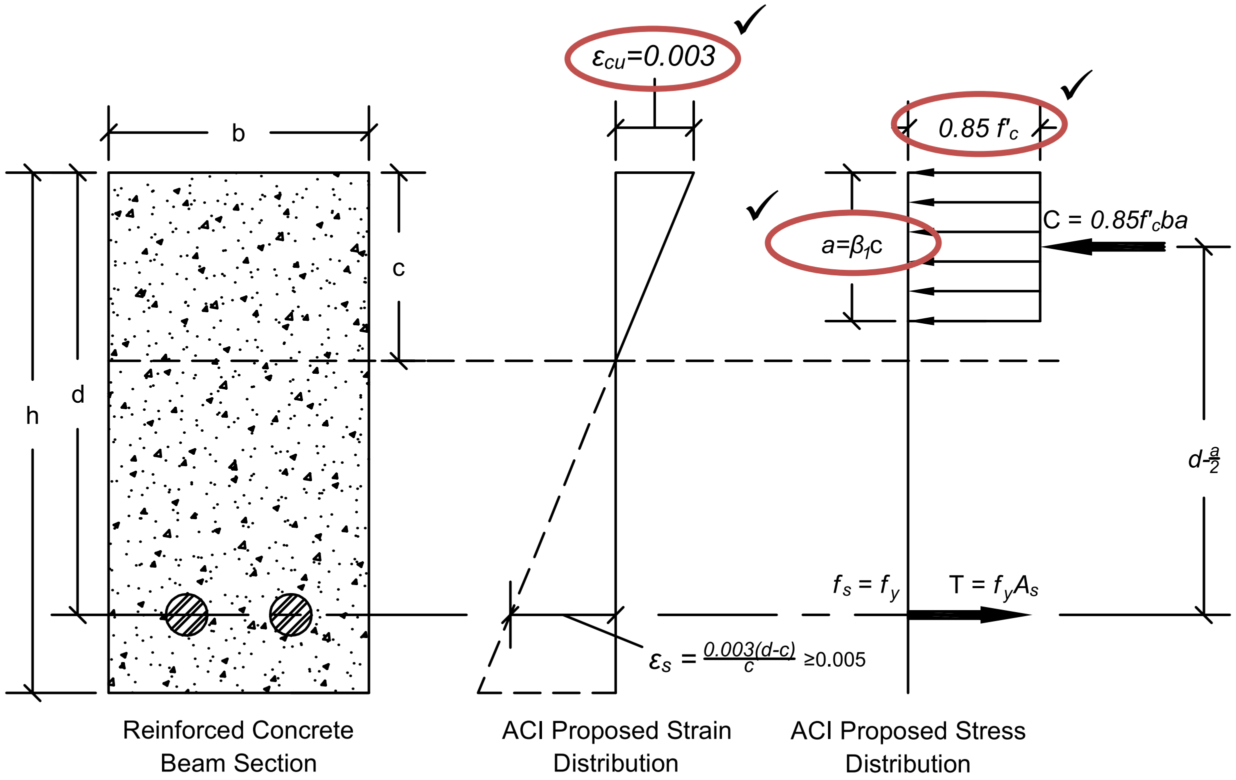


Fig. 24. Uniaxial compression strain

Stress-Strain Analysis of BCSA Concrete

Conclusions



- Concrete design codes are adequate and conservative for estimating flexural strength of BCSA.

Thanks

References

[1] A. Klein, “Calcium aluminosulfate and expansive cement containing same,” *United States Pat. Off.*, vol. 58, no. 3, pp. 155–526, 1963.

[2] E. Bescher, J. Stremfel, C. Ramseyer, and E. K. Rice, “The role of CSA in concrete sustainability,” *Twelth International Conference on Recent Advances in Concrete Technology and Sustainability Issues*. pp. 612–632, 2012.

[3] N. Markosian, R. Tawadrous, M. Mastali, R. J. Thomas, and M. Maguire, “Performance evaluation of a prestressed belitic calcium sulfoaluminate cement (Bcsa) concrete bridge girder,” *Sustain.*, vol. 13, no. 14, 2021.

[4] C. D. Murray, R. W. Floyd, and C. C. E. Ramseyer, “Using Belitic Calcium Sulfoaluminate Cement For Precast, Prestressed Concrete Beams,” PCI J., vol. 64, no. 2, pp. 55–67, 2019.

[5] N. A. Markosian, R. Thomas, M. Maguire, and A. Sorensen, “Calcium Sulfoaluminate Cement Concrete for Prestressed Bridge Girders: Prestressing Losses, Bond, and Strength Behavior,” Logan, Utah, 2019.

[6] R. Maggenti, S. Gomez, and R. Luena, “Bridge Hinge Reconstruction,” Structure Magazine, no. January, San Fransisco, pp. 30–32, Jan-2015.

[7] T. M. Bowser, C. D. Murray, and R. W. Floyd, “Bond Behavior of 0.6 in. (15.2 mm) Prestressing Strand in Belitic Calcium Sulfoaluminate (BCSA) Cement Concrete,” ACI Struct. J., vol. 117, no. 1, pp. 43–52, 2020.

[8] C. W. Chesnut and C. D. Murray, “Shear Capacity of Reinforced Concrete Made with Belitic Calcium Sulfoaluminate Cement,” ACI Struct. J., vol. 120, no. 1, pp. 177–186, 2023.

[9] R. J. Thomas, A. D. Sorensen, I. Quezada, and M. Maguire, “Calcium Sulfoaluminate Cement,” *Concr. Int.*, vol. 40, no. 4, pp. 65–69, 2018.

[10] T. Hanein, J. L. Galvez-Martos, and M. N. Bannerman, “Carbon footprint of calcium sulfoaluminate clinker production,” *J. Clean. Prod.*, vol. 172, no. November, pp. 2278–2287, 2018.

[11] F. P. Glasser and L. Zhang, “High-performance cement matrices based on calcium sulfoaluminate-belite compositions,” *Cem. Concr. Res.*, vol. 31, no. 12, pp. 1881–1886, 2001.

[12] M. B. Ali, R. Saidur, and M. S. Hossain, “A review on emission analysis in cement industries,” *Renew. Sustain. Energy Rev.*, vol. 15, no. 5, pp. 2252–2261, 2011.

[13] G. Jen, N. Stompinis, and R. Jones, “Chloride ingress in a belite-calcium sulfoaluminate cement matrix,” *Cem. Concr. Res.*, vol. 98, pp. 130–135, 2017.

[14] J. Péra and J. Ambroise, “New applications of calcium sulfoaluminate cement,” *Cem. Concr. Res.*, vol. 34, no. 4, pp. 671–676, 2004.

[15] H. C. Mertol, “Behavior of High-Strength Concrete Members Subjected to Combined Flexure and Axial Compression Loadings,” North Carolina State University, 2006.

[16] Hognestad, E., Hanson, N.W. and McHenry, D. "Concrete stress distribution in ultimate strength design." *ACI Journal Proceedings*. Vol. 52, No. 12. 1955.

Questions

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