Controlled Low Strength Material (CLSM) in Transportation Projects

Presented By:

National Ready Mixed Concrete Association

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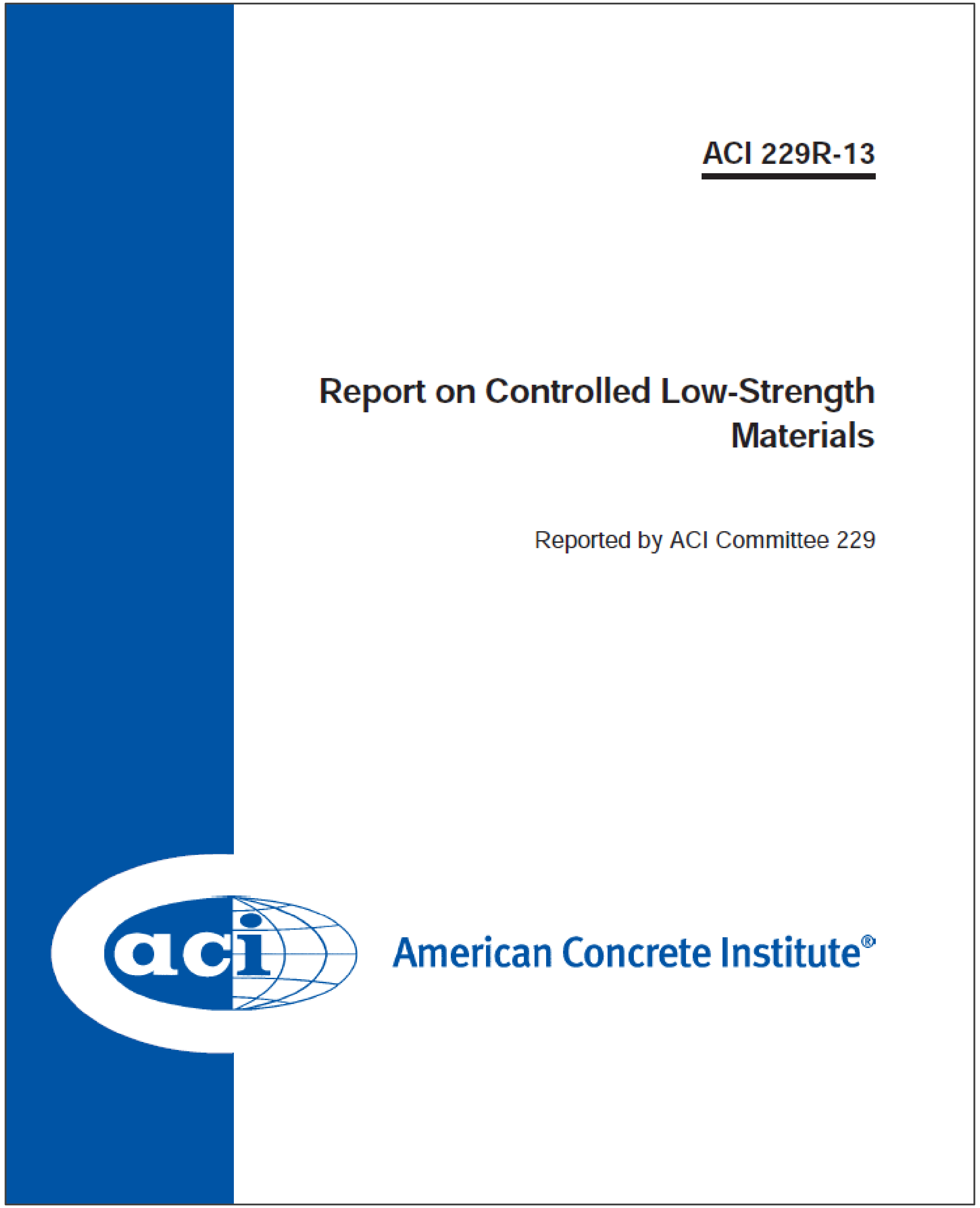
About the Course

Learning Units

- AIA Provider Number: G416 Course: CLSM101 | 1.0 LU/Elective | 1.0 PDH
- **Learning Objectives:**
  - Recognize when CLSM may be used on transportation projects.
  - Learn about mixture design and the various component materials that may be used.
  - Understand the various properties that may be used to define CLSM.
  - Learn the test methods used to evaluate CLSM during the construction process.


ACI 229R-13

Report on Controlled Low-Strength Materials

Reported by ACI Committee 229

American Concrete Institute®

Reference 1 - ACI 229R-13: Report on Controlled Low Strength Materials

Reference 2 – NCHRP Report 597

Reference 3 - www.flowablefill.org/

Reference 4 - NCPI National Clay Pipe Institute

Reference 5 - ASTM STP1331: Specifications and Use of Controlled Low-Strength Material by State Transportation Agencies

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Controlled Low Strength Material

- Self-consolidating cementitious material used primarily as a backfill and as an alternative to compacted fill.
- Other terms used to describe this material include:
  - flowable fill,
  - controlled density fill,
  - flowable mortar,
  - plastic soil-cement, and
  - soil-cement slurry.

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Controlled Low Strength Material

- Cement
- Sand
- Water
- Air-Entraining Additive
- Other Admixtures/Additives

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Controlled Low Strength Material

- Flowable Fill Overview (Courtesy of Chaney Enterprises)

Controlled Low Strength Material

- Intended to result in a compressive strength of 1,200 psi or less.
- Most CLSM applications require unconfined compressive strengths of 300 psi or less.
- Long-term strengths (90 to 180 days) should be targeted to be less than 100 psi for excavation with hand tools.

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Controlled Low Strength Material

- structural fill (~1,200 psi)*,
- backfill and bedding,
- anticorrosion fills,
- electrically conductive materials,
- low-permeability fills,
- thermal or insulating fills,
- durable pavement base, and
- erosion control.

*Note: Not to be considered as low strength concrete.

Controlled Low Strength Material

- Advantages:
  - Readily available
  - Easy to deliver
  - Versatile
  - Strong and durable
  - Quick opening to traffic
    - (4 hours or less)
  - Does not settle
  - Reduces excavation costs
  - Improves worker safety

- Advantages:
  - Allows all weather construction
  - Can be excavated
  - Requires less inspection
  - Reduces equipment needs
  - Requires no storage
  - Makes use of coal combustion by-product

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Controlled Low Strength Material

- CLSM generally costs more per cubic yard (cubic meter) than most soil or granular backfill materials
- Its many advantages often result in lower in-place costs.
- For some applications, CLSM is the only reasonable backfill method available.

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Controlled Low Strength Material

Labor	Granular Backfill	Flowable Fill
Placement (2 laborers @ 35.09*)	$70.18	$35.09
Compaction (2 laborers @ 35.09*)	$70.18	n/a
Heavy Equipment Operator	$45.82*	n/a
Hand Compactor	$15.00*	n/a
Backhoe	$25.00*	n/a
Total labor/hour	**$226.18**	**$35.09**

Source: Chaney Enterprises

84% labor cost savings

* National industry average including overhead costs

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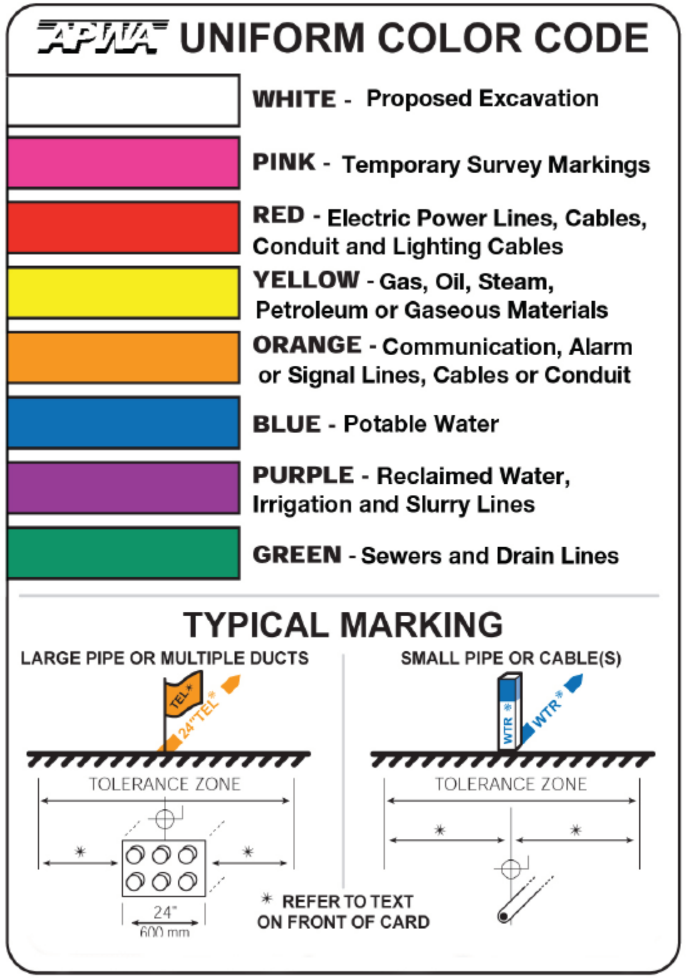
Controlled Low Strength Material

- When excavating around conduit etc., the obvious material change in CLSM versus the surrounding soil or granular backfill is recognized by the excavating crew, alerting them to the existence of the conduit.

- Coloring agents have been used in mixtures to help identify the presence of CLSM.



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Controlled Low Strength Material

- Materials normally meet ASTM, but not always necessary.
- Materials selection based on:
  - availability;
  - cost;
  - specific application; and
  - necessary mixture characteristics.

    (flowability, strength, excavatability, and density)

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Controlled Low Strength Material

- Cement:
  - Type I or Type II ASTM C150
  - Blended ASTM C595*
  - Performance ASTM C1157*

*Note: if prior testing indicates acceptable results.

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Controlled Low Strength Material

- Fly Ash:
  - Class C or F ASTM C618 preferred
    - But not necessary (carbon contents up to 20-25% may be allowable)
  - improve flowability,
  - increases strength,
  - reduce bleeding,
  - reduce shrinkage, and
  - reduce permeability.

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Controlled Low Strength Material

- Fly Ash:
  - High-fly-ash-content CLSM results in lower densities (compared to mixtures w/high agg. contents).
- Other cementitious materials acceptable:
  - CKD
  - Silica Fume
  - Slag

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Controlled Low Strength Material

- Admixtures:
  - Air-entraining admixtures:
    - improved workability,
    - reduced shrinkage,
    - little or no bleeding,
    - minimal segregation,
    - lower unit weights, and
    - control of ultimate strength development.

- Admixtures:
  - Air-entraining admixtures:
    - Water content can be reduced as much as 50 percent when using AE.
    - Higher air contents enhance thermal insulation and resistance to f-t cycles.
    - To prevent segregation w/high air, mixtures need sufficient fines to promote cohesion.

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Controlled Low Strength Material

- Water:
  - Meet ASTM C94
    - Ready mixed concrete water is acceptable.

Controlled Low Strength Material

- Aggregates
  - Meet ASTM C33
    - But not necessary
  - The type, grading, and shape of aggregates affect the physical properties:
    - flowability and
    - compressive strength.

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Controlled Low Strength Material

- Aggregates (examples of suitable aggregates):
    - ASTM C33 within specified gradations,
    - Pea gravel or pea stone with sand,
    - ¾ inch minus aggregate with sand,
    - Native sandy soils, with more than 10 percent passing #200,
    - Quarry waste products, generally ⅜ in. minus.

Controlled Low Strength Material

- Aggregates
  - Uncontrolled excavation allowable in some cases.
  - Silty sands w/up to 20% passing #200 satisfactory.
  - Soils w/variable grading also effective.
  - Soils with clay fines have exhibited problems with:
    - incomplete mixing,
    - mixture stickiness,
    - excess water demand,
    - shrinkage, and
    - variable strength.

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- Other Non-Standard Acceptable Aggregates:*
  - coal combustion products,
  - crusher fines,
  - discarded foundry sands,
  - glass cullet,
  - reclaimed crushed concrete,
  - ground tire rubber.

*Note: expansive materials discouraged.

(e.g. wood, wood ash, other organics)

Controlled Low Strength Material

- Properties
  - In-service CLSM, especially lower-strength CLSM, exhibits characteristic properties of soils.
  - Characteristics of CLSM are affected by mixture constituents and proportions of the ingredients in the mixture.
  - Can be highly variable.

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Controlled Low Strength Material

- Wet Properties
  - Flowability
  - Segregation
  - Subsidence
  - Hardening time
  - Pumping

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Controlled Low Strength Material

- Wet Properties
  - Flowability
  - Varies from stiff to fluid.
  - Methods of expressing flowability:
    - ASTM D6103: 3 x 6 in. open-ended cylinder modified flow test,
    - ASTM C143 standard concrete slump cone, and
    - ASTM C939 grout flow cone.

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Controlled Low Strength Material

- Wet Properties
  - Flowability
    - ASTM D6103: Good flowability - no noticeable segregation and spread is at least 8 in. in diameter.
    - ASTM C143*: Slump cone
      - Low flowability: slump less than 6 in.
      - Normal flowability: slump 6 to 8 in.
      - High flowability: slump greater than 8 in.

*typically used for non-flowable CLSM

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Controlled Low Strength Material

- Wet Properties
  - Segregation
    - Separation of materials when flowability produced by adding water.
    - For highly flowable w/out segregation,
      - adequate fines for aggregate suspension and stability,
      - fly ash and other mineral admixtures can account for these fines,
      - silty or noncohesive fines (up to 20% of total aggregate) have been used.

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Controlled Low Strength Material

- Wet Properties
  - Subsidence
    - Reduction in volume of CLSM as it releases water and entrapped air through mixture consolidation.
    - Excess water (not for hydration)
      - absorbed by the surrounding soil or released bleed water.
      - Most subsidence occurs during placement,
      - degree is dependent on free water released,
      - typically ⅛ to ¼ in. per foot of depth,
      - associated with mixtures of high water content,
      - lower water contents may exhibit little or no subsidence.

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Controlled Low Strength Material

- Wet Properties
  - Hardening time
    - Approximate time for CLSM to go from the plastic state to a hardened state with sufficient strength to support a person of average weight.
    - This time is greatly influenced by the amount and rate of bleed water released.
    - Chemical admixtures may be used to accelerate set (excludes CaCl).

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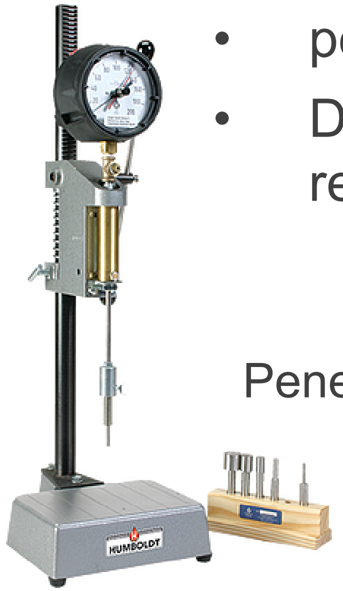
Controlled Low Strength Material

- Wet Properties
  - Hardening time
    - Dependent on type and quantity of cementitious material.
    - Normal factors affecting the hardening time are:
      - Type and quantity of cementitious material(s)
      - Aggregate shape and absorption
      - Permeability and degree of saturation of surrounding soil
      - Moisture content of CLSM
      - Proportioning of CLSM
      - Mixture temperature and ambient placing temperature
      - Humidity
      - Depth of fill
      - Use of admixtures

- Wet Properties
  - Hardening time
    - Time can be as short as 1 hour, but generally takes 3 to 5 hours under normal conditions.
    - Suitable tests for determining CLSM hardening time:
      - penetration-resistance test according to ASTM C403 and D6024.
      - Depending on the application, penetration numbers of 500 to 1500 are normally required to assure adequate bearing capacity



Penetrometer or Kelly Ball

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Controlled Low Strength Material

- Wet Properties
  - Pumping
    - Voids in the mixture should be adequately filled with solid particles to provide cohesiveness and stability for transport through the pressurized pump line without segregation.
    - The mixture should be statically stable so that it does not segregate and cause settling problems during pumping or in place.
    - CLSM with high entrained-air contents can be pumped, although care should be taken to maintain low pump pressures.

Controlled Low Strength Material

- In-Place Properties
  - Strength (bearing capacity)
  - Density
  - Settlement
  - Thermal insulation/conductivity
  - Permeability
  - Shrinkage (cracking)
  - Excavatability
  - Shear Modulus

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Controlled Low Strength Material

- In-Place Properties
  - Density
    - Wet density in place:
      - Normally 115 to 145 lb/ft^{3},
      - CLSM with only fly ash, cement, and water should have a density between 90 to 100 lb/ft^{3},
      - Lower unit weights can be achieved by:
        - using lightweight aggregates,
        - high entrained-air contents, and/or
        - foamed mixtures.

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Controlled Low Strength Material

- In-Place Properties
  - Permeability
    - Excavatable CLSM is like compacted granular fills.
    - Typical values:
      - 10^{-4} to 10^{-5} in./s (or cm/s).
      - Mixtures with higher strength and higher fines content can achieve permeabilities as low as 10^{-7} in./s.

Controlled Low Strength Material

- In-Place Properties
  - Shrinkage (cracking)
    - Shrinkage and shrinkage cracks do not affect the performance.
    - Ultimate linear shrinkage:
      - 0.02 to 0.05 percent
    - CLSM with high volumes of fly ash (~965 lb/yd^3) exhibit higher amounts of linear shrinkage.

Controlled Low Strength Material

- In-Place Properties
  - Excavatability
    - CLSM with a compressive strength of 100 psi or less can be excavated manually.
    - A removability modulus (RE) helps to determine excavatability

U.S. Units

$$RE = \frac{W^{1.5} \times 104 \times C^{0.5}}{10^6}$$

Metric Units

$$RE = \frac{W^{1.5} \times 0.619 \times C^{0.5}}{10^6}$$

RE < 1.0, is removable.
RE > 1.0, is not easily removed.

[W is the dry mass density (lb/ft^3 or kg/m^3), and C is the 28-day unconfined compressive strength (lb/in^2 or kPa)]:

Credit: Hamilton County, Ohio CLSM-CDF Specification and as reported in NCHRP Report 597 (2008) and ACI Report 229

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Controlled Low Strength Material

- In-Place Properties
  - Excavatability
    - Mixtures with high coarse aggregate quantities can be difficult to remove by hand, even at low strengths.
    - Mixtures using fine sand or only mineral admixtures as aggregate filler have been excavated with a backhoe up to strengths of 100 to 300 psi.

Controlled Low Strength Material

- In-Place Properties
  - Excavatability
    - Acceptable long-term performance has been achieved with combined cement contents from 40 to 100 lb/yd^3 and Class F fly ash contents up to 350 lb/yd^3.
    - Lime (CaO) contents of fly ash that exceed 10 percent by weight can be a concern where long-term strength increases are not desired.

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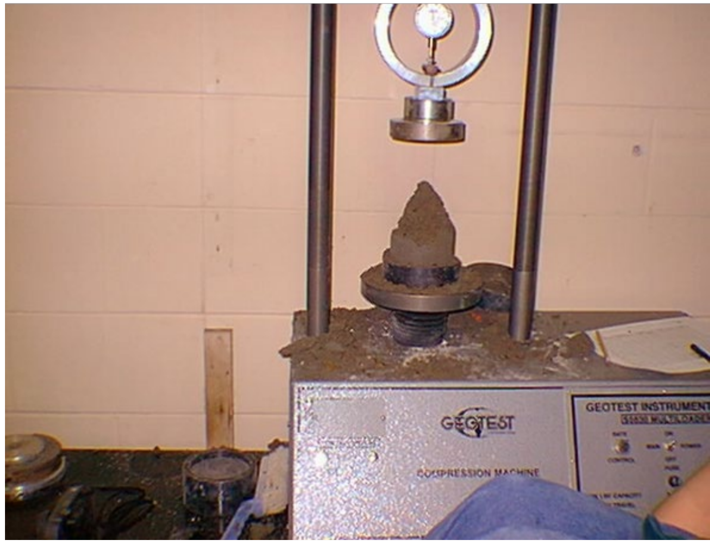
Controlled Low Strength Material

- In-Place Properties
  - Excavatability
    - For CLSM with high cementitious content (or w/fly ash or slag), long-term (56, 90, or 180 days) strength tests should be conducted to estimate the potential for excavatability.
    - In addition to limiting the cementitious content, entrained air can be used to maintain low compressive strength.



Controlled Low Strength Material

- Proportioning
  - Well-graded fine aggregate = more stable CLSM which resists
    - segregation and
    - excessive bleeding.
  - Remember: Avoid too much clay!
  - Cementitious starting point:
    - 25 to 100 lb/yd^3 of cement and
    - up to 300 lb/yd^3 of fly ash

    (promotes setting and long-term strength).

Controlled Low Strength Material

- Proportioning
  - ACI 211.1 proportioning may be used to establish initial mixture design.
  - Basic CLSM mixtures:
    - fine aggregate: 2500 to 3500 lb/yd^3,
    - water: 400 to 500 lb/yd^3,
    - portland cement: 25 to 200 lb/yd^3,
    - fly ash: 0 to 700 lb/yd^3,
    - results in ~2-5% entrapped air.

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Controlled Low Strength Material

- Proportioning

12 REPORT ON CONTROLLED LOW-STRENGTH MATERIALS (ACI 229R-13)

Table 6.4—Sample calculations for 1 yd³ (1 m³) of material

1 yd³	1 m³
94 lb cement/(3.15 × 62.4 lb/ft³) = 0.48 ft³	56 kg cement/(3.15 × 1000 kg/m³) = 0.018 m³
450 lb water/(1.00 × 62.4 lb/ft³) = 7.21 ft³	267 kg water/(1.00 × 1000 kg/m³) = 0.267 m³
Assumed air vol (3% × 27 ft³) = 0.81 ft³	Assumed air volume (3% × 1m³) = 0.03 m³
Volume, sand = 27 ft³ – 0.48 ft³ – 7.21 ft³ – 0.81 ft³ = 18.5 ft³	Volume, sand = 1 m³ – 0.018 m³ – 0.267 m³ – 0.03 m³ = 0.685 m³
Weight, sand = 18.5 ft³ × (2.65 × 62.4 lb/ft³) =3060 lb	Mass, sand = 0.685 m³× (2.65 × 1000 kg/m³) =1815 kg

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Controlled Low Strength Material

Table 6.6—Adjustments to proportioning (from ACI 229R-13)

Property	Problem	Adjustment
Slump	Too high	a) Reduce water content b) Increase fines
	Too low	a) Increase water content b) Add water-reducing admixture
Stability	Mixture is segregating	a) Decrease water b) Increase fines c) Increase cementitious materials d) Add air entrainment e) Add viscosity-modifying admixture (VMA)
Yield	Too low	a) Confirm specific gravity used for constituents is correct b) Increase constituents
	Too high	a) Confirm specific gravity used for constituents is correct b) Decrease constituents
Strength	Too low	a) Increase cementitious materials b) Decrease air entrainment c) Decrease water in conjunction with use of water-reducing admixture
	Too high	a) Decrease cementitious materials b) Increase air entrainment

Controlled Low Strength Material

- Mixing performed in:
  - central-mixed concrete plants,
  - ready mixed concrete trucks,
  - pugmills, and
  - volumetric mobile concrete mixers.

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Controlled Low Strength Material

- Mixing performed in trucks:
  - Load truck mixer at standard charging speed in the following sequence:
    - Add 70 to 80 percent of water required
    - Add 50 percent of the aggregate filler
    - Add all cement and fly ash required
    - Add balance of aggregate filler
    - Add balance of water

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Controlled Low Strength Material

- Transporting
  - Ready mix trucks
  - Dump trucks/non-agitating mixers (discouraged)
  - Pumps (conveyed transporting)
  - volumetric-measuring and continuous-mixing concrete equipment (VMCM) for jobsite mixing

Controlled Low Strength Material

- Placing
  - chutes,
  - conveyors,
  - buckets, or
  - pumps.
  - Internal vibration, compaction, or consolidation NOT required, consolidates under own weight.

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Controlled Low Strength Material

- Placing
  - Protect from freezing
  - No need to cure like concrete
  - Place continually (e.g. trench backfill) or in lifts (e.g. under pipes)

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Controlled Low Strength Material

- Testing
  - Visual, and/or
  - Consistency,
    - Flowability
    - Unit Weight (Density),
  - Strength.

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Controlled Low Strength Material

- Testing in place:

ASTM D6024	This specification covers determination of ability of CLSM to withstand loading by repeatedly dropping metal weight onto in-place material.
ASTM C403/C403M	This test measures degree of hardness of CLSM. California DOT requires penetration number of 650 before allowing pavement surface to be placed.
ASTM D4832	This test is used for molding cylinders and determining compressive strength of hardened CLSM.
ASTM D1196/D1196M	This test is used to determine modulus of subgrade reaction (K values).
ASTM D4429	This test is used to determine relative strength of CLSM in place.

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How Can We Assist You for Free?

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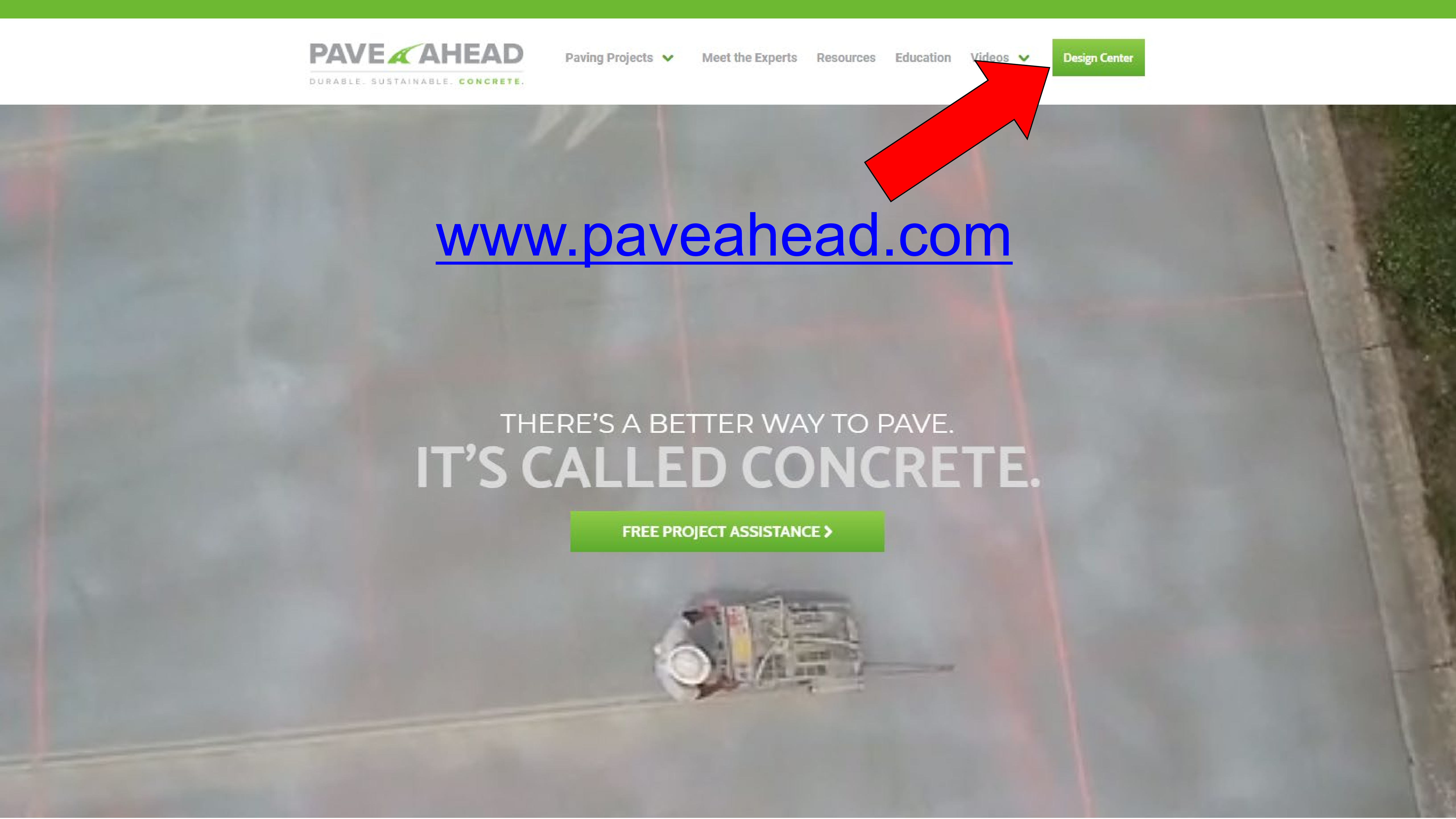
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- Jul 13th Innovation with Concrete Overlays for DOT's and Municipalities
- Aug 10th Resiliency–Proper Planning Prevents Disaster and Aids in Crisis Management–Concrete Perspective
- Sep 14th Advancements in Performance Engineered Mixtures (PEM's)
- Oct 12th Sustainability, Recycle and Bicycle

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