2nd International Conference on Best Practices for Concrete Pavements
Florianopolis, Brazil – November 2-4, 2011

Sustainable Concrete Pavements
Small Steps, Big Gains

Shiraz Tayabji
Fugro Consultants, Inc., Columbia, Maryland, USA

Presentation Outline

- Sustainability concepts
- Pavement sustainability considerations
  - Construction phase
  - Use phase
- Specific concrete pavement sustainability applications
  - Optimizing pavement design
  - Concrete materials considerations
  - Concrete mixture

Focus of presentation:

Factors that can come into play after the concrete pavement selection is made – during the design & construction phase

What is Sustainability?

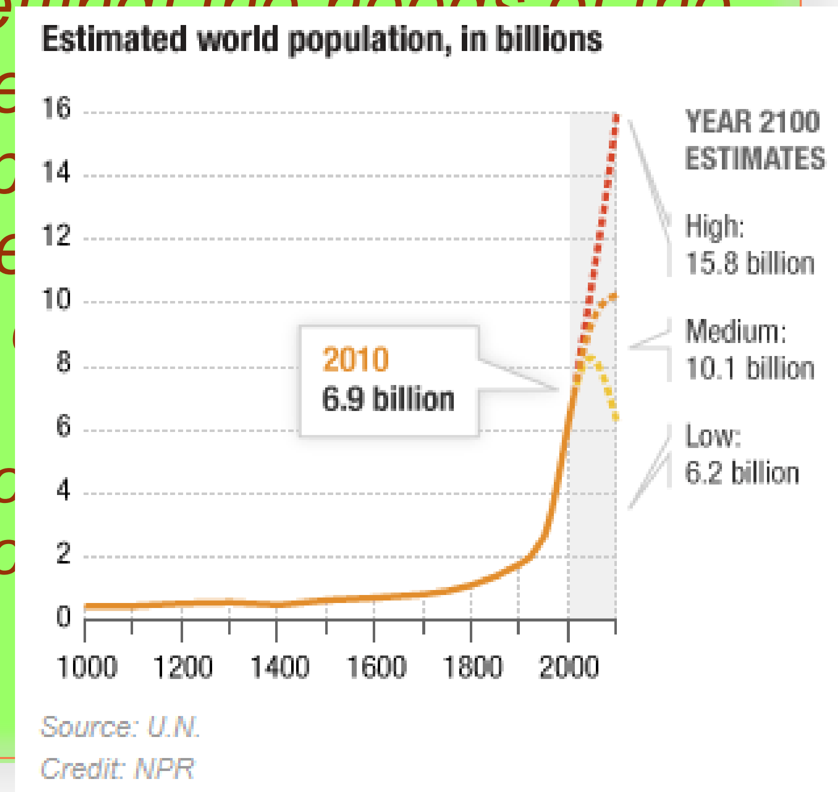
- **Sustainability** – derived from Latin: *sustinēre* (from *sus*, up and *tenēre*, to hold) Essentially the capacity to **endure**.
- Term now applied very broadly to every facet of life, but increasingly in the context of human sustainability on Earth – particularly as causes of global warming and climate change are debated.

What is Sustainability?

UNITED NATIONS
PLANET EARTH - SOL SYSTEM

World Population

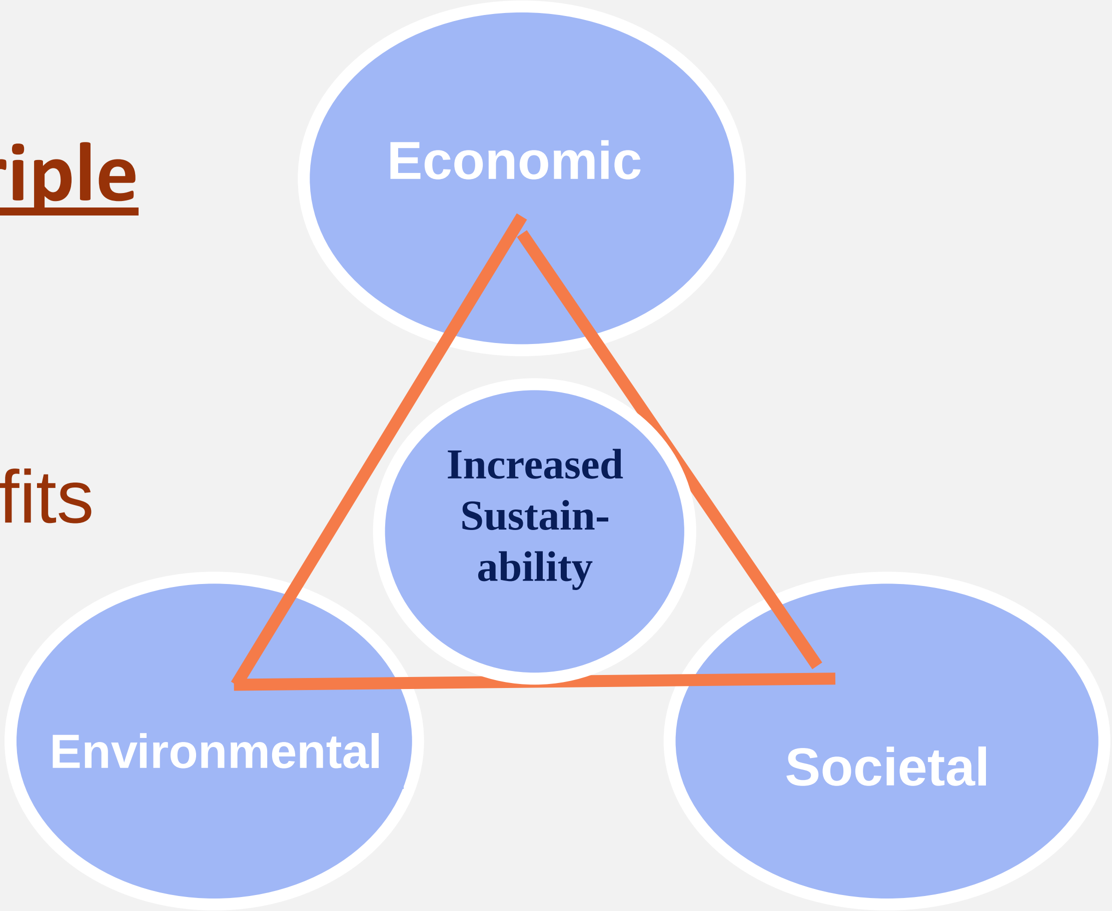
- **1100 AD – 300,000,000 (equal to current US population)**
- **1800 AD – 1 billion**
- **1900 AD – 2 billion**
- **2011 October 31 – 7 billion**



Term applied broadly to everything now & increasingly in the context of constructed projects

Sustainable Infrastructure

- Must address **The Triple Bottom Line:**
  - Economic benefits
  - Environmental benefits
  - Societal benefits



- **Focusing on one benefit takes the system out of balance**
- **Moving towards the center balances the system**

Sustainability – Construction Phase vs. Use/Operation Phase (GHG Focus)

THE BUSINESS CASE: SUSTAINABILITY ACCOUNTING

EXAMPLE:

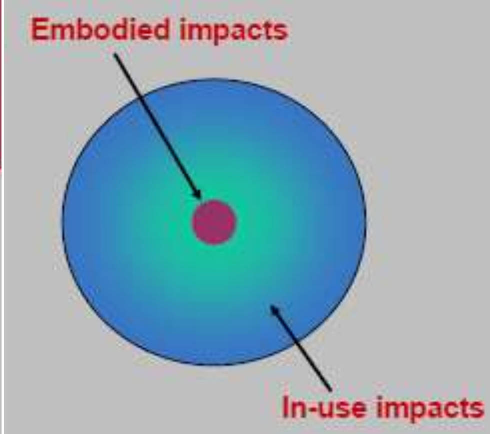
Benefits

- Employment (direct indirect)
- Use of alternative fuels
- Use of alternative raw materials
- Investment in local community
- Employment (direct / indirect)
- Designs for minimal energy use / CO_2 emissions
- Use of recycled materials in construction

Raw material extraction	Cement manufacture	Concrete Manufacture plus (cement & concrete placing)
Land use / sensitive land use	Use of fossil fuels CO_2 SO_x, NO_x, CO	Health & safety Dust

Costs

CARBON STRATEGY: THE HOLISTIC VIEW



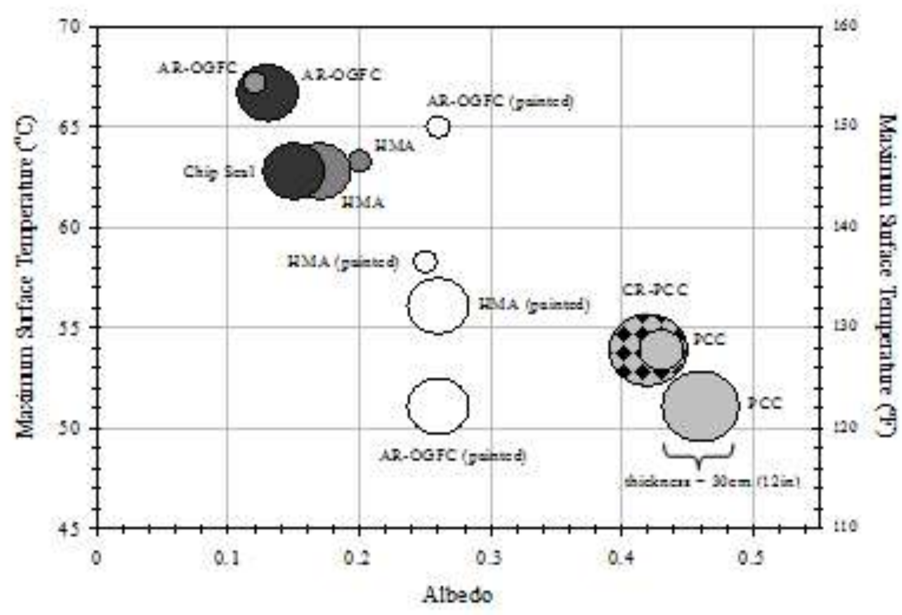
90% of the environmental impact occurs during the in-use phase (from heating, cooling and lighting)

10% is from the 'embodied energy' used to produce the fabric of the building itself (taken over a 60 year life-cycle)

What About Pavement Use Phase?

- At least 80% of the energy and emissions associated with pavements is incurred during use
  - Vehicle Fuel Efficiency
    - Traffic flow
    - Rolling resistance
  - Albedo Effect
    - Heat island
    - Lighting costs
  - Noise Pollution

NATIONAL CENTER of EXCELLENCE
SMART INNOVATIONS FOR URBAN CLIMATE AND ENERGY
ARIZONA STATE UNIVERSITY



Surface Reflectivity - Lighting

Enhanced Nighttime Visibility:

- Improved pedestrian and vehicle safety
- Reduced lighting & energy requirement:
  - Fewer fixtures/watts
  - Up to 33% reduction
  - AASHTO - 40% lower
  - Huge budget impact!

Concrete cuts highway lighting costs. Studies show proper lighting levels can be reached on concrete with 50% fewer fixtures than needed for dark-colored pavement.

[Fortune, 1959]

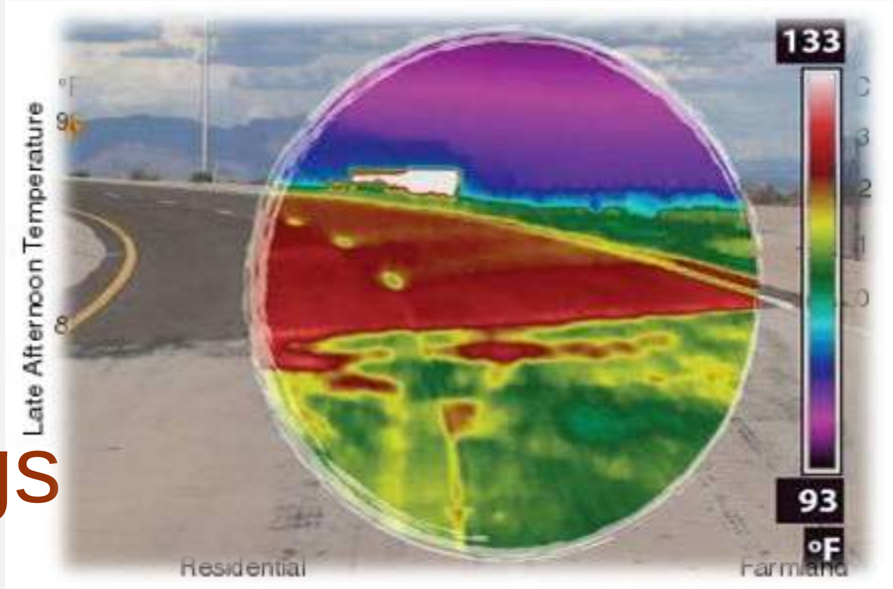
Surface Reflectivity – Urban Heat

Urban Heat Island Mitigation:

➢Urban areas up to 9°F warmer due to UHI → greater energy use and resulting pollution

➢Concrete pavements are an effective mitigation strategy

- o lower city temperatures
- o lower cooling costs
- o reduce smog formation



➢Potential energy savings $2B in US alone *(LBNL'08)*

Sustainable Concrete Pavements

- Making the Construction Phase More efficient

- This is where good engineering meets sound materials technology & good construction practices by minimizing energy and resources used, minimizing life cycle cost & significantly reducing GHG (CO2) emission
  - By optimizing key concrete pavement design features
  - By working with limited material resources to achieve design objectives
  - By balancing competing, and often contradictory, objectives during the construction phase

Concrete Pavements: A (Reasonably) Mature Technology in the Year 2011

1920's
Life – 10+ years

1960's
Life – 20+ years

Resulting from improvements in design, construction & material technologies

& continuing to evolve

2005 on
Long life - 40+ years

Highway Concrete Pavements: The Practice

- Jointed plain concrete pavement
  - 4.6 m joint spacing – US & international practice
  - Slab thickness
    - US: 150 mm (streets) to 200 to 250 mm (secondary roads) to 250 to 350 mm (primary systems)
    - Europe: 250 to 275 mm (primary systems)
  - Jointing – use of dowel bars for medium/heavy volume of truck traffic
  - Bases - stabilized base for medium/heavy volume of truck traffic

Long-Life Concrete Pavements

Current US Expectations

- Original PCC surface service life – 40+ years
- Paveme ... ailures and material
- Paveme ... for cracking, faulting
- Paveme ... and surface texture characteristics with <u>minimal intervention activities to correct for ride & texture, for joint resealing, and minor repairs</u>

But, are we really doing our part to design & construct <u>sustainable</u> long-life concrete pavements?

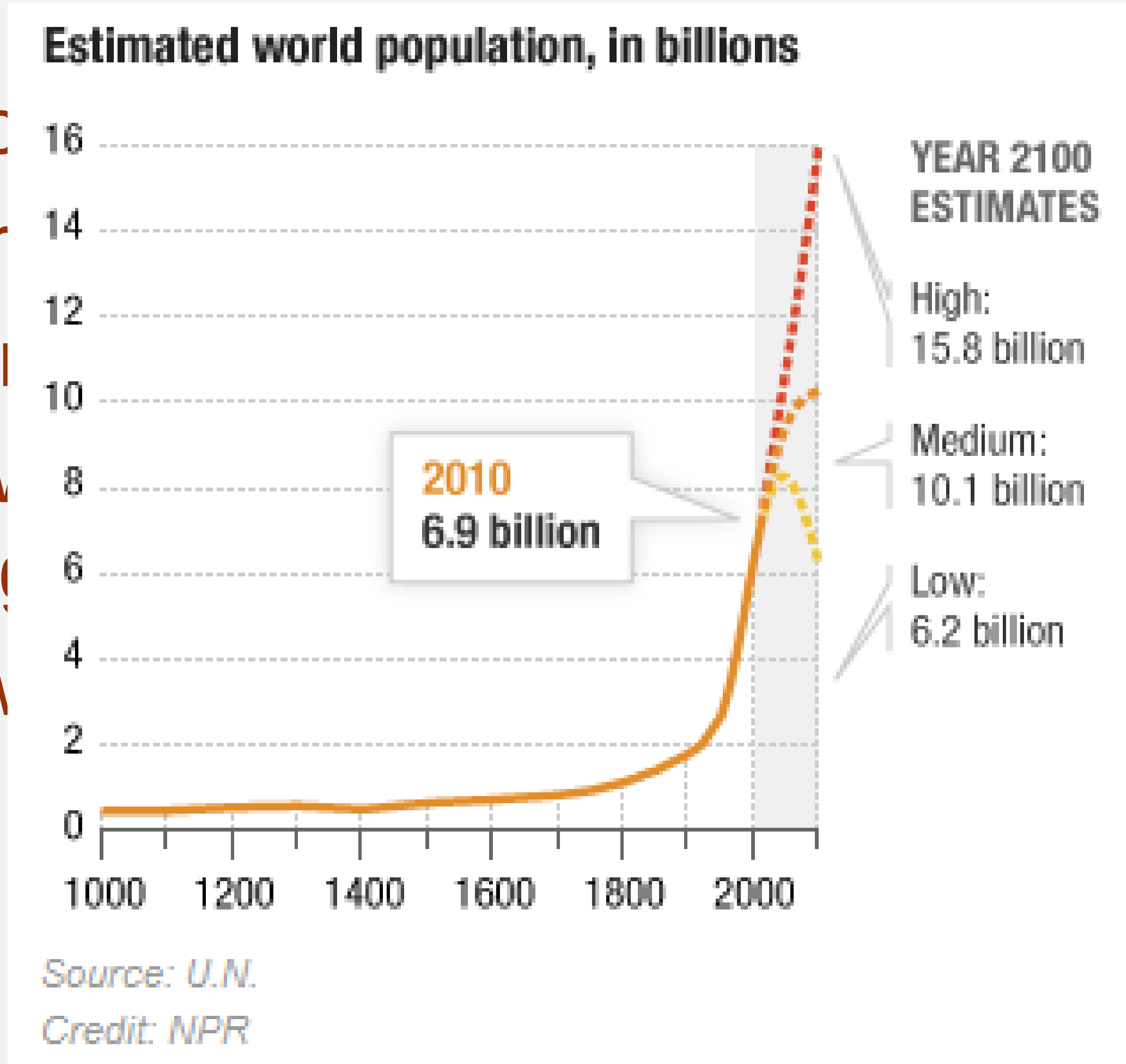
Are Concrete Pavements Sustainable?

- Long pavement lives?
- Minimal maintenance requirements?
- 100% recyclable?
- Minimal waste of resources?
- High reflectance (Lighting visibility)?
- Lower heat island effects?
- Safe and quiet?

Must Provide Environmental/Societal/Economic Benefits

Current Discussion Items

- Are our c
- Is there r
- Will the i
- How do w ainable technolog
- Should w



INTERNATIONAL CONFERENCE ON SUSTAINABLE CONCRETE PAVEMENTS: PRACTICES, CHALLENGES, AND DIRECTIONS

September 15–17, 2010—Sacramento, California

Sustainable Strategies From Raw Material Production To Long-Term Service

Sustainability Conference Highlights

Conference papers addressed

- **Pavement design optimization**
- **Concrete materials & mixtures**
- **Construction practices**
- **Life cycle assessment**
- **Industry innovations**
- **Highway agency practices – implementation of sustainability considerations in everyday practice**

Consideration of sustainability is not a one-time activity. It needs to be a life-long habit.

Key Messages from the Conference

- Consider both the construction phase and the use phase – wrt energy use and GHG emission
  - Metrics for determining benefits being developed (LCA)
- For the construction phase
  - Minimize environmental impacts
  - Conserve resources
- By
  - Reducing concrete volume in the pavement
  - Reducing paste volume in the concrete
  - Reducing the portland cement portion in the paste
  - And, optimizing use of other materials

Key Messages from the Conference - Need to Quantify Sustainability Benefits

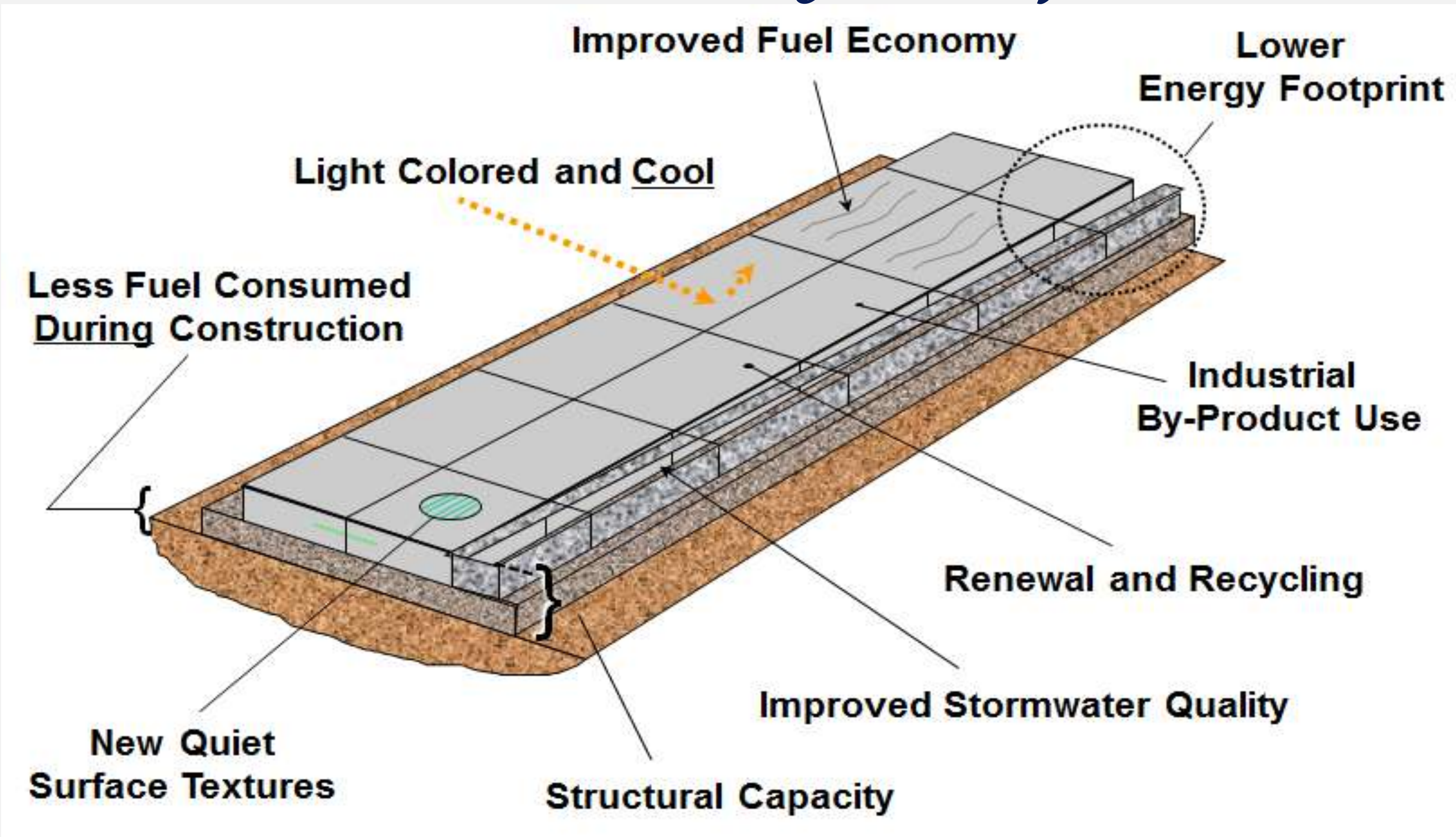
- To prove an improvement is an improvement
- To assess the relative value of change
- To provide incentive for change

- Sustainability metrics are being developed and <u>will be required</u> in the US for Federally funded projects in the near future

How Do We Measure Life Cycle Impacts?

- "Greenwashing" is rampant – almost everything is now labeled as sustainable or green
- Rating systems
  - US Green Roads
  - Other
- Life cycle inventory (LCI)/life cycle assessment (LCA)
  - Based on ISO 14000
  - Need to establish regional data and usable software tools

Integrated Design - Maximize Sustainability Benefits



Adapted from Wathne, ACPA

How Can We Make the Construction Phase More Sustainable?

- Optimize concrete pavement design features
  - Reliable designs for long-life (MEPDG)
  - Reduce concrete volume ➔ less thick pavements
- Optimize concrete mixture design
  - Use less paste ➔ less portland cement
  - Using local/recycled materials (two lifts, etc)
- Reduce <u>100%</u> reliance on portland cement
  - Use less OPC & more “greener” cementitious materials
- Make construction more efficient (improve practice)
  - Use processes less damaging to the environment

Why Does Concrete Matter?

- Portland cement production is responsible for ~1.5% of U.S. total CO_2; similar in other industrialized countries
- One ton of cement ~> One ton of CO_2
  - About half of CO_2 production is from decomposition of carbonate rock

- Portland cement is responsible for approximately 90% to 95% of the CO_2 and 85% of the embodied energy in concrete

US Pozzolan and Slag Use

- Class F fly ash: 15% - 25%
- Class C fly ash: 15% - 35% (limited use)
- Slag: 25% - 50%
- Silica fume: Not used in US for paving
- Natural pozzolan: Not <u>yet</u> used in US for paving

Blended cement use is allowed & is common

However, ASTM C1157 cements not widely used yet

New Cementitious Materials

- Next-generation sustainable cements for concrete
  - High SCM content blended cements
    - Up to 85% slag in structural concrete
    - Up to 50% slag in paving concrete
  - Alkali-activated cements
    - Do not rely on the byproduct of the cement hydration
    - Alkali activators stimulate hydration of fly ash, etc
  - Geopolymers
    - Use alkali solutions to dissolve and polymerize reactive minerals rich in alumino-silicate glass
      - Non-hydration reaction
      - Use of fly ash or metakaolin

New Cementitious Materials

- Next-generation sustainable cements for concrete
  - Cements that sequester (use) CO_2
    - Source
      - Atmosphere
      - Exhaust gases from coal-fired power plants
    - One process
      - Pass CO_2 laden exhaust gases through seawater
      - Synthetic aggregate
      - Carbon sequestered cement
    - CSC Materials, Inc.
      - Not prone to ASR- do not release hydroxyl anions
      - Hardens in hours
      - Useable quantities not yet produced

New Cementitious Materials

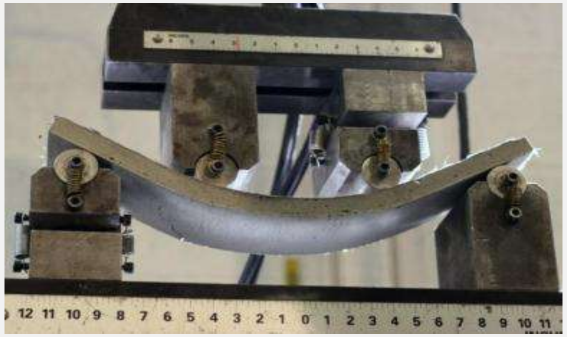
- Eco-friendly cements for concrete mixtures
  - Novacem©
    - Uses magnesium silicate instead of limestone
      - Lower heating temperature (about half)
    - Absorbs large amounts of CO_2 as it hardens/cures
    - Carbon negative
  - Supercritically carbonated calcareous composites (SC^4)
    - Very new technology from the UK
    - Super-critical CO_2 treatment of the cementitious material
    - Fully carbonate the material
    - Significant increase in strength and reduced permeability

New Cementitious Materials

- Energetically modified cements
  - Patented process
    - Intensive grinding of OPC with pozzolans
    - 15 years of development in Sweden
  - Increases the binding capacity of the cement
  - Increases the rate of strength gain and increased strength
    - Lower cement requirement
  - Plant in Texas
    - Swedish process
    - More reactive fly ash- CemPozz®

New Concrete Materials

- Engineered cement composites
  - High-performance, fiber-reinforced cement-based materials
  - Like FRC, except
    - No coarse aggregate is used
    - Lower fiber content
  - Highly ductile composite- “bendable concrete”
  - High fracture toughness
  - Autogenous healing of hairline cracks
  - Higher compressive strength



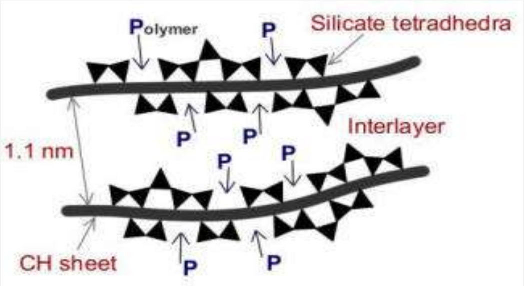


Illustration courtesy of Rouhollah Alizadeh;
Photograph courtesy Nicole Casal Moore/University of Michigan

New Concrete Materials

- Titanium dioxide-modified concrete
  - TiO_2 is a potent photocatalyst
    - Break down organic compounds
      - Exposed to sunlight in the presence of water vapor
  - No_x removed and broken down
    - Benign substances
    - Washed away by rainfall
  - Maintains whiteness
    - Reduce heat island effects
  - TX Active®
    - Developed in Italy
    - I-35W Bridge in Minneapolis

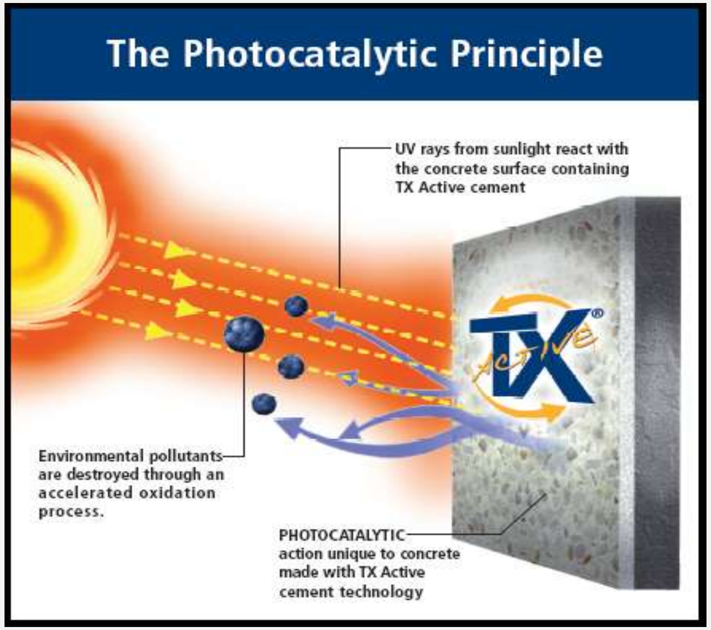
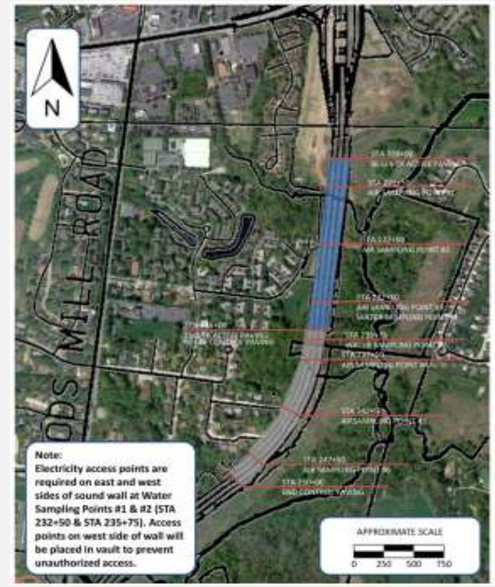


Photo courtesy of the FIGG Bridge Engineers, Inc., and Tim Davis;
Sketch : **ESSROC Italcementi Group**

New Concrete Materials

- Titanium dioxide-modified concrete
  - Applications in Europe
  - US: 450 meter test section placed in 2010
    - SR 141 near St. Louis, Missouri
  - TiO_2 in the top lift of a two lift pavement
  - TiO_2 in pervious shoulder pavement
  - Helps improve air quality
  - Helps improve water quality



New Concrete Materials

- Pervious concrete
  - Concrete with narrowly graded coarse aggregate
    - Very little or no fine aggregate
  - A system of interconnected voids
    - Typically15-35% voids
    - Drain water very quickly
  - Advantages
    - Reduce surface runoff
    - Filters stormwater
    - Recharge the ground water
    - Reduces hydroplaning
    - Absorbs noise

Conference & Practice Highlights:

Pavement Design Optimization

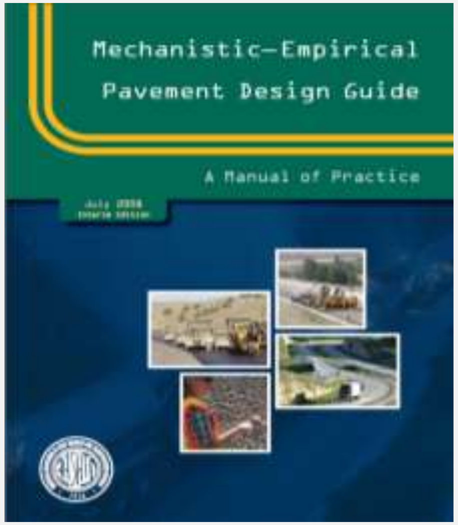
Reducing Portland Cement Use

Optimizing Concrete

Improving Construction Practices

Pavement Design Optimization

- New Mechanistic-Empirical Pavement Design Guide (MEPDG) allows **optimization** of many key design features to develop LLCP designs
  - Joint spacing
  - Base type
  - Edge support
  - Load transfer at joints
  - Concrete thickness

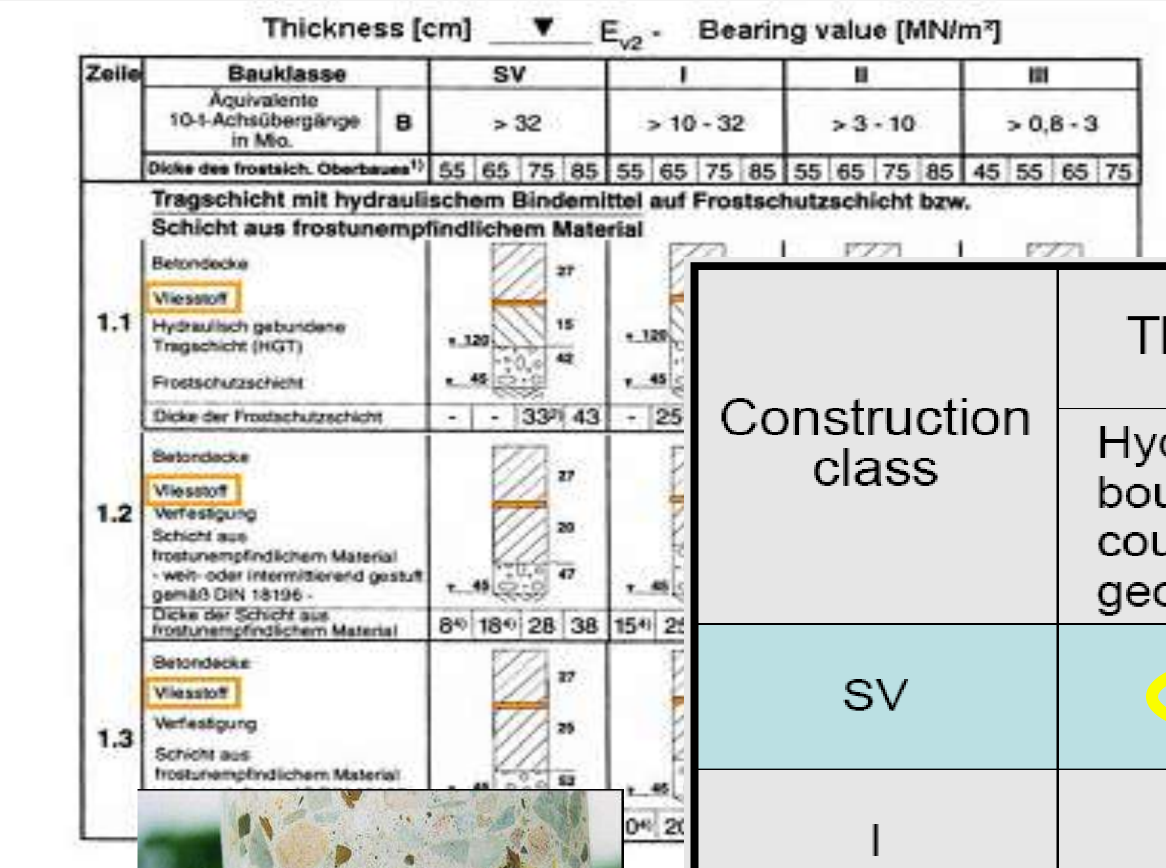


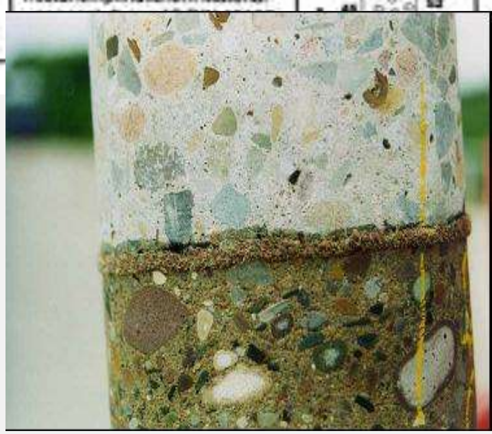
- End result – more cost-effective & reliable designs
- End result – more sustainable designs

Pavement Design Optimization

- Some simple changes in approach to reduce concrete volume & amount of other materials <u>without compromising performance</u>
  - Reduce slab thickness
    - Improve foundation/base (European approach)
    - Use widened lane & shorter joint spacing
  - Reduce materials
    - Reduce no. of dowel bars (9 or 10 vs. 12)
    - Reduce joint sealant material (single cut sawing)
- Other changes
  - Consider two-lift design & construction to allow use of local/marginal & recycled materials in the lower lift.

German Standard Designs



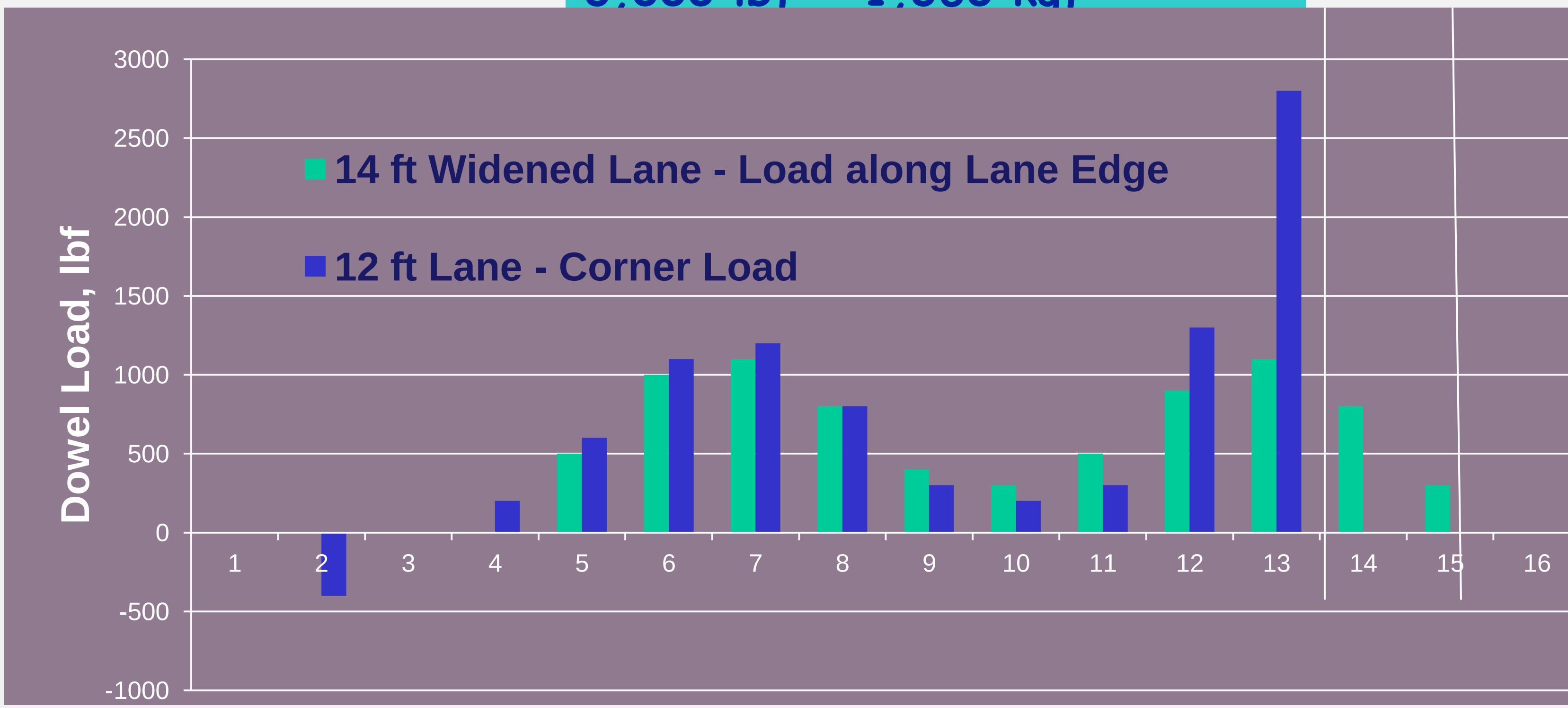


Construction class	Thickness of concrete pavement in cm		
	Hydraulically bound base course with geotextile	Bituminous base course	Crushed stone base course
SV	27	26	30
I	25	24	28
II	24	23	27
III	23	22	26

Dowel Loads Across a Joint

40,000 lb TAL; 18,000 kg TAL
3,000 lbf = 1,360 kgf

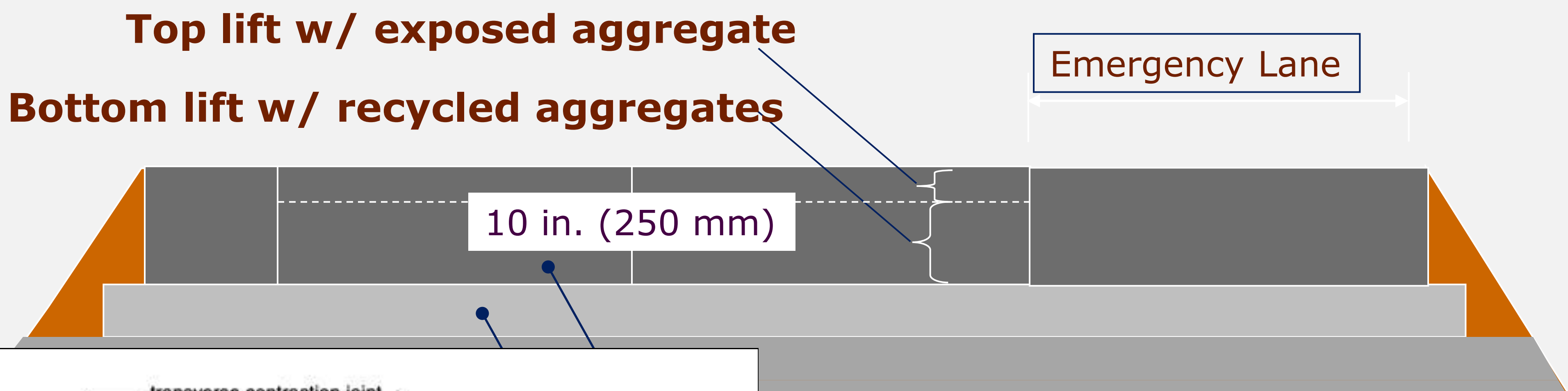
- **For corner loading, outer 4 dowels very critical**
- **Need for 9 or 10 optimally distributed dowel bars**

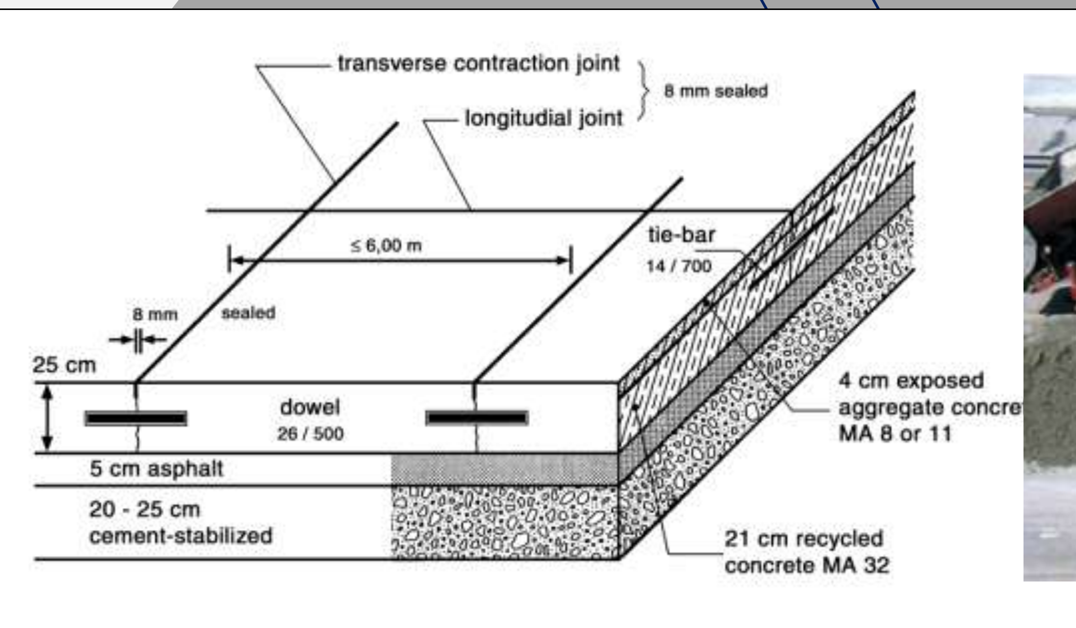


Two-Lift Concrete Pavement Construction (based on European Practice)

- Two-lift construction to maximize the use of locally available/recycled materials
  - The lower lift can be made with materials that might not perform well in a surface layer
  - The top lift can be designed to withstand the harsh environmental and loading conditions at the pavement surface

Typical European Section
(Less PCC thickness than in US)





Concrete Texturing – The Practice
(affects safety & noise level)

- Surface texture provides desired level of skid resistance, but noise a concern
- Common Methods
  - Longitudinal tine
    - 3 by 3 by 20 mm – better/preferred
  - Transverse tine – out of favor!!
  - Next generation diamond grinding (under development)

Low Noise Concrete Texturing – New for US

- Grinding
- Under Development
  - Next generation grinding
  - Exposed aggregate

MnRoad - 2010

LLCP Joint Sealing Approaches

- Conventional approach
  - Initial sawcut – 1/4 in. or less
  - Widening cut for sealant reservoir – shape factor
- New single cut approach – 1/8 to 3/16 in.– more widely used now
  - Narrow unsealed
  - Narrow filled
  - Narrow sealed

Conference Highlights:

Pavement Design Optimization

Reducing Portland Cement Use

Optimizing Concrete

Improving Construction Practices

Cement Reduction for Paving Concrete

- Some simple changes to reduce cement use
  - Reduce paste content
    - Use of **optimized gradation** & use larger aggregate size
    - Reconsider minimum cementitious materials requirement (current: typically, 540 pcy); consider end product spec
  - Increase use of SCMs (flyash & slag)
    - Results in more durable concrete
    - Efficient use of waste products/by-products
  - Use Greener cements
    - Blended cements (US ASTM C595)
    - Performance-based cements (US ASTM C1157) – PLC use
    - Non-portland cements – under development

Caltrans Concrete Spec
A 21st Century Concrete Specification

- Significantly reduces carbon-footprint of concrete
  - Increased the use of SCMs
  - Decreased the use of cement
  - Allowed the mix of any SCMs (ternary mixes, etc.)

Greener Cements

ASTM C1157 Performance Cements

- US ASTM C 1157 offer equivalent performance to US ASTM C 150 cements
- Types may be customized to address specific performance requirements
  - Sulfate resistance, low heat of hydration, high early strength
- Often include supplementary cementitious material to lower clinker factor
  - Fly ash, slag cement, and/or natural pozzolans

Sacramento Conference Paper

USE OF PERFORMANCE CEMENTS (US ASTM C1157) IN COLORADO AND UTAH

- PORTLAND-LIMESTONE CEMENT

Tom Van Dam, APTech

Brooke Smartz, Holcim

Todd Laker, Holcim

International Conference on Sustainable Concrete Pavements

September 15-17, 2010

Colorado 2007
40th and Havana Streets – Denver

- Side by side comparison of US ASTM C150 I/II and US ASTM C1157 GU cements
- No noticeable performance differences
- Cold weather construction possible
- Aligns with City of Denver's Greenprint CO_2 reduction initiatives

Other examples were also presented – Colorado & Utah

Study Summary

- Performance cements (US ASTM C 1157) provide an option to reduce environmental impact without compromising performance

- A number of transportation projects have been constructed in Colorado & Utah and show successful applications of US ASTM C 1157 cements

Greener Cements

Portland Limestone Cements (PLC)

- PLC Overview
  - Reduces GHG emission during production – less clinker
  - Performance of PLC similar to C 150 cements
- Canadian CSA A3001-08 standard includes:
  - (a) portland cement
  - (b) blended hydraulic cement
  - (c) **portland-limestone cement**
  - (d) supplementary cementing materials
  - (e) blended supplementary cementing materials

US ASTM C 150 allows up to 5% limestone addition

Portland-limestone cements as defined by CSA A3001-08 *Cementitious Materials Compendium* standards contain from 5% to 15% limestone.

Sacramento Conference Paper

Use of Low-CO_2 Portland Limestone Cement for Pavement Construction in Canada

Michael Thomas

University of New Brunswick

Kevin Cail, Bruce Blair, Anik Delagrave,

Paul Masson and Ken Kazanis

Lafarge North America

International Conference on Sustainable Concrete Pavements: Practices, Challenges, and Directions, Sacramento, CA, Sept. 15 to 17, 20102010

CSA A3001-08 Types of Hydraulic Cement

Blended PLC – 2010 Amendment

Portland cement type	Blended hydraulic cement type*	Portland-limestone cement type†‡	Blended PLC – 2010 Amendment	Name§
GU	GUb	GUL	GULb	General use cement
MS	MSb	–		Moderate sulphate-resistant cement
MH	MHb	MHL	MHLb	Moderate heat of hydration cement
HE	HEb	HEL	HELb	High early-strength cement
LH	LHb	LHL	LHLb	Low heat of hydration cement
HS	HSb	–		High sulphate-resistant cement

New in 2008 →

**The suffix "b" indicates that the product is a blended hydraulic cement.*

†The suffix "L" indicates that the product is portland-limestone cement.

‡Portland-limestone cements should not be used in an environment subjected to sulphate exposure as defined in Table 3 of CAN/CSA-A23.1.

PLC is produced to provide equivalent performance to PC in Canada

So requirements for Type GUL (up to 15% limestone) same as Type GU (< 5%)

CSA A23-09 Use of Portland Cement in Concrete

- Portland limestone cement is permitted for use in all classes of concrete except for sulfate exposure classes (S-1, S-2, S-3)

Overall Study Summary

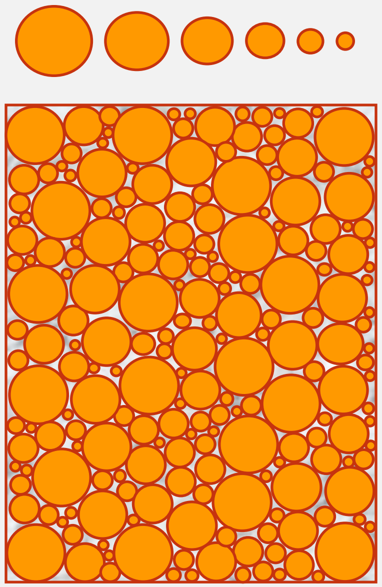
- PLC with 12% limestone performance, when optimized for equal strength ➔ portland cement (Type PC)
- Blended PLC with 12% limestone and 15% slag performance ➔ PC with 23% less clinker
- PLC also performs well with (further) additions of SCM at the ready-mixed concrete plant (less CO_2 emissions).
- PLC or blended PLC together with (further) SCM additions at the concrete plant
  - **Reduces the clinker content of paving mixes by up to 50%**
  - **CO_2 reductions ➔1 to 1½ tons per concrete truck!**

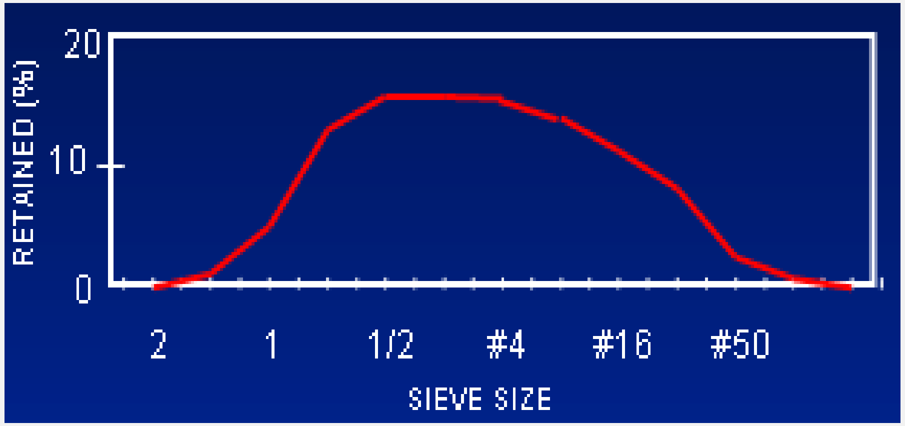
Conference Highlights:

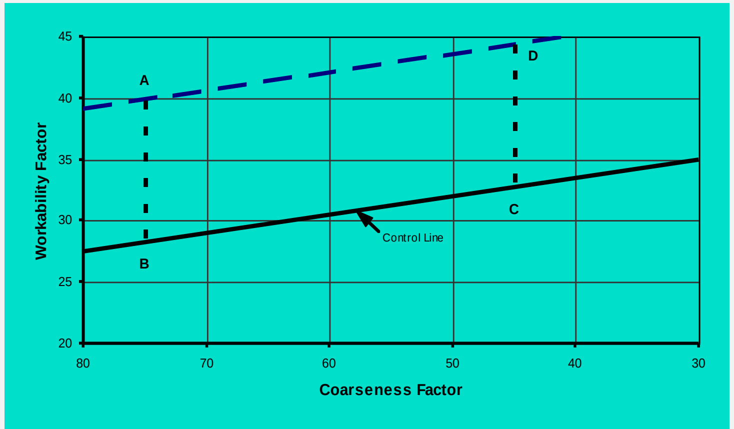
Pavement Design Optimization
Reducing Portland Cement Use
Optimizing Concrete
Improving Construction Practices

Reducing Paste (Cement)
Optimizing Aggregate Gradation

- Use of combined gradation (Shilstone)
  - **Less paste, less cement; more economical**
  - Dense mixture
  - Better for slipform paving
  - Less sensitive to excessive consolidation
  - Better finishing







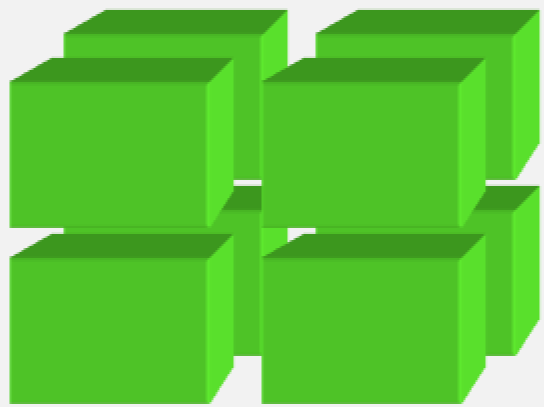
Reducing Paste (Cement)
Use Larger Aggregate Size

- Larger the Particle Sizes:
  - Less surface area to coat

(reduced paste & water demand ➔ better concrete)

6 sq. cm surface area

1 cubic cm



12 sq. cm surface area

Conference Highlights:

Pavement Design Optimization
Reducing Portland Cement Use
Optimizing Concrete
Improving Construction Practices

Sustainability at the Construction Stage
(Becca Lane, MTO – Sacramento Conference)

- Use of quality materials and good construction practices to ensure long life concrete pavement
  - And, use of locally available concrete aggregate resources
- List of pre-qualified concrete aggregate sources to reduce risk of material related distress
- Good QC / QA practices
  - Verify concrete properties, slab thickness & strength to ensure durability
- Ensure smoothness – good ride quality increases pavement life & results in fuel savings (Canada NRC findings)

Ready for Implementation Now

Small Steps, Big Gains

- Optimize long-life pavement designs
  - Thickness reduction; fewer dowel bars
  - Single cut joints; better bases/foundation
- Reduce portland cement content
  - Use SCMs, US ASTM C 595 & ASTM C 1157 cements
  - Use optimized aggregate gradation & larger aggregates
- Continue to improve construction efficiencies
  - Increase use of locally available/recycled materials

Climate change and our future

WE MUST DO OUR SHARE AS ENGINEERS TO MAKE LIFE ON EARTH MORE SUSTAINABLE FOR OURSELVES & FOR FUTURE GENERATIONS – 7 BILLION & GROWING!

THIS IS A CHALLENGING GOAL, BUT WE ENGINEERS AND CONTRACTORS AND MATERIAL SUPPLIERS LIKE A CHALLENGE!

Achieving sustainability will enable the Earth to continue supporting human life as we know it.

Source Wikimedia," Blue marble" images of earth from NASA


Thank You!