
Innovations in Concrete Pavements
Concrete Innovations
May 17th, 2023
Presented By:
Brian Killingsworth, P.E.
National Ready Mixed Concrete Association
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Where Have We Been?
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The First Concrete Pavement in the U.S.

Source: American Concrete Pavement Association (ACPA)

- Court Ave., Bellefontaine, OH placed in 1891
- George Bartholomew (Buckeye Portland Cement Co.)
- 6 inches of concrete (2-inch top layer and 4-inch bottom layer)

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Historical Concrete Paving

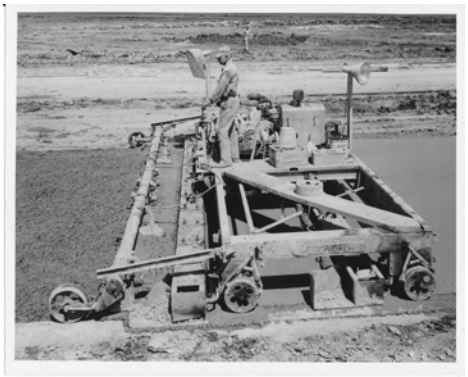
Caltrans Ridge Road 1915

North on I-5 out of Los Angeles through the La Liebre Mountains headed towards Bakersfield.

4

Historical Concrete Paving

Source: Koss Construction Co.



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Modern Concrete Slipform Pavers

Source: Gomaco

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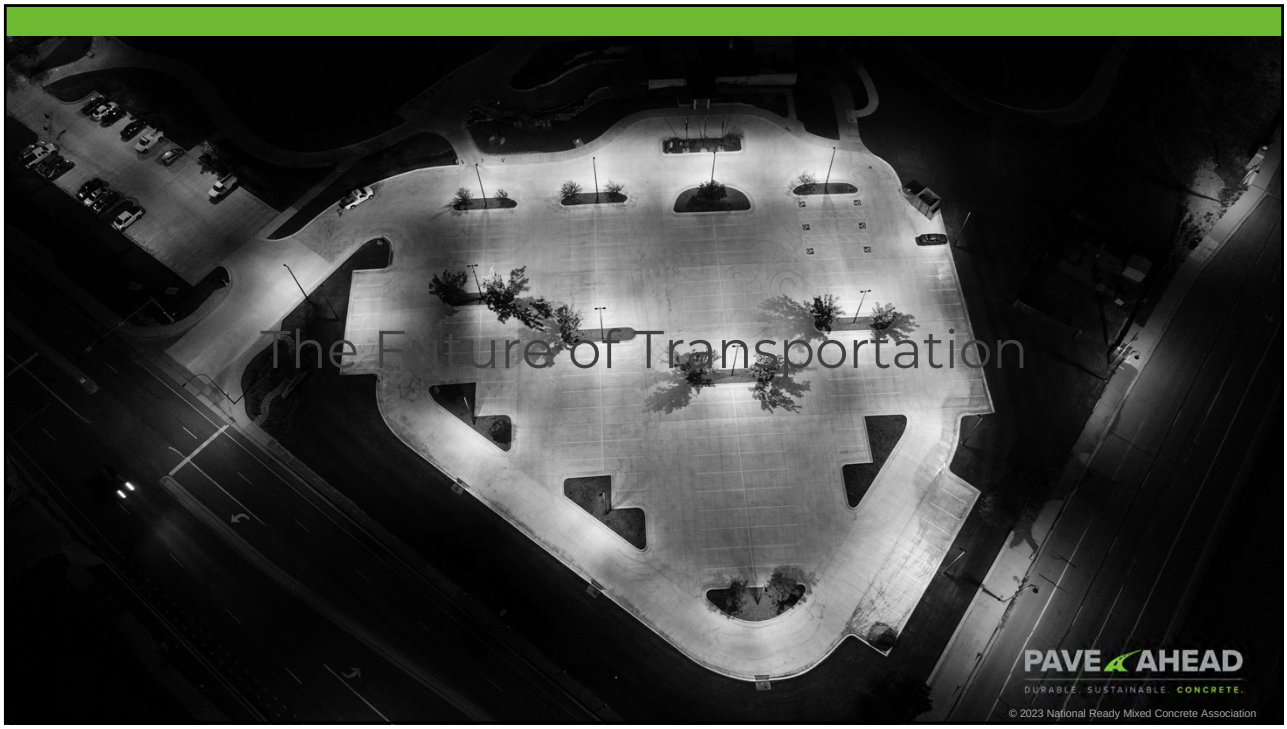
The Future of Transportation
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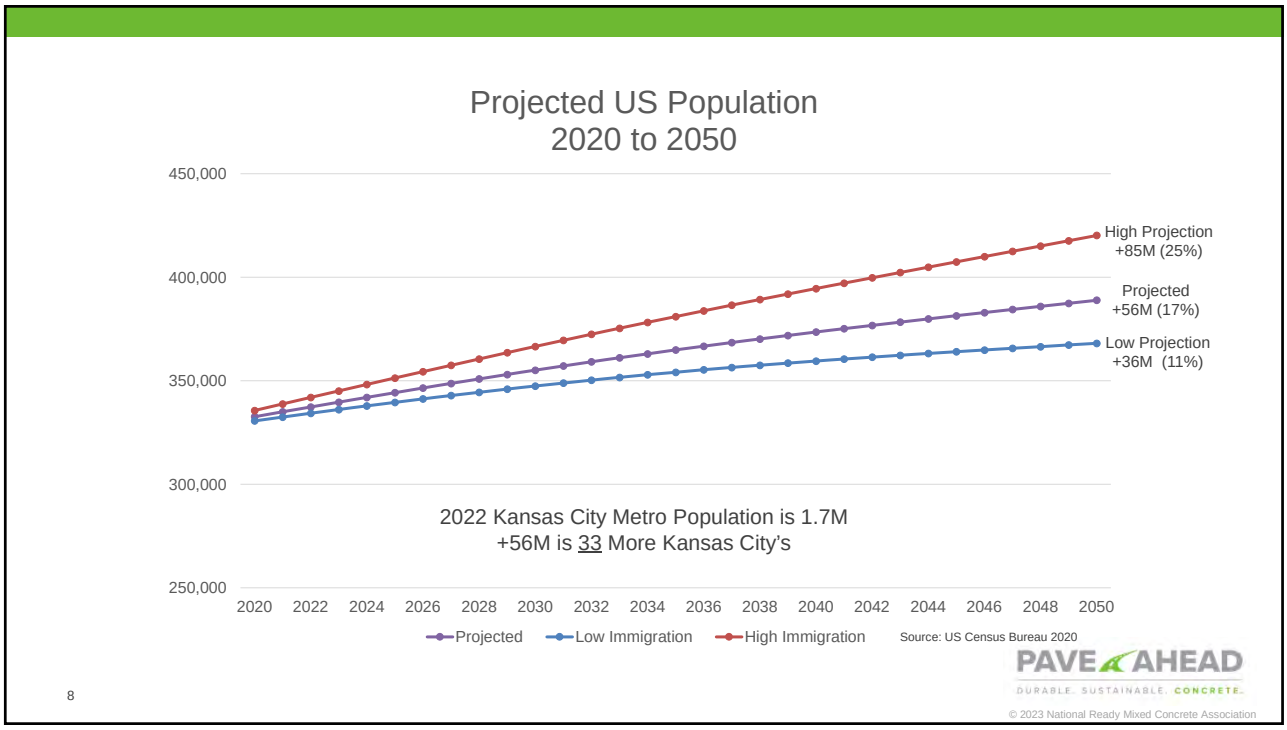
Projected US Population
2020 to 2050
450,000
400,000
350,000
300,000
250,000
2020 2022 2024 2026 2028 2030 2032 2034 2036 2038 2040 2042 2044 2046 2048 2050
High Projection
+85M (25%)
Projected
+56M (17%)
Low Projection
+36M (11%)
2022 Kansas City Metro Population is 1.7M
+56M is 33 More Kansas City's
Projected
Low Immigration
High Immigration
Source: US Census Bureau 2020
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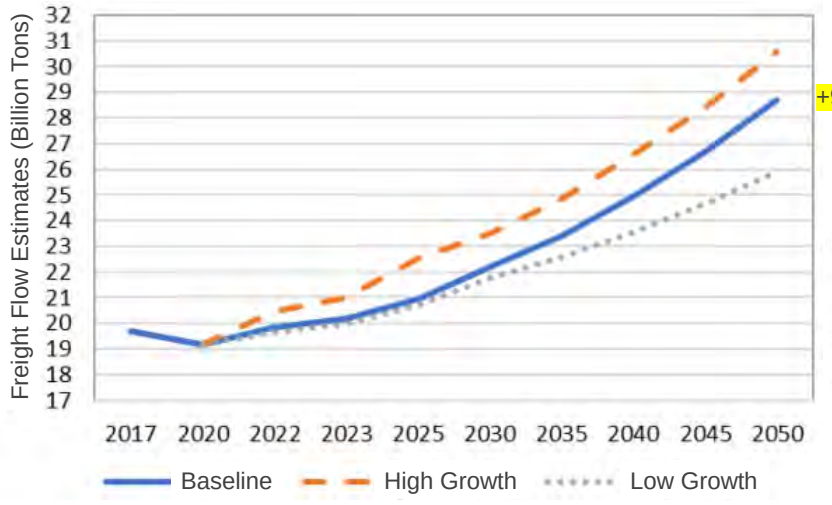
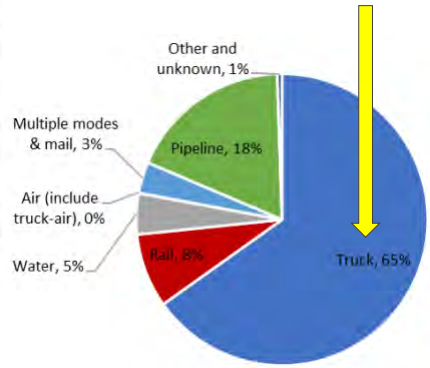
Freight Flow Estimates 2020 - 2050



+9.6B (+50%)



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9 Source: Bureau of Transportation Statistics
https://www.bts.gov/newsroom/freight-activity-us-expected-grow-fifty-percent-2050#:~:text=New%20long%2Dterm%20projections%20released,trillion%20(in%202017%20dollars).

North American and Global E-Commerce

Five Below – Buckeye, AZ
858,000 SF Distribution Center
Scannell Properties
Courtesy of ARCO Design/Build


The Future of Concrete Paving
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Innovative Design Methods
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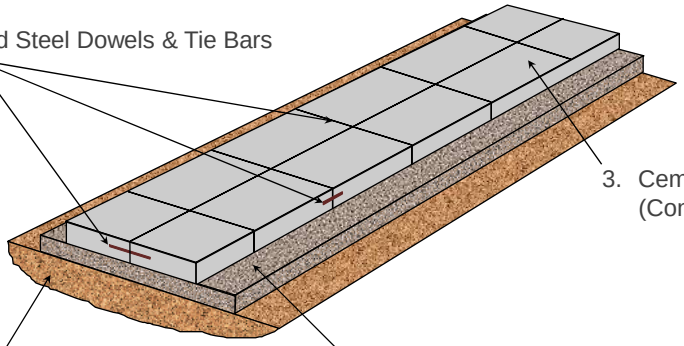
Concrete Pavement Cross-Section Design



4. Joint Spacing and Steel Dowels & Tie Bars
3. Cement-Based Surface Material (Concrete, RCC, Pervious, Etc.)
2. Aggregate or Stabilized Subbase (If Needed)
1. Engineered or Stabilized Subgrade

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Concrete Industry Pavement Design Tool

www.pavementdesigner.org

PavementDesigner.org

Webinar: paveahead.com/education/
Concrete Pavement Design Tool

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Short Slab Design

- Typical slab joint spacing for unreinforced pavement:
  - 21 to 24 times the thickness (6”x24=144”=12’) or
  - 5.25 * ℓ (radius of relative stiffness)

- What happens if joint spacing is reduced to ~10 times the thickness?
- Short slabs distribute wheel loads over shorter panels.
  - Short slabs = reduced potential for curl.
  - Short slabs = reduced wheel load stress.

- Reduce thickness, maintain same load-bearing capacity.

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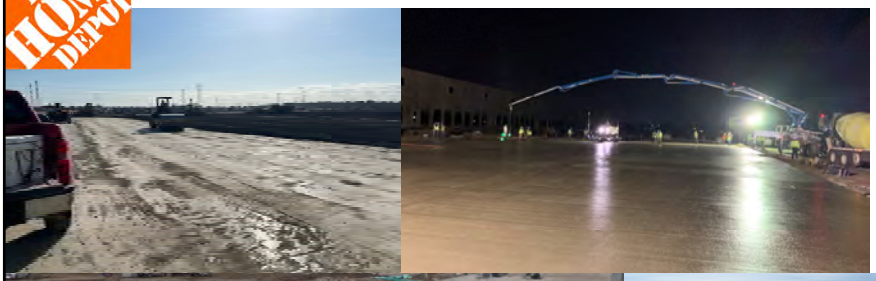
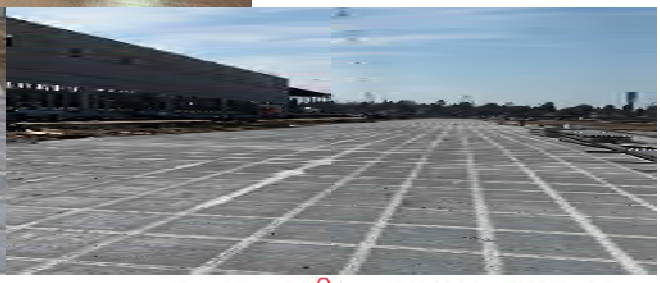
Short Slab Design – Case Study





Houston, TX – 2021
Traffic: ~4.0M ESALs
Size: 2.7M sq.ft.
Thickness: 5.5 in. (14cm)
- 580 psi (4.0 MPa) flexural strength
- With macrosynthetic fibers
- 6 ft. (1.8m) joint spacing
- 8 in. (20cm) cement treated base

TCPavements® PNA CONSTRUCTION TECHNOLOGIES FORTA® CONCRETE FIBER

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Jointless Slab Design

- Goal:
  - Eliminate joints
  - Reduce potential for curling and tensile stress (environment & load)
  - Tensile reduction can include shrinkage reduction
- Jointless Design:
  - Combination of materials formulated to reduce:
    - Shrinkage
    - Curl
  - Materials may include:
    - Admixtures
    - Specialty cements
    - Fibers
    - Nanotechnologies

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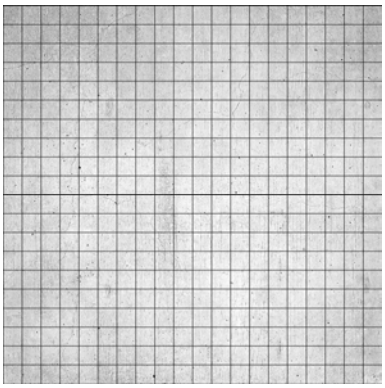
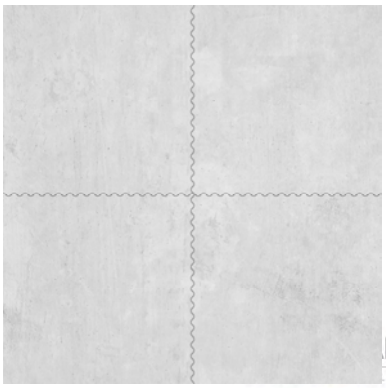
Jointless Slab Design

- Slab length example 150-ft x 150-ft, but can be larger
- Armored joints at construction joints in heavy wheel load applications
- Specialized concrete design methods & proprietary mixtures



Credit: MEGASLAB®



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Jointless Slab Design

Wagner Equipment
CAT Dealer
Aurora, CO
500′ x 60′ Jointless Slab

Credit: MEGASLAB®

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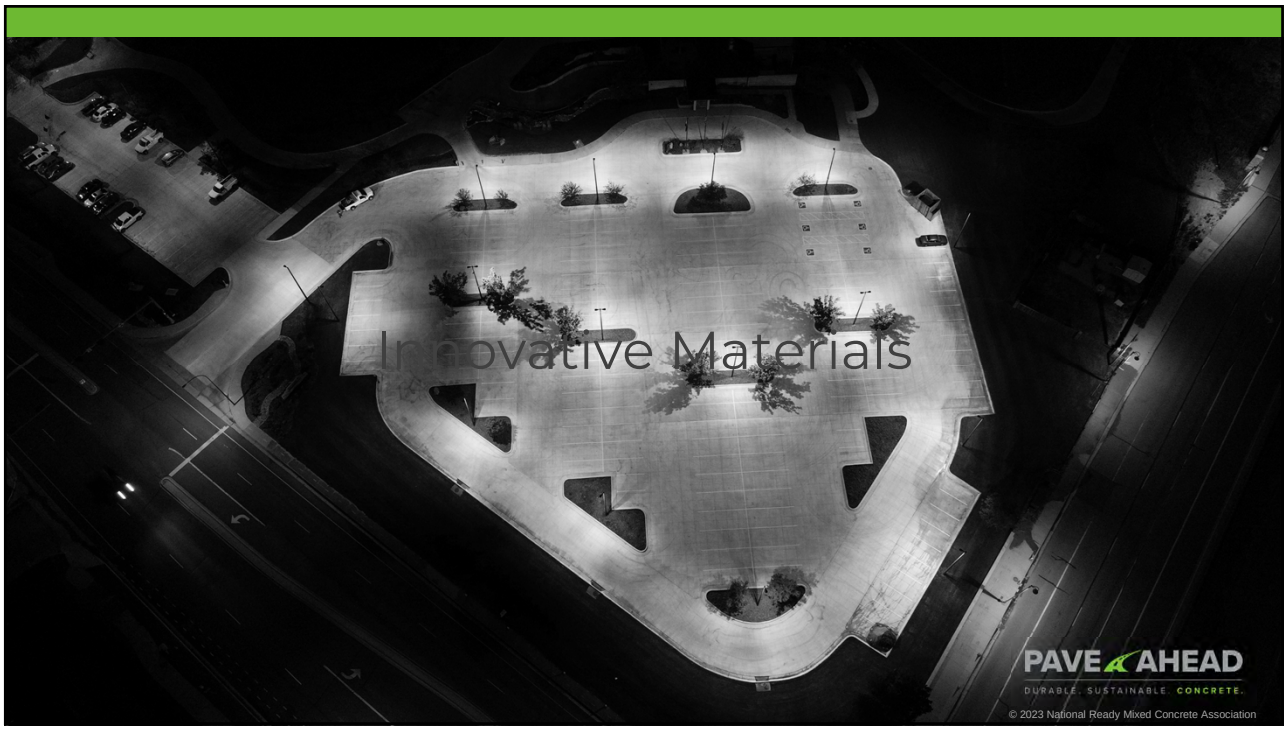

ASTM C150 Portland Cement

- Type I - For use when the special properties specified for any other type are not required.
- Type IA - Air-entraining cement for the same uses as Type I, where air-entrainment is desired.
- Type II - For general use, more especially when moderate sulfate resistance or moderate heat of hydration is desired.
- Type IIA - Air-entraining cement for the same uses as Type II, where air-entrainment is desired.
- Type III - For use when high early strength is desired.
- Type IIIA - Air-entraining cement for the same use as Type III, where air-entrainment is desired.
- Type IV - For use when a low heat of hydration is desired.
- Type V - For use when high sulfate resistance is desired.

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Innovative (Blended) Cements: Going Beyond ASTM C150

ASTM C595 Standard Specification for Blended Hydraulic Cements

ASTM C595

Type	Description	Notes
Type IL (X)	Portland-Limestone Cement	Where X can be between 5 and 15% limestone
Type IS (X)	Portland-Slag Cement	Where X can be up to 70% slag cement
Type IP (X)	Portland-Pozzolan Cement	Where X can be up to 40% pozzolan (fly ash is the most common)
Type IT (AX)(BX)	Ternary Blended Cement	Where X can be up to 70% of pozzolan + limestone + slag, with pozzolan being no more than 40% and limestone no more than 15%

ASTM C1157 Standard Performance Specification for Hydraulic Cement

ASTM C1157

Type	Description	Notes
Type GU (X)	General Use	X is optional but may be designated as R for low reactivity with alkali-silica-reactive aggregates or A for air-entraining cement. Performance tests may include: • Chemical analysis • Fineness • Expansion • Initial set time • Air content • Compressive strength • Heat of hydration • Sulfate resistance • ASR reactivity • Early stiffening
Type HE (X)	High Early Strength	
Type MS (X)	Moderate Sulfate Resistance	
Type HS (X)	Moderate Sulfate Resistance	
Type MH (X)	Moderate Heat of Hydration	
Type LH (X)	Low Heat of Hydration	

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Type HS (X)	Moderate Sulfate Resistance	
Type MH (X)	Moderate Heat of Hydration	
Type LH (X)	Low Heat of Hydration	

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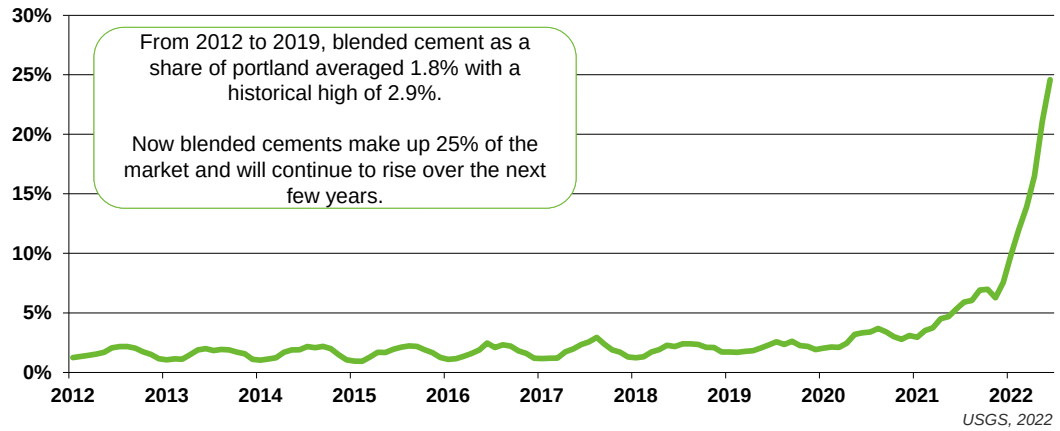
Use of Blended Cements in The U.S.



USGS, 2022

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Admixtures

- Viscosity Modifying
  - Reduce bleeding & segregation with pumping, increase slump retention
- Shrinkage Reducing & Compensating
  - Reduce curl, cracking, crack widths
- ASR Mitigation
  - Allows use of local aggregates, low-alkali cement not necessary
- High-Range Water Reducing
  - Increase strength, reduce mixing time
- Permeability Reducing and Waterproofing
  - Resist chemical attack and abrasion, densify concrete

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EUCLID CHEMICAL gcp MASTER BUILDERS Sika PAVE AHEAD DURABLE. SUSTAINABLE. CONCRETE.

Fibers

- Properties
  - Geometry
    - Length (l)
    - Diameter (d)
    - Aspect ratio (l/d)
  - Texture
    - Straight
    - Embossed
    - Twisted
    - Crimped
    - Hooked-end
    - Sinusoidal
  - Material type

Macrofiber examples

- Types
  - ASTM C1116: Classified as synthetic, steel, glass, or natural (Types I – IV)
  - Synthetic (e.g., polypropylene, polyester, polyolefin)
    - Micro
    - Macro
  - Steel
    - Round
    - Flat
  - Other materials available

Credit: *Fiber-Reinforced Concrete for Pavement Overlays: Technical Overview* (April 2019) National Concrete Pavement Technology Center

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Fibers

- Potential Benefits
  - Increased flexural strength (macro)
  - Improved post-cracking toughness, energy absorption, and fracture energy (macro)
  - Improved flexural fatigue resistance (macro)
  - Potential improvement the load transfer efficiency (macro) (more study needed)
  - Reduced shrinkage (primarily micro, but macro possible)
  - Enhanced deleterious durability by lowered permeability & reduced crack widths (macro)
  - Enhanced abrasion resistance (macro)

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Engineered Cementitious Composites (ECC)

(A) (B)

Gürkan Yıldırım, Mustafa Şahmaran, Özgür Anıl, *Engineered Cementitious Composites-Based Concrete* Woodhead Publishing, 2018, https://www.sciencedirect.com/science/article/pii/B9780081021811000150

Source: Louisiana Transportation Research Center Pavement Research Facility
https://www.lsu.edu/eng/news/2018/12/bendableconcrete.php

ECC Components (typical):

- Cement
- Fly ash
- Water
- Concrete sand
- Poly-vinyl alcohol (PVA) fibers

Source: Professor Victor Li
https://civildigital.com/all-about-flexible-concrete-bendable-concrete-engineered-cementitious-composite-ecc/

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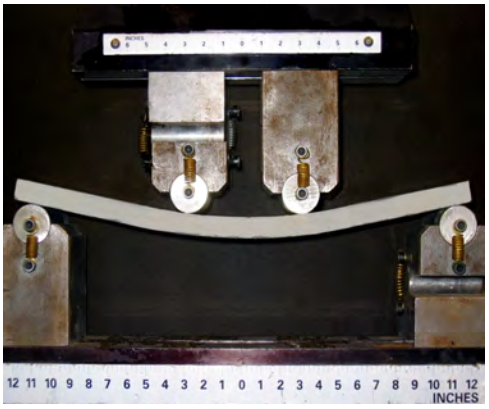
Engineered Cementitious Composites (ECC)



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Engineered Cementitious Composites (ECC)

- Engineered Cementitious Composite (ECC)
  - Adapted from building sciences
  - High fiber (PVA or steel) concrete mixture
  - High fly ash content may be used
  - Typically high strength (up to 30k comp/6k flex)
  - Significant ductility
  - Increased durability (high density/small pore structure)
  - Reduced shrinkage and creep
  - Reduced reflective cracking
  - *Increased fatigue resistance allows for reduced thickness*

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ECC: Another Way to Mill and Fill?

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Ultra-High Performance Concrete (UHPC)

- Manufacturer distributes the premix powder, fibers and admixtures to partners
- Can use high carbon metallic fibers, stainless fibers, poly-vinyl alcohol (PVA) fibers or glass fibers
- Improves strength and ductility
- Less porous than conventional concrete
- More resistant to chlorides, acids, and sulfates
- Has self-healing properties

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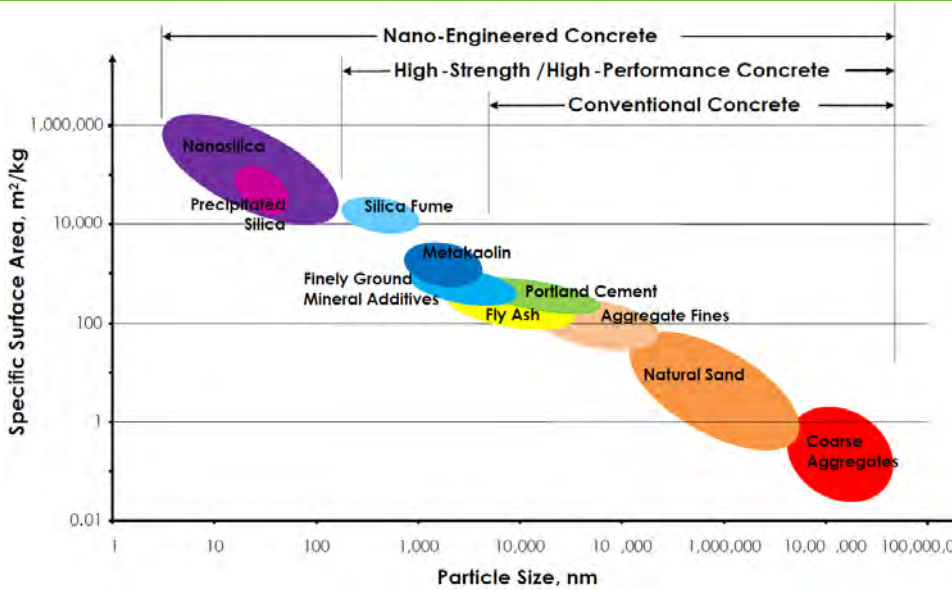
Nanomaterials

Carbon Nanotubes, Nanosilica, Nano-Titanium Dioxide, Nanographene, Nanocellulose



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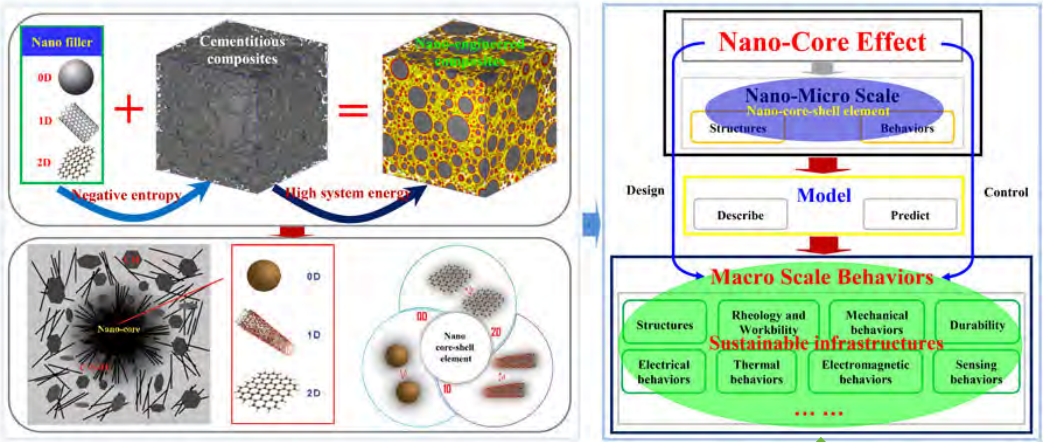
Nanotechnology in Cementitious Composites



Source: https://advanceseng.com/tailoring-cement-concrete-materials-nano-core-effect/

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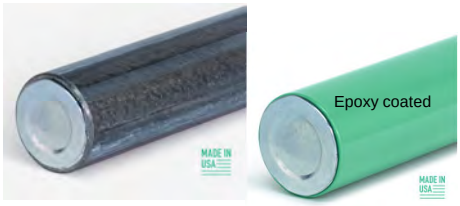
Hollow Pavement Dowels

Source: NRMCA Concrete InFocus Article Fall 2020: Hollow Steel Dowel Bars

- Carbon steel tubular dowel
- Can be made just as rigid as a solid dowel but weigh much less
- Slight increase in dowel outer diameter with a desired wall thickness provides very similar performance to solid steel dowels for bending and bearing
- Verified by University of Pittsburg
- “One-Man Dowel Basket”



Courtesy of Schenk Industrial: O-Dowel

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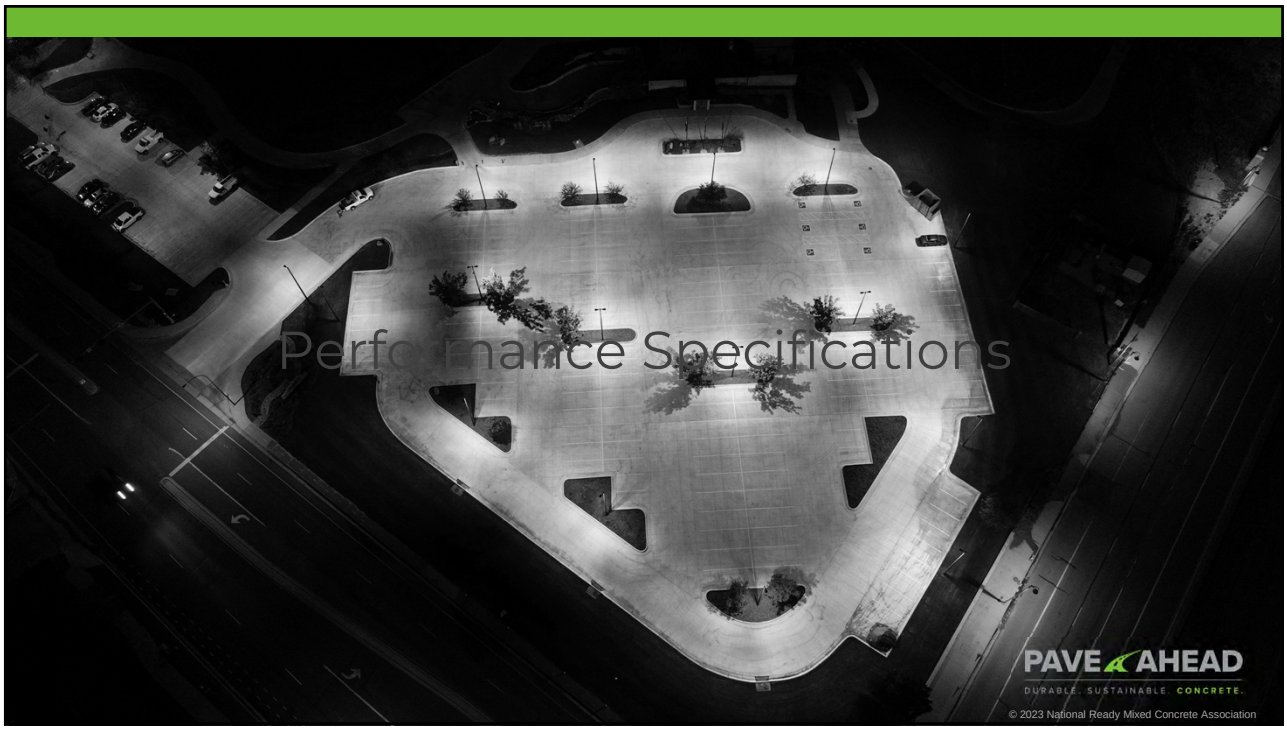

Prescriptive vs. Performance Specifications

Source: Federal Highway Administration

- Prescriptive
  - Agency dictates how the material or product is formulated and constructed.
  - Based on past experiences.
  - Minimal/uncertain ability to innovate.
  - Requires agency to have proper manpower and skill set to provide oversight.
- Performance
  - Agency identifies desired characteristics of the material or product.
  - Contractor controls how to provide those characteristics.
  - Maximum ability to innovate.
  - Reduced oversight burden on the agency.

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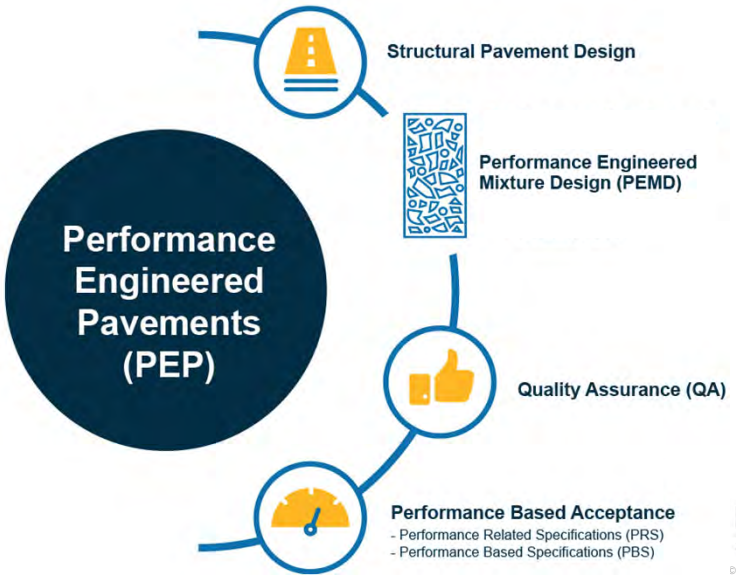
Performance Engineered Pavements

Source: Federal Highway Administration (FHWA-HIF-20-005)



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AASHTO PP 84: Performance Engineered Concrete Pavement Mixtures

- Prescriptive Properties
  - Slump
  - Minimum cement content
  - Single aggregate gradation requirements
- Performance Properties
  - Strength
  - Shrinkage
  - Freeze-thaw resistance
  - Transport properties (permeability)
  - Aggregate stability
  - Workability

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PEM Test Methods for Concrete Paving

Source: Concrete Pavement Technology Center

Property	Test Method
Workability	AASHTO T 119: Slump test
	AASHTO TP 137: Box Test
	AASHTO TP 129 :VKelly test
Air Content and Air-Void System Parameters	AASHTO T 152: Pressure meter
	AASHTO TP 118: SAM meter
	ASTM C457: Microscopical evaluation of air voids
Strength	AASHTO T 97: Flexural strength
	AASHTO T 22: Compressive strength

Property	Test Method
Volume Change/Cracking Resistance	ASTM C157: Unrestrained drying shrinkage
	AASHTO T 334: Restrained shrinkage ring test
	AASHTO T 336: Coefficient of thermal expansion
Chemical Deicer Resistance	AASHTO T 365: LT-DSC
Transport Properties	AASHTO T 277: Rapid chloride penetrability
	AASHTO T 358 or TP 119: Concrete resistivity
Aggregate Durability	AASHTO T 161: Aggregate freeze-thaw resistance
	AASHTO R 80: Alkali-aggregate reactivity

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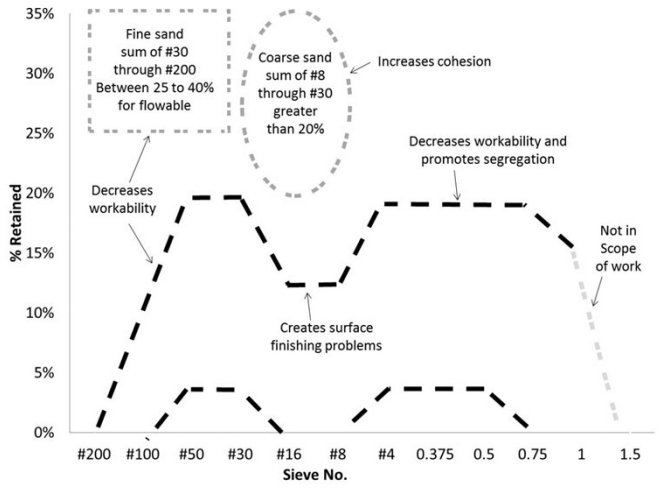
PEM Test Methods for Concrete Paving

Source: https://www.acpa.org/tag/performance-engineered-mixtures/

Recommended Aggregate Gradation Limits



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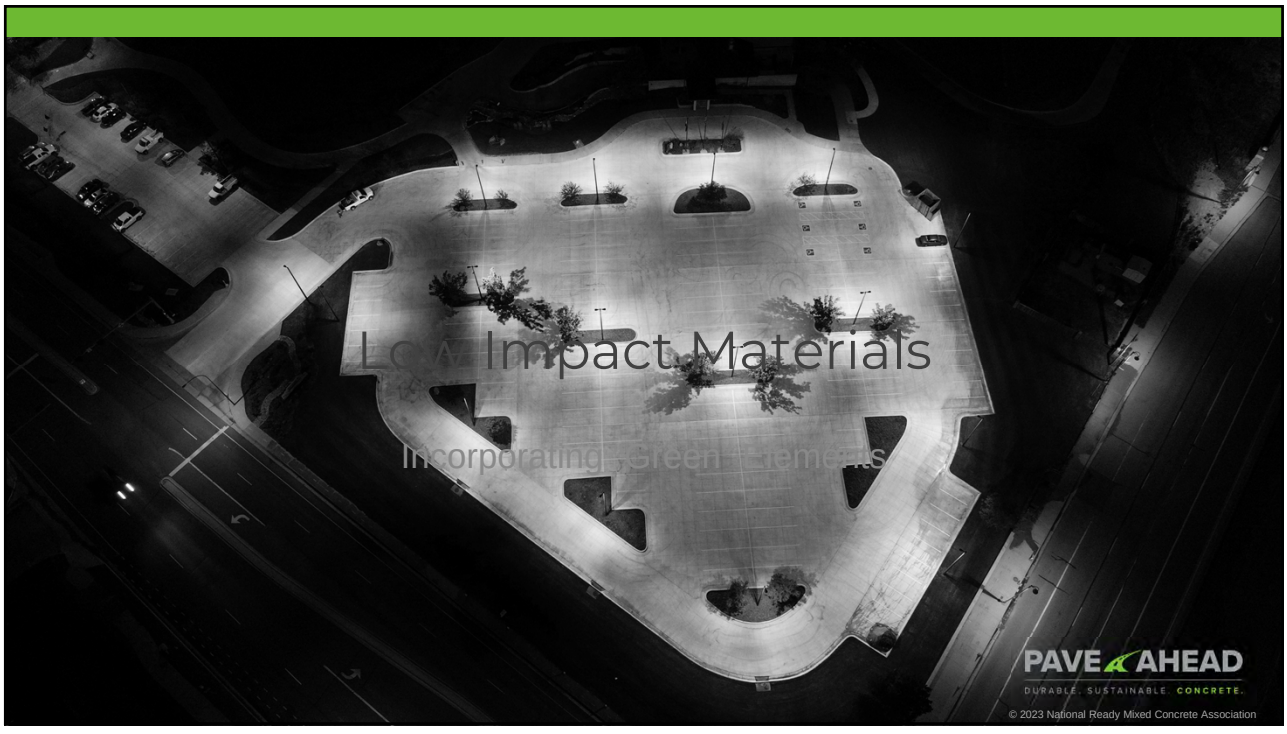
Selection of Other PEM Tests



Concrete Pavement Life-Cycle Stages: Embodied and Operational (Use) GHG Emissions

Embodied | Embodied | Embodied | Embodied | Embodied | Use | Embodied | Embodied | Embodied

GHG Emissions

Product Stage			Construction Stage		Use Stage	End of Life Stage			Resource Recovery
A1 Extract and process raw materials	A2 Transport all materials to concrete plant	A3 Manufacture concrete	A4 Transport to paving project	A5 Construct pavement	B1 - B7 Use and maintain the pavement	C1 Remove pavement or recycle in-place	C2 Haul away waste materials	C3 - C4 Waste processing and disposal	D Reuse/ recovery/ recycling potential

Cradle-to-Gate (Life-Cycle Stages A1-A3)

Cradle-to-Grave (Life-Cycle Stages A1-C4)

Cradle-to-Cradle (Life-Cycle Stages A1-C4, D)

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Food Nutrition Label ~ Environmental Product Declaration

Nutrition Facts

Serving Size 1/2 cup dry (40 g)
Servings Per container: 13

Amount Per Serving

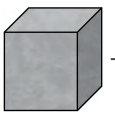
Calories 150 Calories from Fat 25

% Daily Value*

Total Fat 3 g	4%
Saturated Fat 0.5 g	2%
Trans Fat 0 g	0%
Cholesterol 0 mg	0%
Sodium 0 mg	0%
Total Carbohydrate 27 g	9%
Dietary Fiber 4 g	15%
Sugars 1 g	
Protein 5 g	
Vitamin A	0%
Vitamin C	0%
Calcium	0%
Iron	10%

*Percent Daily Values are based on a 2,000 calorie diet. Your daily values may be higher or lower depending on your calorie needs.

Calories:	2,000	2,500
Total Fat	Less than 65 g	80 g
Sat Fat	Less than 20 g	25 g
Cholesterol	Less than 300 mg	300 mg
Sodium	Less than 2,400 mg	2,400 mg
Total Carbohydrate	300 g	375 g
Dietary Fiber	25 g	30 g



ENVIRONMENTAL IMPACTS

Declared Product:
Mix 45FN31C2C • Jeffco Plant
Description: CDOT CLASS B/D/P LOW SLUMP
Compressive strength: 4500 PSI at 28 days

Declared Unit: 1 m^3 of concrete

Global Warming Potential (kg CO_2-eq)	345
Ozone Depletion Potential (kg CFC-11-eq)	8.20E-6
Acidification Potential (kg SO_2-eq)	1.01
Eutrophication Potential (kg N-eq)	0.39
Photochemical Ozone Creation Potential (kg O_3-eq)	22.4
Abiotic Depletion, non-fossil (kg Sb-eq)	7.02E-5
Abiotic Depletion, fossil (MJ)	710
Total Waste Disposed (kg)	102
Consumption of Freshwater (m^3)	3.24

Product Components: natural aggregate (ASTM C33), Portland cement (ASTM C150), batch water (ASTM C1602), fly ash (ASTM C618), admixture (ASTM C494), admixture (ASTM C260)

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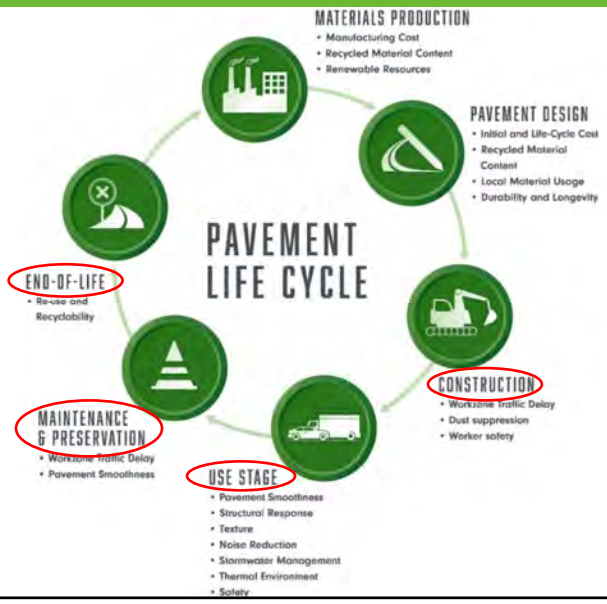
A Better Measure:
Life Cycle Assessments (Cradle-to-Grave)



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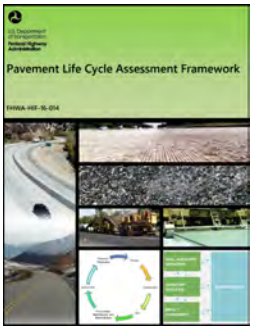
Federal Highway Administration:
Sustainable Pavements Technical Working Group

Source: FHWA

References



Software Tool:

LCA PAVE

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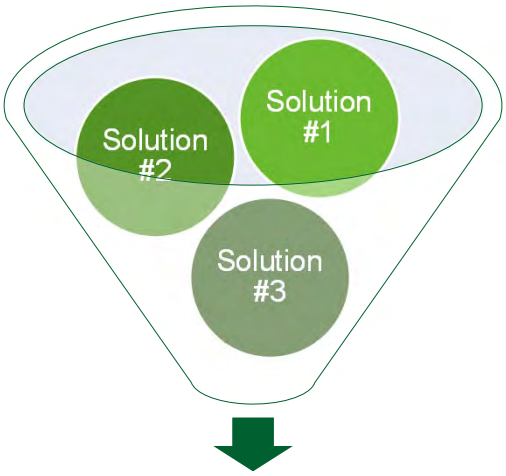
A Combination of Solutions Required to Reach the Goal



Greener Pavements

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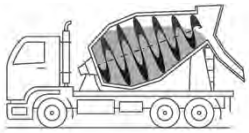
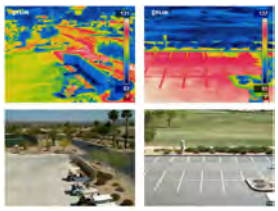
Combining Methods to Decarbonize Pavements



Use Low Carbon & Performance Based Concrete

Build & Maintain Smooth Pavements For Better Fuel Efficiency

Build Low Deflection & Pavements For Better Fuel Efficiency



Build High Albedo Pavement To Reduce Urban Heat Island

Plus Many Others…

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Pollution Reducing Roadways

- Photocatalytic pavements using titanium dioxide (TiO_2)
- TiO_2 creates hydroxyl radicals and superoxides when exposed to UV light
- Oxides naturally decompose atmospheric nitrous dioxides (NO_2)
- Transforms these pollution-causing particulates into water-soluble sulfates (nitrates)
- Nitrates washed away from the pavement surface when it rains.
- Placed in conjunction with concrete sealer

Credit: Pavement Technology, Inc.
Colin Durante

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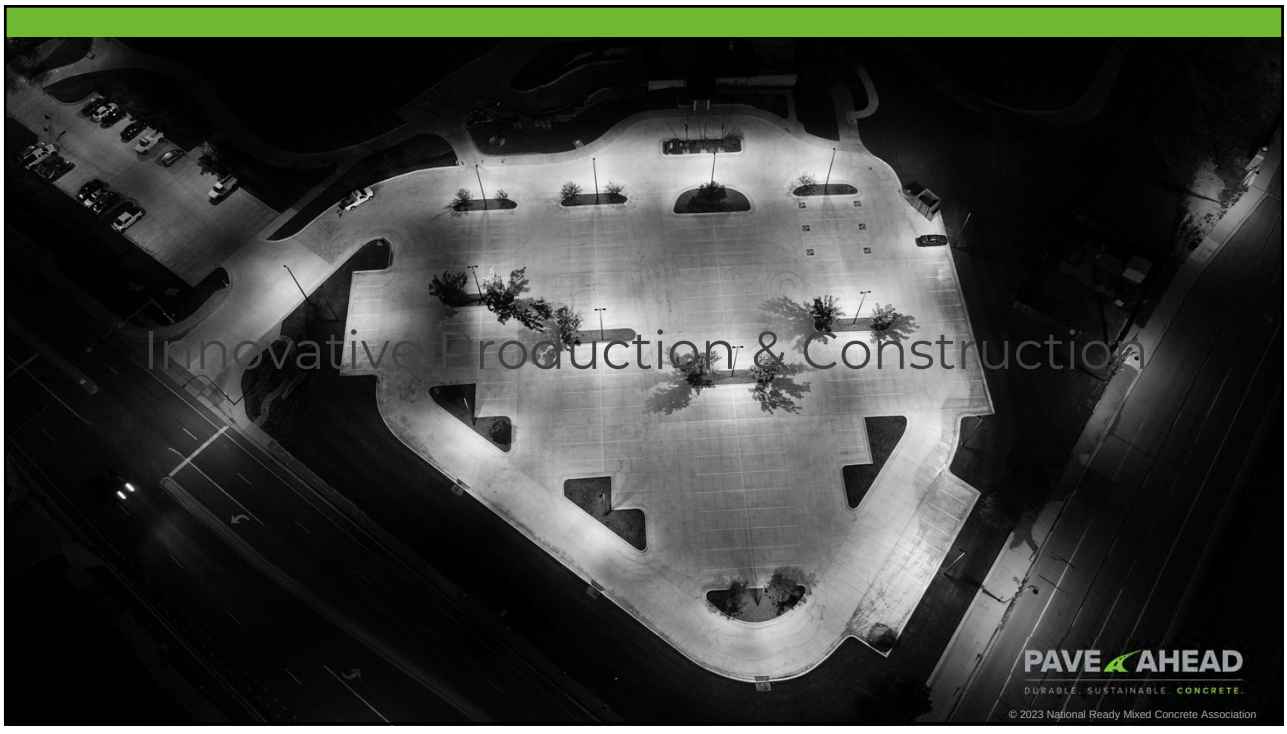

Zero Impact Manufacturing Sites and Projects

- Zero Emission
  - Greenhouse and Other Gases
  - Dust and Particulates
- Zero Harm Discharge
  - Toxic Metals and Chemicals
- Zero Liquid Discharge (ZLD)
  - Wastewater
  - Stormwater
  - Other Harmful Liquids (Fuels, Acids, Solvents, etc.)

Source: Volkswagen

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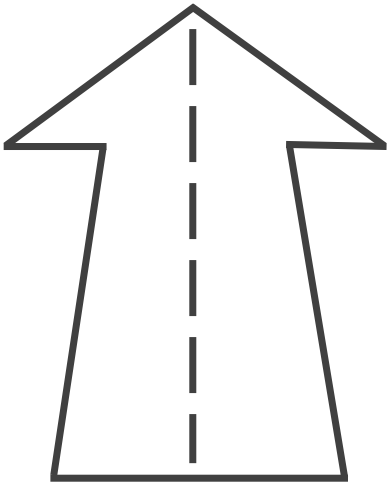
The Future of Concrete Transport

- Automated Operational Systems (Optimize Delivery)
- Real-Time Data and Reporting (Feedback) Systems
- Low or Zero Emission Delivery Vehicles
- Driverless Vehicles



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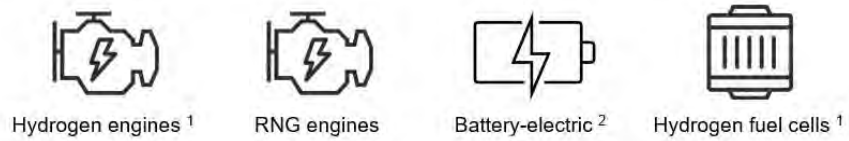
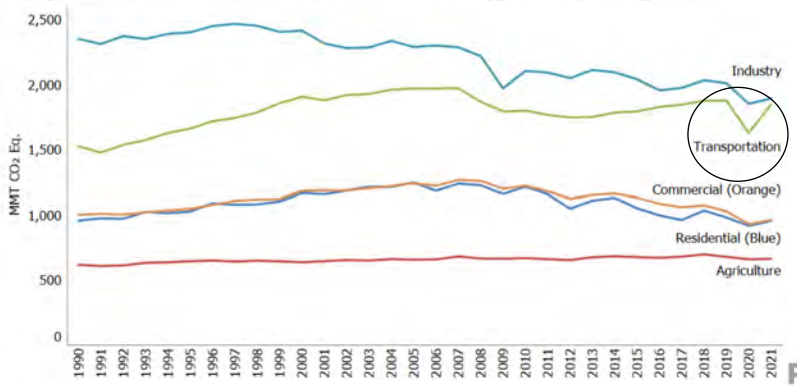
Powering Transportation With Low or Zero Carbon Fuels: Transportation Sector Emissions

Source: https://www.cummins.com/engines/hydrogen-engines





Transportation sector emissions rising at a higher rate than other sectors.
(EPA 2023)

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Powering Transportation With Low or Zero Carbon Fuels: Fuel Agnostic Engines

X15	L9	B6.7
Clean Diesel	Clean Diesel	Clean Diesel
Natural Gas	Natural Gas	Natural Gas
Hydrogen	Hydrogen	Gasoline
		Propane
		Hydrogen

Cummins' new fuel-agnostic engines have nearly identical components below the headgasket.
Components above the headgasket vary to accommodate different fuels, including hydrogen and natural gas.

Source: Cummins and Equipment World

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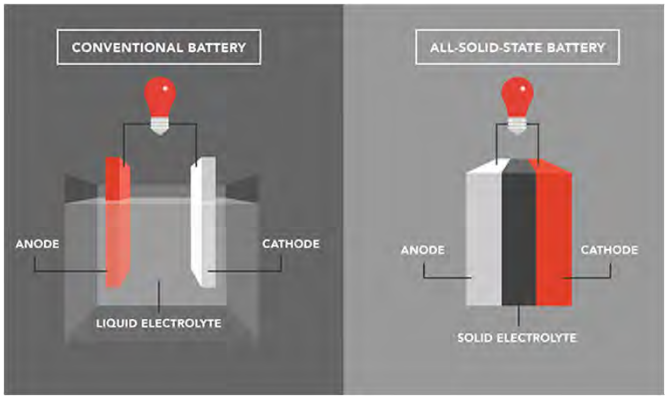
Battery Technology

Source: https://thenextweb.com/news/why-solid-state-ev-batteries-are-better-than-lithium-ion-counterpart

- Better Batteries
  - Longevity (per charge)
  - Power
  - Life
    - Repeated Charging Degradation
  - Size



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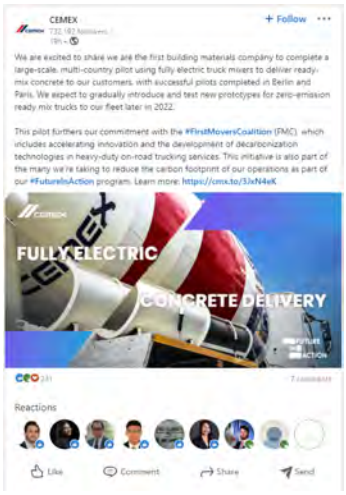
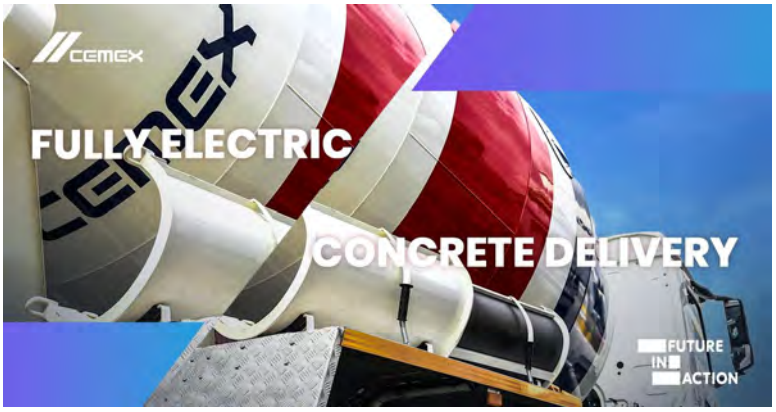
Low Environmental Impact Production & Delivery





February 15, 2022
56 Initial Trial in Germany and France

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Hydrogen Powered Vehicles

Source: https://www.newsweek.com/sponsored/harnessing-hydrogen-realize-carbon-free-society

Toyota Mirai

Hino Motors

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Hydrogen Fuel Enhancement System

Sources: Empire Hydrogen Energy Systems Inc., Vancouver, B.C. and April 20, 2022 Concrete News

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Hydrogen Powered Construction Equipment

Source: JCB https://www.thedrive.com/tech/42956/jcbs-newest-construction-vehicles-burn-hydrogen-instead-of-diesel

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Hydrogen Powered Shipping Vessel

Source: https://www.heidelbergcement.com/en/go-ahead-for-the-worlds-first-zero-emission-cargo-ship

Beginning in 2024, ship aggregates products for HeidelbergCement and grain for partner Felleskjøpet from West Norway to East Norway, and vice versa.

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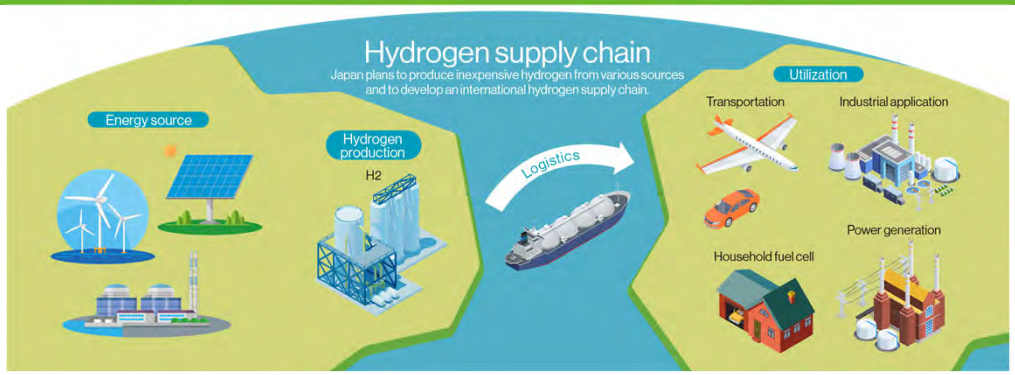
Hydrogen Supply Chain and Logistics

Source: https://www.newsweek.com/sponsored/harnessing-hydrogen-realize-carbon-free-society



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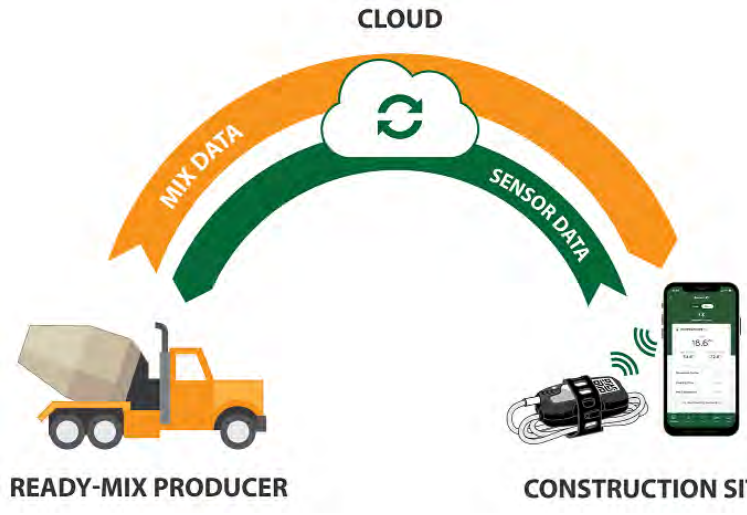
Automated and Real-Time Data



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Source: ©2022 Giatec Scientific Inc. All Rights Reserved.
SmartRock is a registered trademark of Giatec Scientific Inc., the U.S. registration no. 5,930,038

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Wavelogix's REBEL™ Concrete Strength Sensors

Source: https://wavelogix.tech/products/

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Concrete breaks and maturity curves are not needed.

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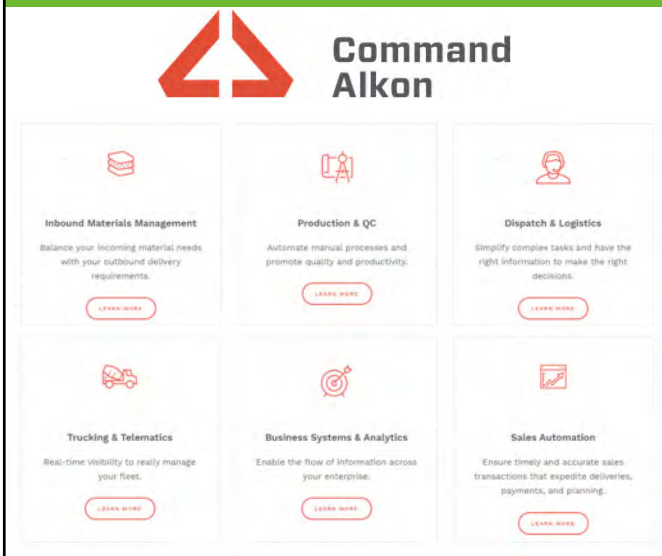

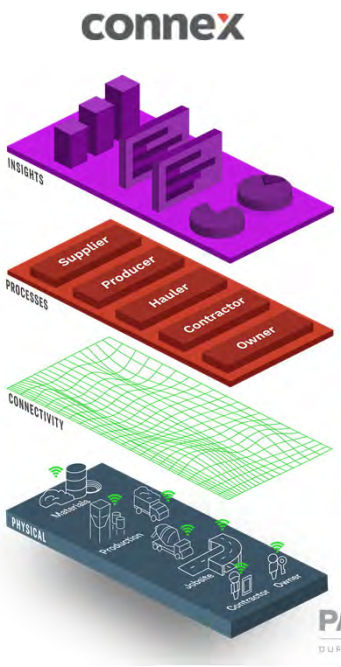

Digitizing the supply chain experience and work collaboratively with all trading partners.

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Precast Slabs

Source: Louisiana DOTD and National Precast Concrete Association

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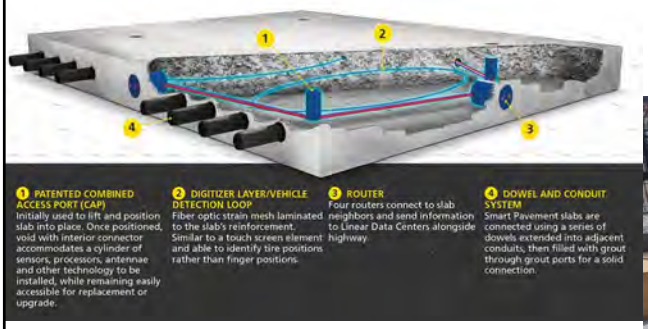
Smart Pavement

Driverless Vehicles, EV Charging, Pavement Heating, etc.

Source: Integrated Roadways and ACPA Concrete Pavement Progress Fall 2022

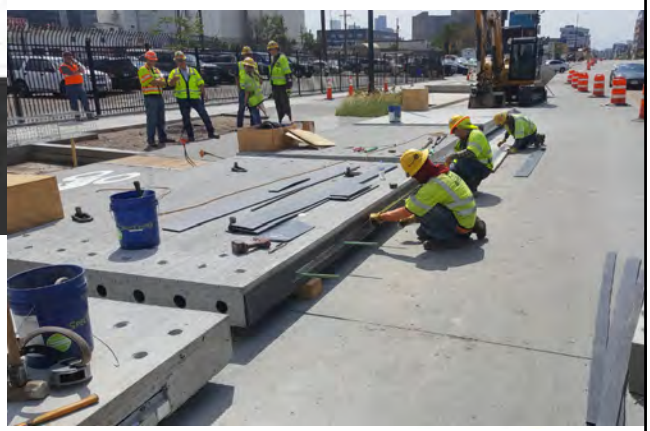


1 PATENTED COMBINED ACCESS PORT (CAP)
Initially used to lift and position slab into place. Once positioned, void with interior connector accommodates a cylinder of sensors, processors, antennae and other technology to be installed, while remaining easily accessible for replacement or upgrade.

2 DIGITIZER LAYER/VEHICLE DETECTION LOOP
Fiber optic strain mesh laminated to the slab's reinforcement. Similar to a touch screen element and able to identify tire positions rather than finger positions.

3 ROUTER
Four routers connect to slab neighbors and send information to Linear Data Centers alongside highway.

4 DOWEL AND CONDUIT SYSTEM
Smart Pavement slabs are connected using a series of dowels extended into adjacent conduits, then filled with grout through grout ports for a solid connection.



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Pavement Ride Quality Data Collection

- Crowdsourced pavement data collection through smartphone

carbin

CSHub MIT CONCRETE SUSTAINABILITY HUB

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Other Innovations

- Three-Dimensional Printing With Concrete Materials of Transportation Structures
- Compact Construction Equipment
  - Improved Mobility (Transport and On-Site)
  - Confined Spaces
- Incorporating Resilience in Transportation Against:
  - Fire
  - Water
  - Earthquake
- Advancements with Materials Testing
- Advanced Asset Management
- Smart Roads – Pavement & Vehicle Communication/Interaction

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The Next Generation

- Reduced or net-zero carbon emission concrete (It is already here!)
- Smart sensors embedded in concrete (Some technologies already available)
- Self-healing pavement (Nano-materials currently available)
- Solar and energy-harvesting roads
- Charging lanes for electric vehicles
- Smart streetlights
- Heated roadways

Smart concrete could pave the way for high-tech, cost-effective roads
Luna Lu, Vishal Saravade Nov 12, 2020

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NRMCA Resources
How Can We Assist You for Free?
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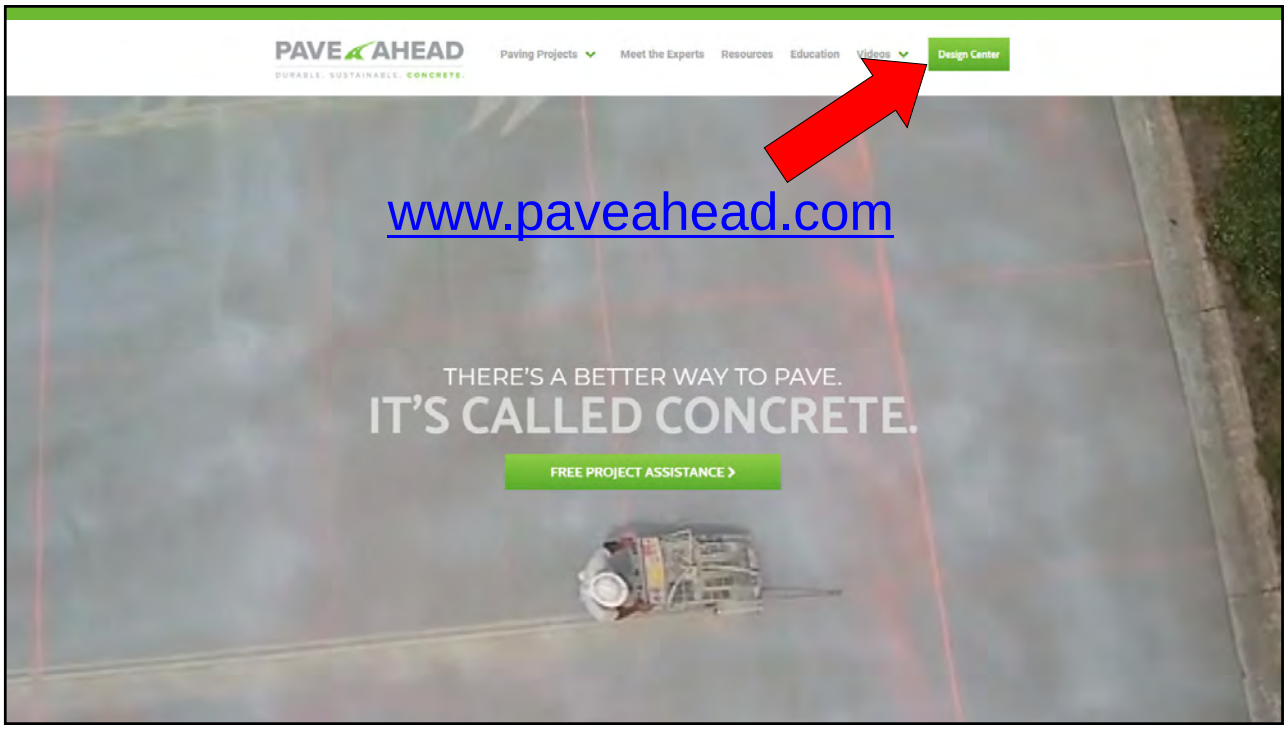
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