Towards Sustainable Pavement Systems: Webinar Series

Webinar #3:

Sustainable Strategies for Concrete Pavements: Materials, Design, and Construction

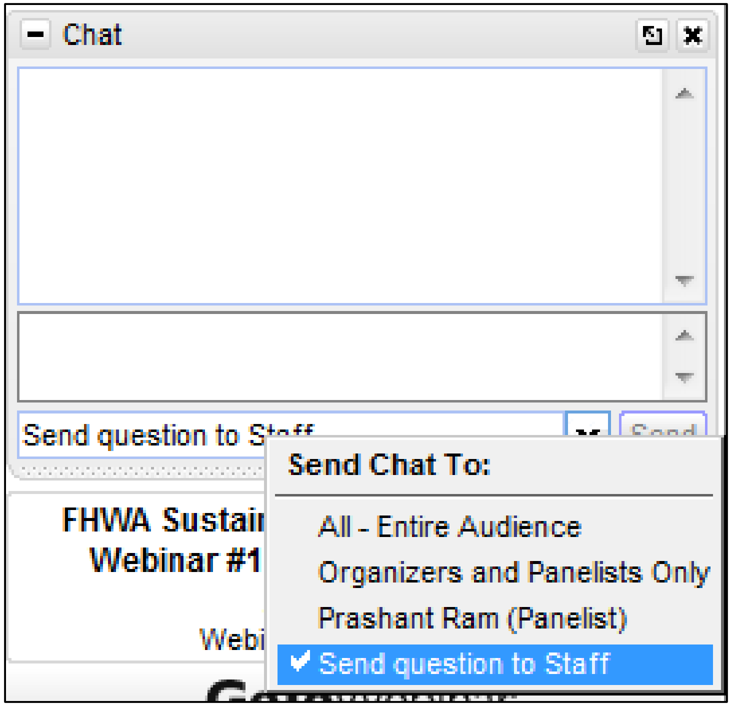
June 25, 2015

Webinar Series

- Sponsored by Federal Highway Administration
- “Towards Sustainable Pavement Systems: A Reference Document”
  - http://www.fhwa.dot.gov/pavement/sustainability/
- Total of 5 webinars from April to September
- Webinars recorded for posting on FHWA website

Housekeeping

- Formal Presentations:
  - 1 hour 40 min
- Questions:
  - 20 minutes
  - Use chat box to submit
  - Use dropdown menu to "send questions to staff"



- Professional Development Hours (PDHs) Certificates
  - 2 hours per webinar

Today's Webinar

- Topic: Sustainable Strategies for Concrete Pavements: Materials, Design, Construction
- Speakers:
  - Gina Ahlstrom, FHWA
  - Tom Van Dam, NCE
  - John Harvey, University of California-Davis
  - Jeff Roesler, University of Illinois
  - Mark Snyder, Engineering Consultant
- Moderators:
  - Kurt Smith, Applied Pavement Technology, Inc.
  - Tom Van Dam, NCE

FHWA Sustainable Pavements Program

Background and Overview

Gina Ahlstrom

US DOT is Committed to Advancing Sustainability

- DOT will incorporate sustainability principles into our policies, operations, investments and research through innovative initiatives and actions such as:

  – Infrastructure investments and other grant programs,
  – Innovative financial tools and credit programs,
  – Rule- and policy- making,
  – Research, technology development and application,
  – Public information, and
  – Enforcement and monitoring.

Policy Statement

Signed Secretary Anthony R. Foxx, June 2014

U.S. Department of Transportation
Federal Highway Administration

FHWA
Sustainable Pavements Program

- Support the US DOT goals for sustainability
- Increase the body of knowledge regarding sustainability of asphalt and concrete materials throughout the pavement life cycle
- Increase the use of sustainable technologies and practices in pavement design, construction, preservation, and maintenance

"Towards Sustainable Pavements: A Reference Document"

- Guidelines for the design, construction, preservation and maintenance of sustainable pavements using asphalt and concrete materials

- Educate practitioners on how sustainability concepts can be incorporated into pavements

- Encourage adoption of sustainable practices

A Collaborative Effort

- Comprehensive review of current literature
- Extensive review by representative from key stakeholders groups:
  - State Departments of Transportation
  - Other Public Agencies
  - Asphalt and Concrete Industries
  - Academia

FHWA Sustainable Pavements Program

- Materials and Consideration of Life Cycle
- Aggregate Materials
- Hydraulic Cement Materials and Concrete Mixtures

Tom Van Dam

Materials and Consideration of the Life Cycle

- Must consider material choices from a life cycle perspective
  - What are the agency’s sustainability goals?
  - What are the impacts of using a material once versus multiple times?
  - What are the trade-offs in increasing the use of recycled, co-product, or waste materials (RCWMs)?

Recycled, Co-Product, or Waste Materials (RCWMs)

- Recycled materials are obtained from old pavement and are included in new pavement
  - e.g. reclaimed asphalt pavement (RAP) and recycled concrete aggregates (RCA)
- A co-product is from another process (often industrial) that brings value
  - e.g. slag cement
- Waste are materials that would normally be landfilled
  - e.g. fly ash? air-cooled blast furnace slag aggregate?

Considerations When Using RCWMs

- Does the RCWM result in equivalent or better performance?
  - What if it is just slightly worse?
- Does the RCWM have to be transported great distances?
- Does the RCWM make it more difficult to recycle the pavement in the future?

Other Material Considerations

- Does longer life justify increased material transportation or production-related impacts?
- Does the pavement design make best use of lower impact materials?
- Are the impacts of transporting materials considered?
- Are specifications protecting the owner’s interest or a barrier to innovation?
- Are there impacts on construction variability?

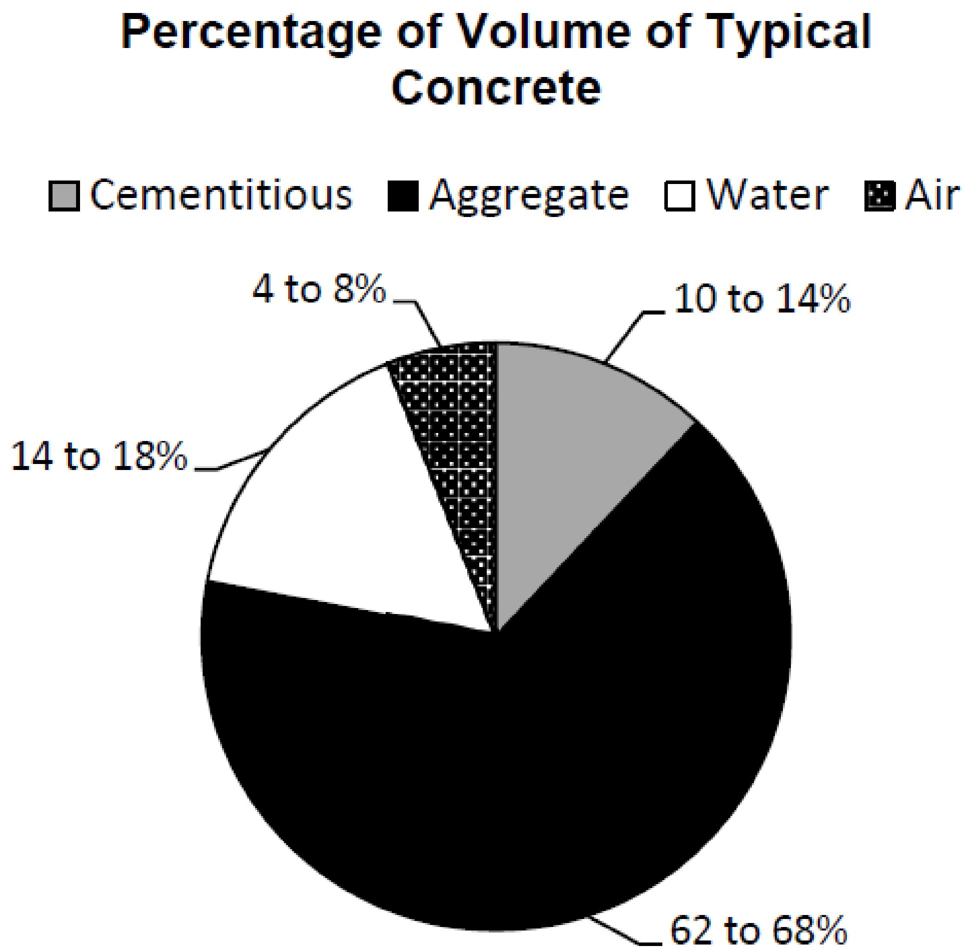
Aggregate Materials

- Largest share of mass and volume in a pavement structure
  - Have relatively low environmental footprint per unit mass
  - Consumed in large quantities
- Impact incurred in mining, processing, and transporting aggregates
  - Impact of transportation can be very large

Aggregates

- Used in asphalt and concrete mixtures, bound and unbound base and subbase
- Natural aggregates are classified as crushed stone or sands and gravels
- Manufactured aggregates are often created to possess unique characteristics
  - Lightweight most common
  - Can also include RCWMs such as air-cooled blast furnace slag

Typical Volumes of Aggregate



Tayabji, Smith, and Van Dam 2010

Aggregates – The Facts (2012)

- Produced in all 50 states
- 1,324M tons of crushed stone worth $12B
  - 82% used as construction materials and 10% used in cement manufacturing
- 927M tons of sand & gravel worth $6.4B
  - 93% used in road construction

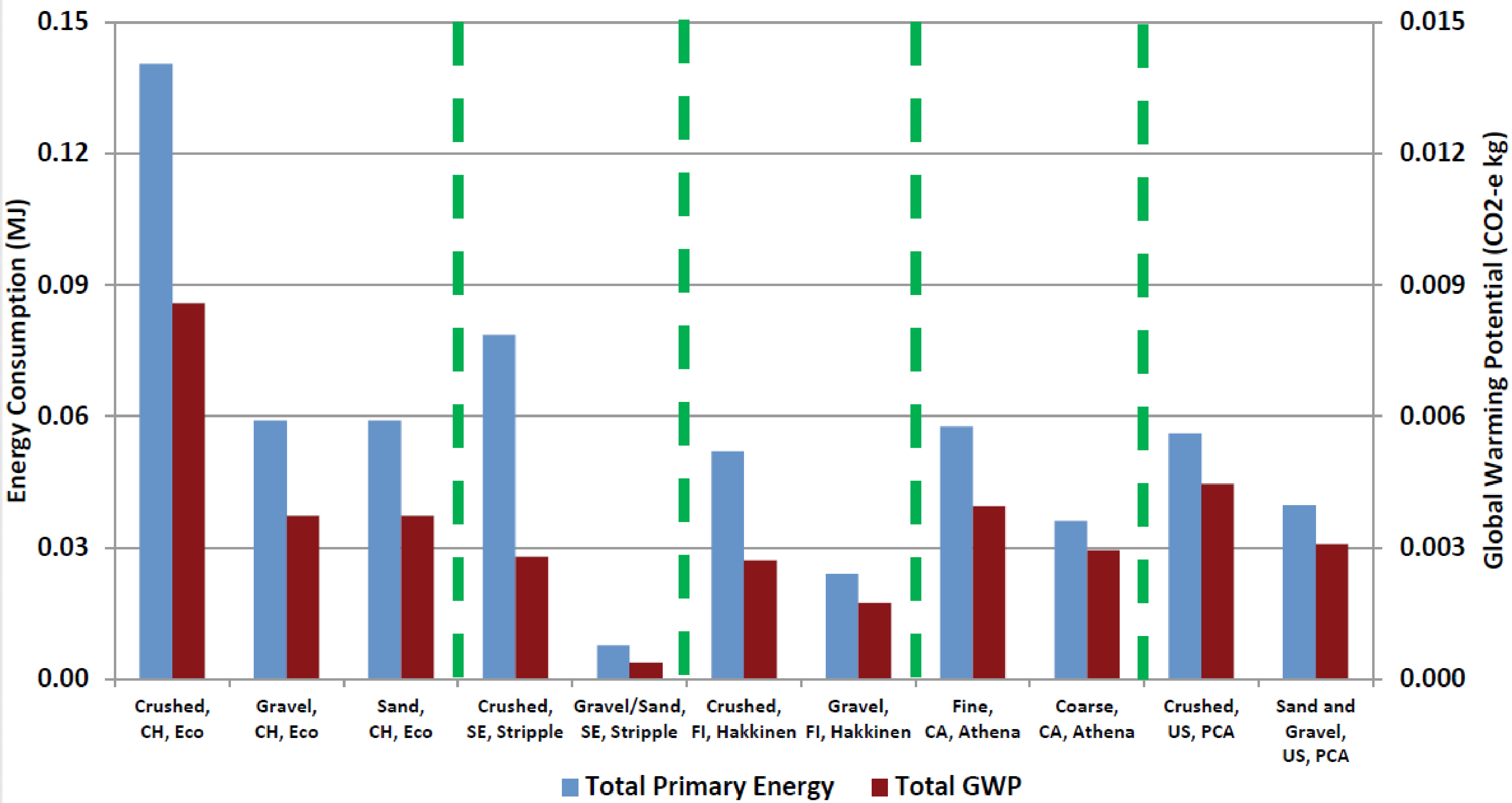
RCWMs Used as Aggregate

- Reclaimed asphalt pavement (RAP)
- Recycled concrete aggregate (RCA)
- Recycled asphalt shingles (RAS)
- Air-cooled blast furnace slag (ACBFS)
- Steel furnace slag (SFS)
- Foundry sand

Aggregates and Environmental Impacts

- Energy consumption and GHGs – depends on source of electrical power and transport distance
  - Crushed stone has greater impacts
- Other impacts include fugitive dust, water consumption, land-use issues, and community impacts
- Impacts make it difficult to permit new aggregate sources
  - Transport distance increasing

Aggregate Impacts: Energy and GHGs



Transportation Mode and Fuel Consumption

Mode	Ton-Miles/Gallon
Trucks[2]	150
Rail	478
Inland towing	616

Notes:

1. This is gross fuel use, not life-cycle fuel use.
2. Truck load assumed to be 25 tons (22.6 mt) on a 40 ton (36.28 mt) gross vehicle weight truck, loaded one way.

About 22 lbs of CO_2 from burning one gallon of diesel fuel

Strategies for Improving Sustainability

- Reduce use of virgin aggregate over the life cycle
- Reduce impact of virgin aggregate acquisition and processing
- Reduce impact of transporting aggregates
  – Use barges or rail if possible

Example: The Illinois Tollway

- Committed to recycling 100% of existing pavements
- Two-lift composite concrete using RCWM in bottom lift
- In-place recycling of existing pavements
- Decisions are first economic, then environmental

Photo compliments of Steve Gillen, Illinois Tollway Authority

Aggregate Issues and Future Directions

- Proximity of aggregate sources to urban centers
  - Trade-off between transportation and local community impacts
- Increasing pressures to increase use of RCWMs
  - Trade-off with regards to performance
- Increased use of marginal aggregates
- Demand for specialty aggregates increasing to meet specific sustainability goals

Hydraulic Cement and Concrete Mixtures

- Hydraulic cement concrete is humankinds most commonly used material after water
  - Approximately 1 yd^3/person/year
- Large economic, environmental, and social impacts
  - 80.5 million tons of cement manufactured in the U.S. in 2014
  - In 2013, linked to just under 0.5% of US GHGs
- About 5 percent of cement is used in paved roads

	On-site Energy 10^6 kJoules	On-site Energy %	CO_2 Emissions 10^6 tonne	CO_2 Emissions %
Raw Materials – Quarrying and Crushing				
Cement Materials	3,817	0.7%	0.36	0.3%
Concrete Materials	14,287	2.6%	1.28	1.2%
Cement Manufacturing				
Raw Grinding	8,346	1.5%	1.50	1.4%
Kiln: fuels	410,464	74.0%	38.47	36.8%
Reactions			48.35	46.3%
Finish Milling	24,057	4.3%	4.32	4.1%
Concrete Production				
Blending, Mixing	31,444	5.7%	5.65	5.4%
Transportation	61,933	11.2%	4.53	4.3%
Total	**554,409**	**100%**	**104.50**	**100%**

Source: Energy and Emission Reduction Opportunities from the Cement Industry, U.S. Department of Energy.

Portland Cement in Concrete

Cement

Gravel
Sand
Water

Typical concrete at the gate:
0.26 t CO_2 /yd^3 concrete
0.24 t CO_2 from portland cement

Sustainability is Enhanced by Using Less Portland Cement

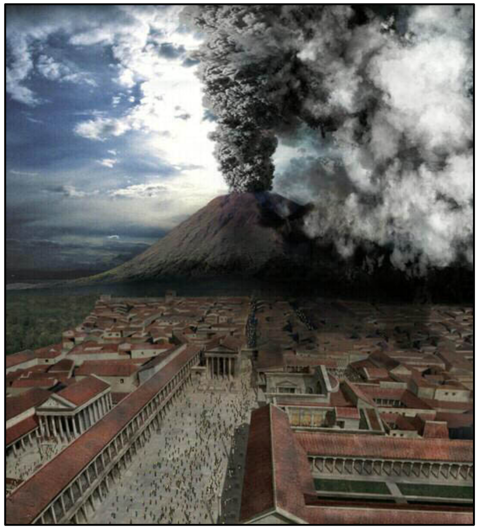
- Reduce clinker in cementitious material
- Reduce cementitious content in concrete
  - From 564+ lbs/yd^3 to 500 lbs/ft^3 or less
  - Context sensitive
- Reduce concrete needed over the life cycle
  - Improved design – thinner structures
  - Improved durability

Reducing Clinker Content in Cement

- Replace clinker with ground limestone and inorganic processing additions
  - AASHTO M 85 portland cement can have up to 5% limestone and 5% inorganic additions
  - AASHTO M 240 Type IL blended cement can have up to 15% limestone
- Replace clinker with supplementary cementitious materials (SCMs)
  - Added at concrete plant
  - Obtained as blended cement (AASHTO M 240)

Supplementary Cementitious Materials (SCMs)

- Fly ash
  - Collected from flue gases of coal burning power plant
- Slag cement
  - From iron blast furnace
- Natural pozzolan
  - Calcined clay, volcanic ash, ground pumice, etc.

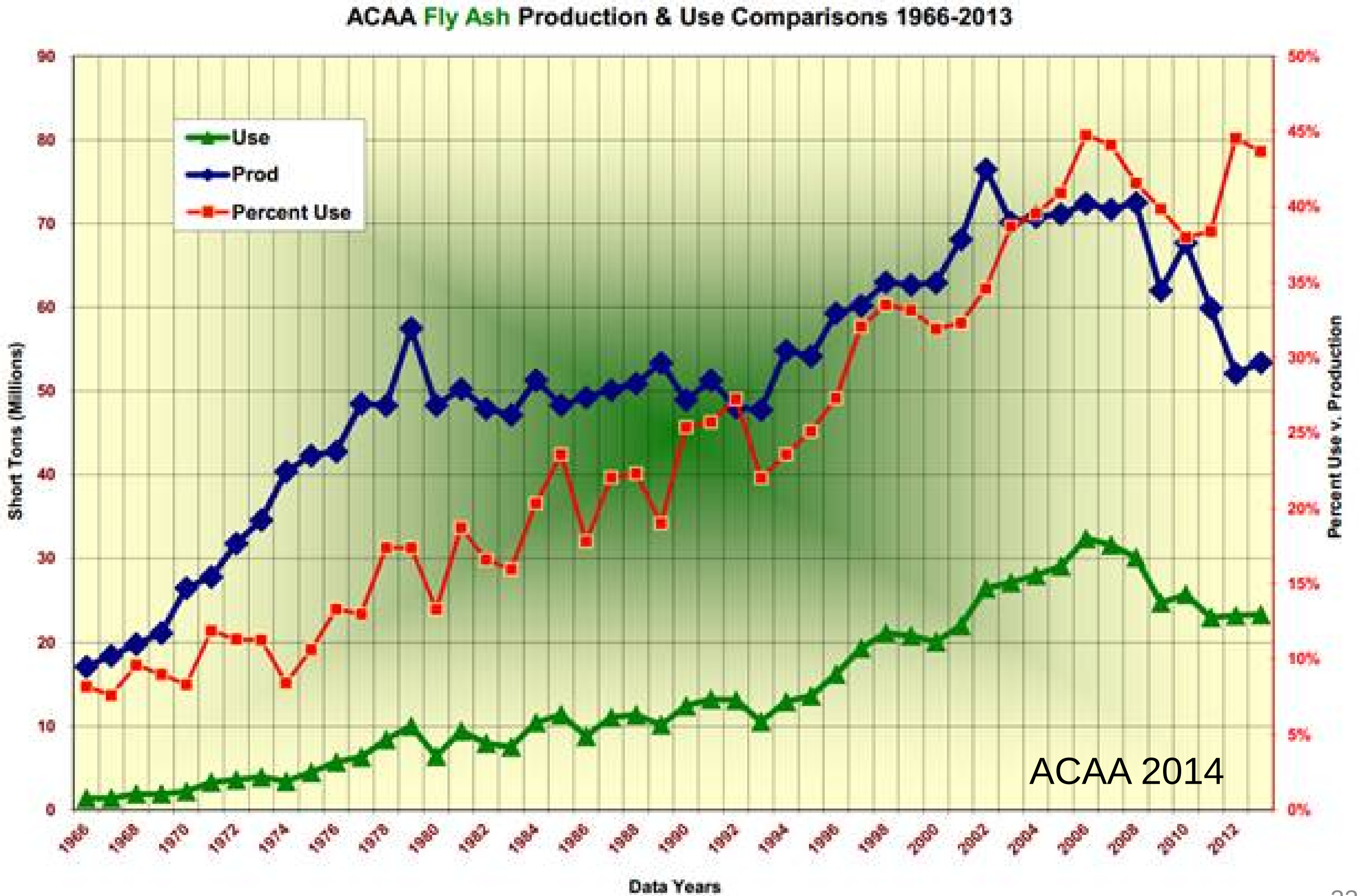


Typical Replacement Levels for SCMs in Paving Concrete

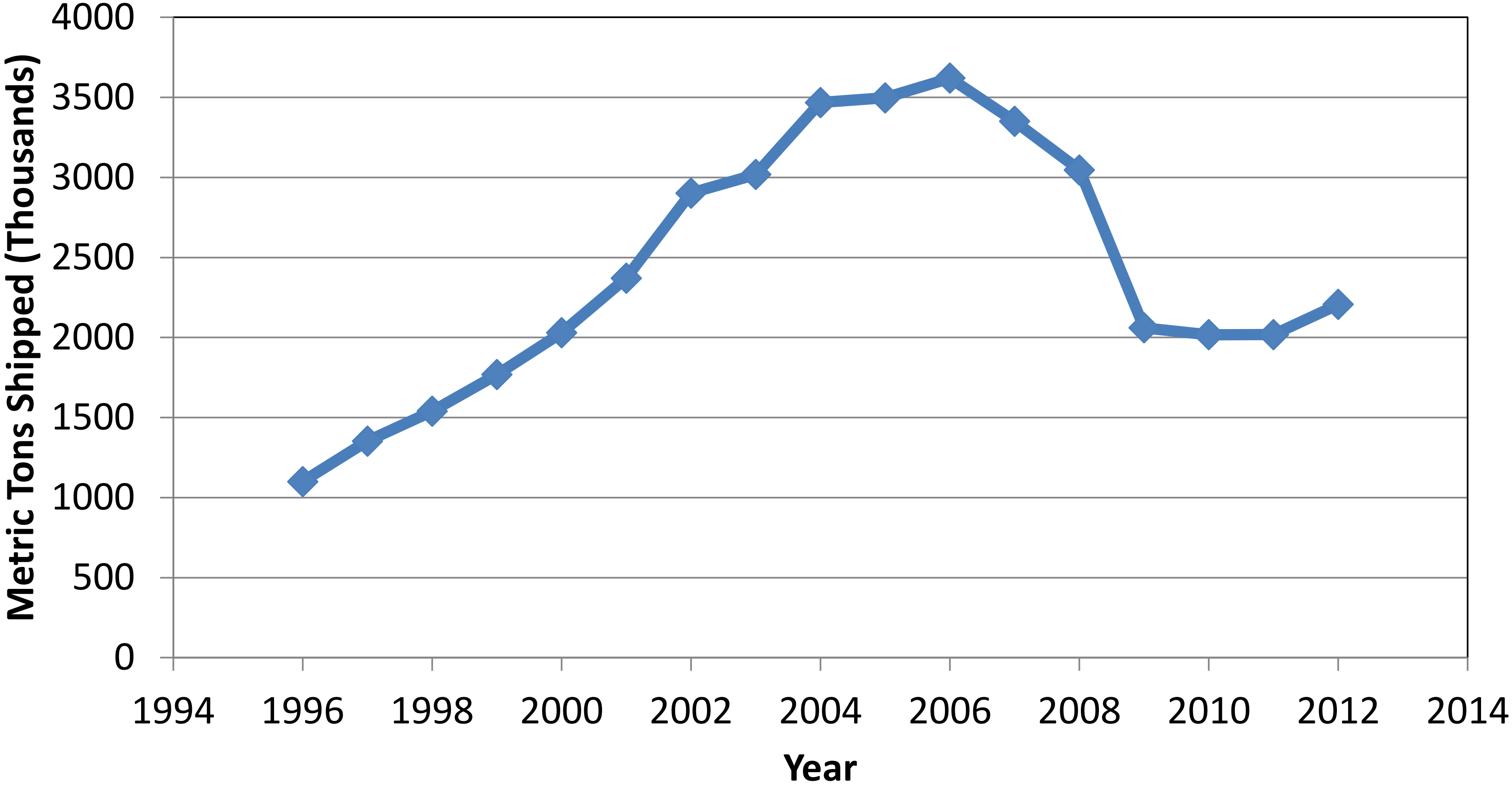
• Class F fly ash:	15% - 25%
• Class C fly ash:	15% - 40%
• Slag:	25% - 50%

Note that replacement levels can be much higher in mass concrete placements, as high as 85%

Fly Ash Utilization



Shipments of Slag Cement

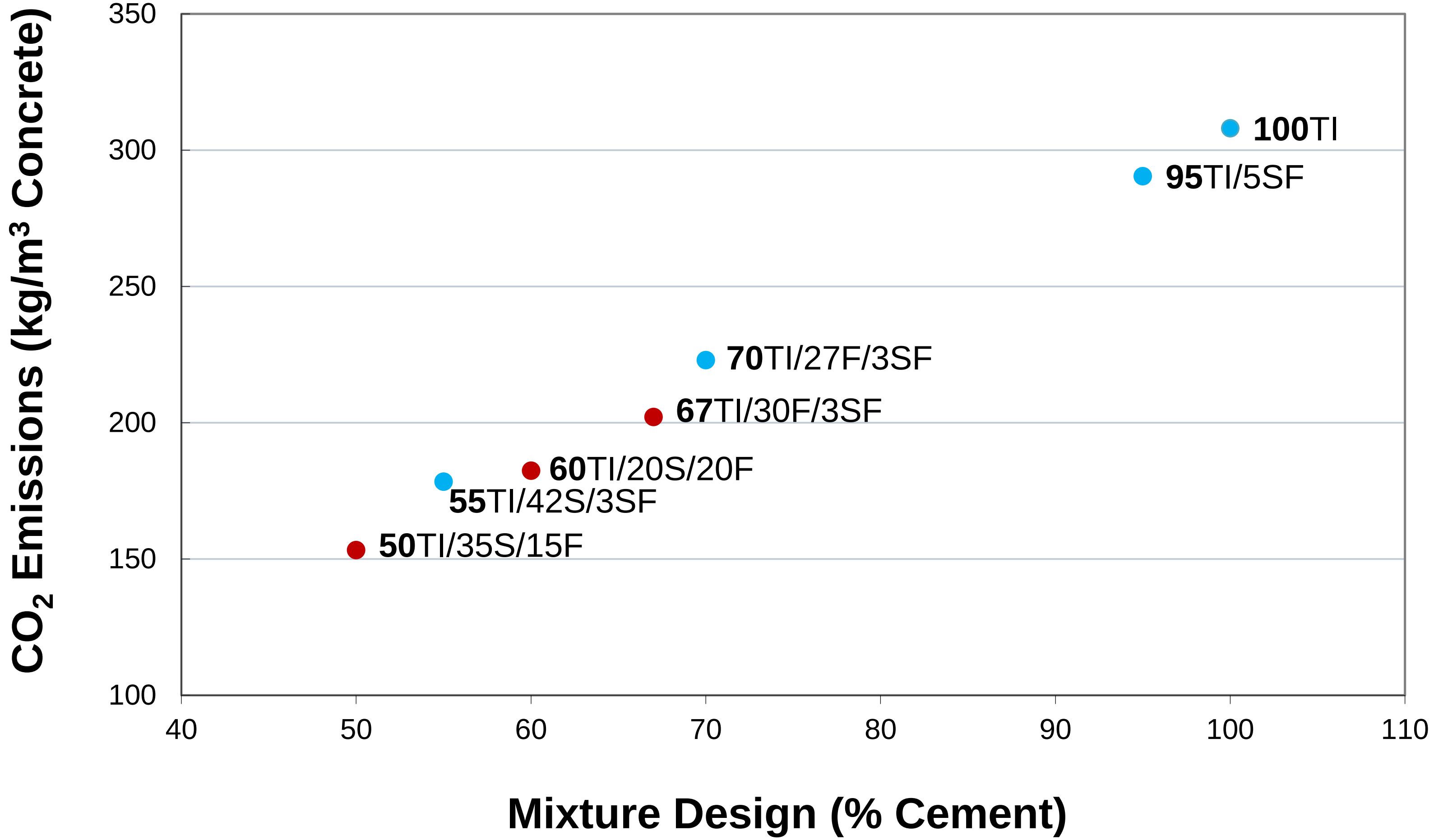


Adapted from Slag Cement Association

AASHTO M 240 Blended Cements

- Produced by cement manufacturers
- Type IP(X), Type IS(X), Type IL(X), and Type IT (X)(Y)
  - Blended with pozzolan, slag cement, limestone or ternary blend
- Also designated as air entrained (A), moderate of high sulfate resistant (MS or HS), or moderate or low heat of hydration (MH or LH)

SCMs and CO_2 Emissions

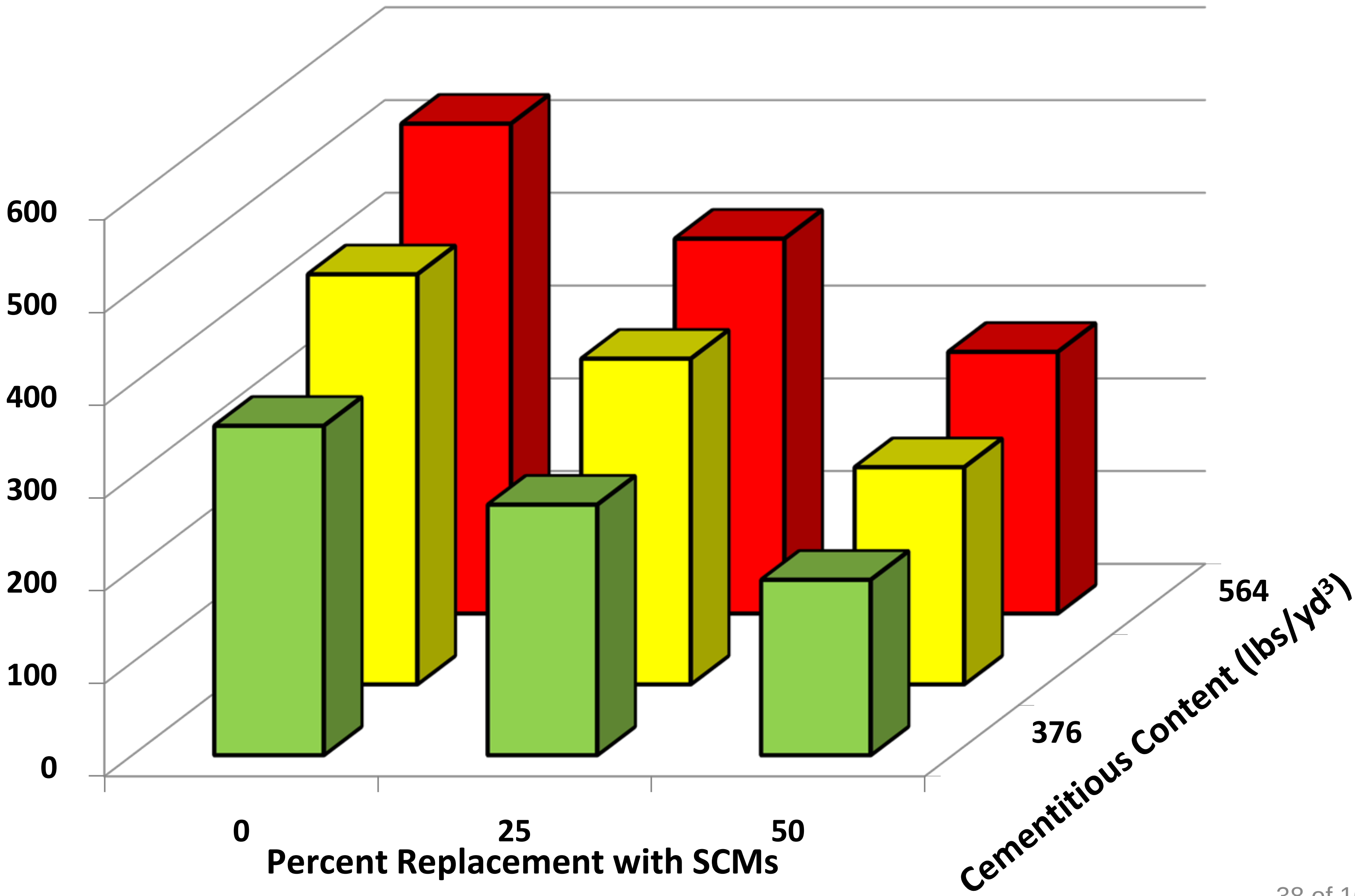


From Tikalsky (2009), "Development of Performance Properties of Ternary Mixtures"

Reduce Cement By Increasing Aggregate Volume in Concrete

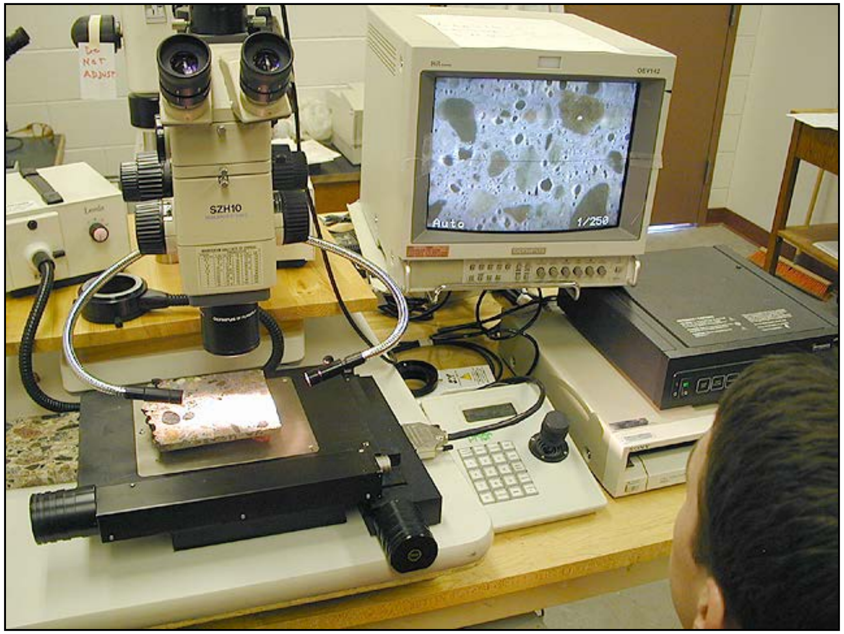
- Maximize aggregate content
  - Use of optimized aggregate grading for paving
- Ensure volume stability of aggregates
  - Porous aggregates require special handling
- Ensure aggregate durability
  - Freeze-thaw
  - Alkali-aggregate reactivity

Cement Content, SCMs, and CO_2



Making Concrete Durable

- Good mixture design with relatively low permeability and shrinkage
- Resistance to freezing and thawing
  - In the presence of deicers
- Mitigation of alkali-aggregate reactivity
- Resistance to sulfate attack

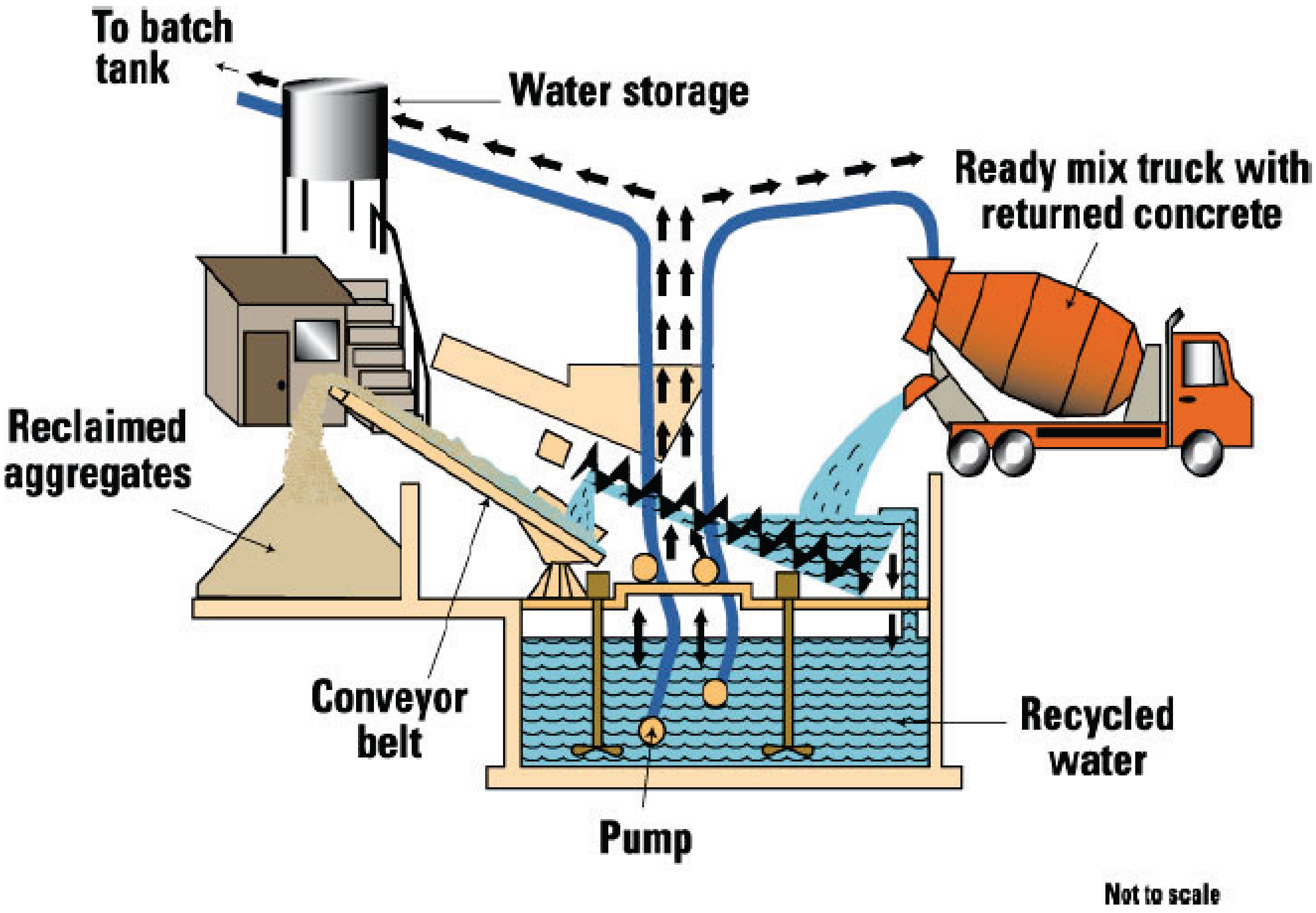


Reduced cementitious content and the use of SCMs helps create durable concrete

Strategies to Improve Sustainability of Concrete

- Reduce energy and GHGs during cement production
- Reduce energy and GHGs during concrete production
- Reduce water use
- Increase use of RCWMs and marginal materials as aggregate
- Improve durability of concrete

Water Recycling at Concrete Plant



Taylor et al. 2006. *Integrated Materials and Construction Practices for Concrete Pavements: A State-of-the-Practice Manual*

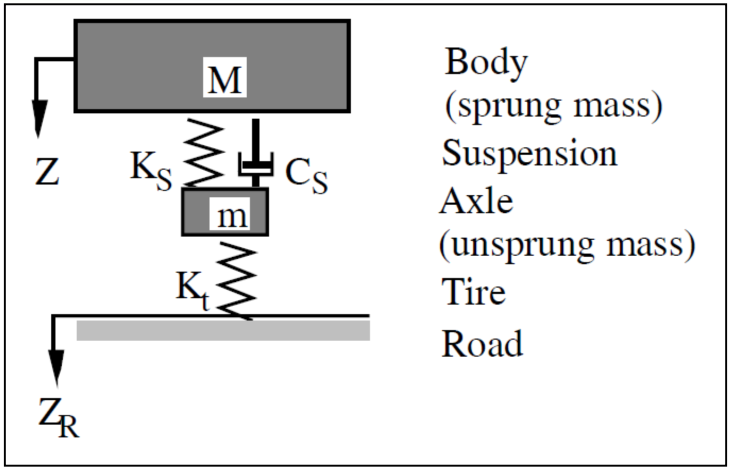
FHWA Sustainable Pavements Program

- Key Issues for Pavement Design
- Example Case Studies

John Harvey

Key Issues for Pavement Design

- Surface performance
  - Smoothness affects vehicle fuel use and maintenance
  - Consider life cycle smoothness, not just initial
  - Importance increases with increased traffic

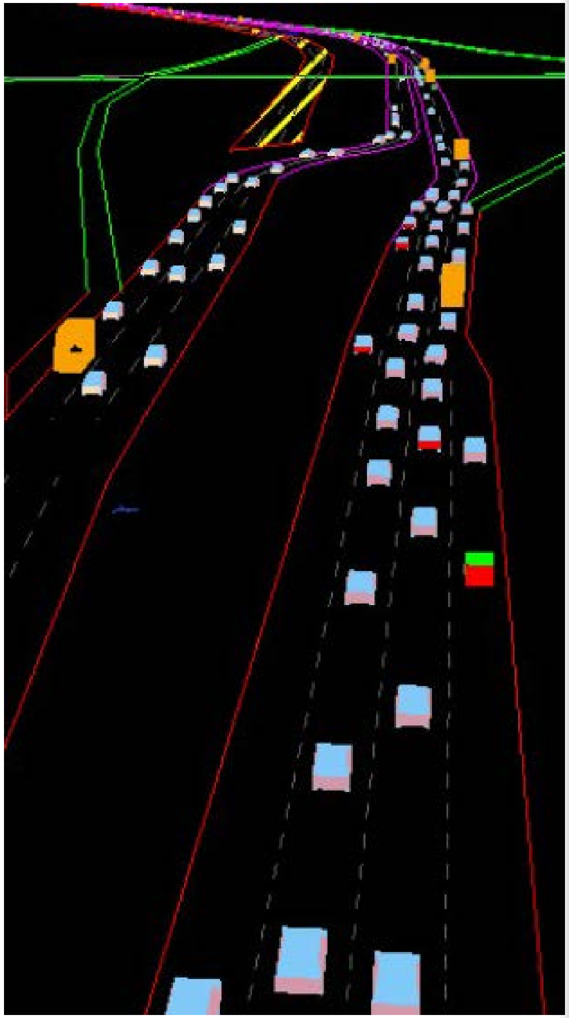


Gillespie and Sayers
EB Lee

- Design life selection
  - Longer life usually means lower life cycle cost and impact
  - Also means higher initial investment (cost, environmental impact)
  - Should include consideration of end-of-life alternatives

Key Issues for Pavement Design

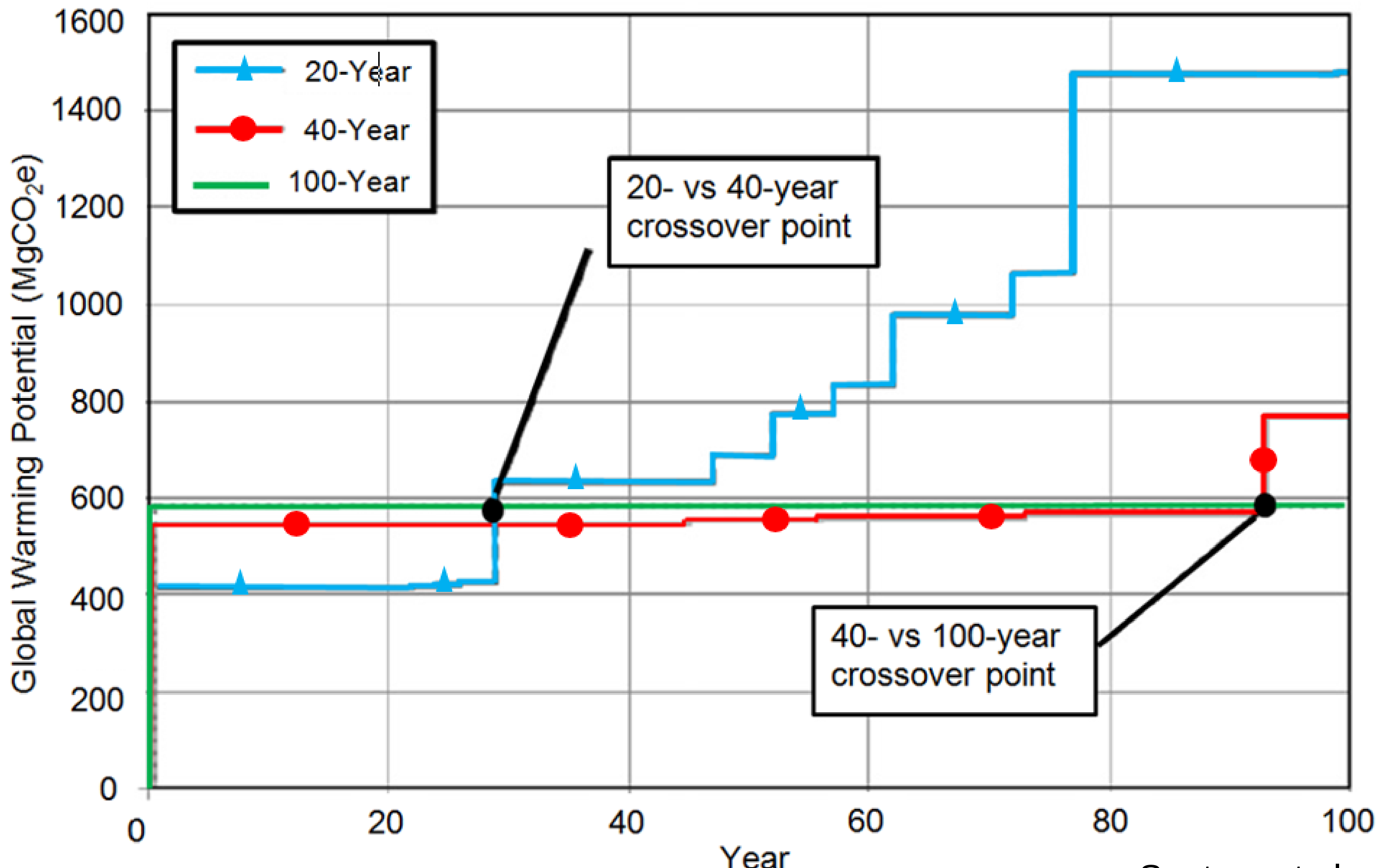
- Pavement type selection
  - Impacts every phase of the pavement life cycle
  - Relative sustainability of different types depends on location, design traffic, and available materials
- Construction and materials selection interaction
  - See discussion of concrete materials
  - Consider ability to get high quality construction
  - Consider work zone traffic delays
- Construction quality requirements
- End-of-Life recycling strategies



Paramics, Lee et al.

Consideration of Payback Time Example: Design Life

- Return time and uncertainty for high early environmental impact choices



Santero et al.

Consideration of Payback Example: Different Grinding Construction Smoothness and Traffic Scenarios

- Grinding effect on IRI (-2σ; mean; +2σ):

$$IRIchange\left(m/km\right) = -0.6839 + 0.6197 \times IRI\_beforeGrinding\left(m/km\right)$$

- IRI progression on rehabilitated lanes:

$$\sqrt{IRI\left(m/km\right)} = -1.74 \times 10^{-1} + 9.66 \times 10^{-5} \times \sqrt{CumulativeESAL} + 1.15 \times \sqrt{InitialIRI\left(m/km\right)}$$

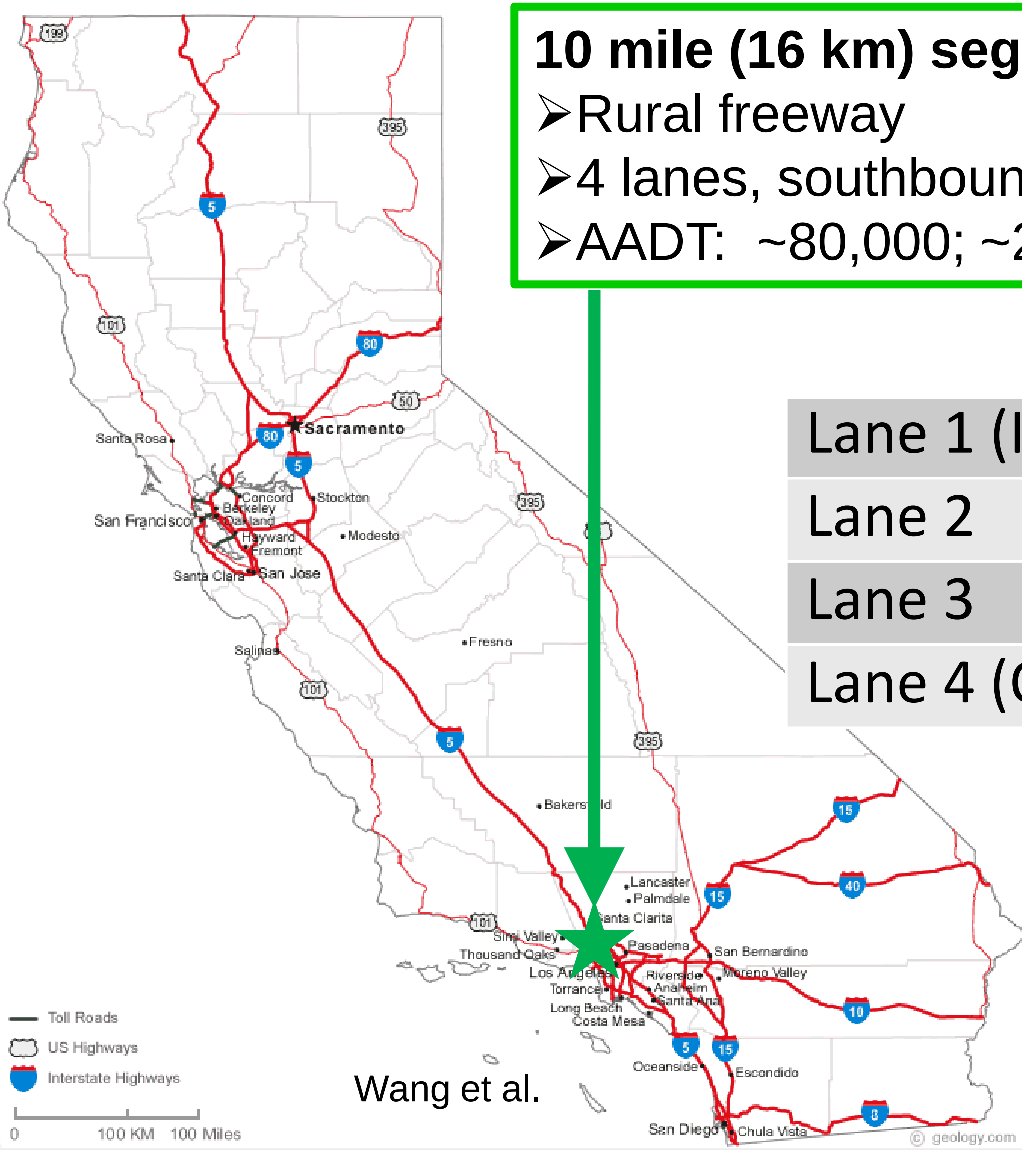
- Vs. Do Nothing (Maintenance Only)

From (1) Caltrans Pavement Condition Survey; and (2) R. Stubstad, M. Darter, et al. The Effectiveness of Diamond Grinding Concrete pavements in California, 2005

Case Study 2 (LA-5): Effect of construction smoothness

10 mile (16 km) segment in need of rehab
- ➢Rural freeway
- ➢4 lanes, southbound
- ➢AADT: ~80,000; ~25% trucks

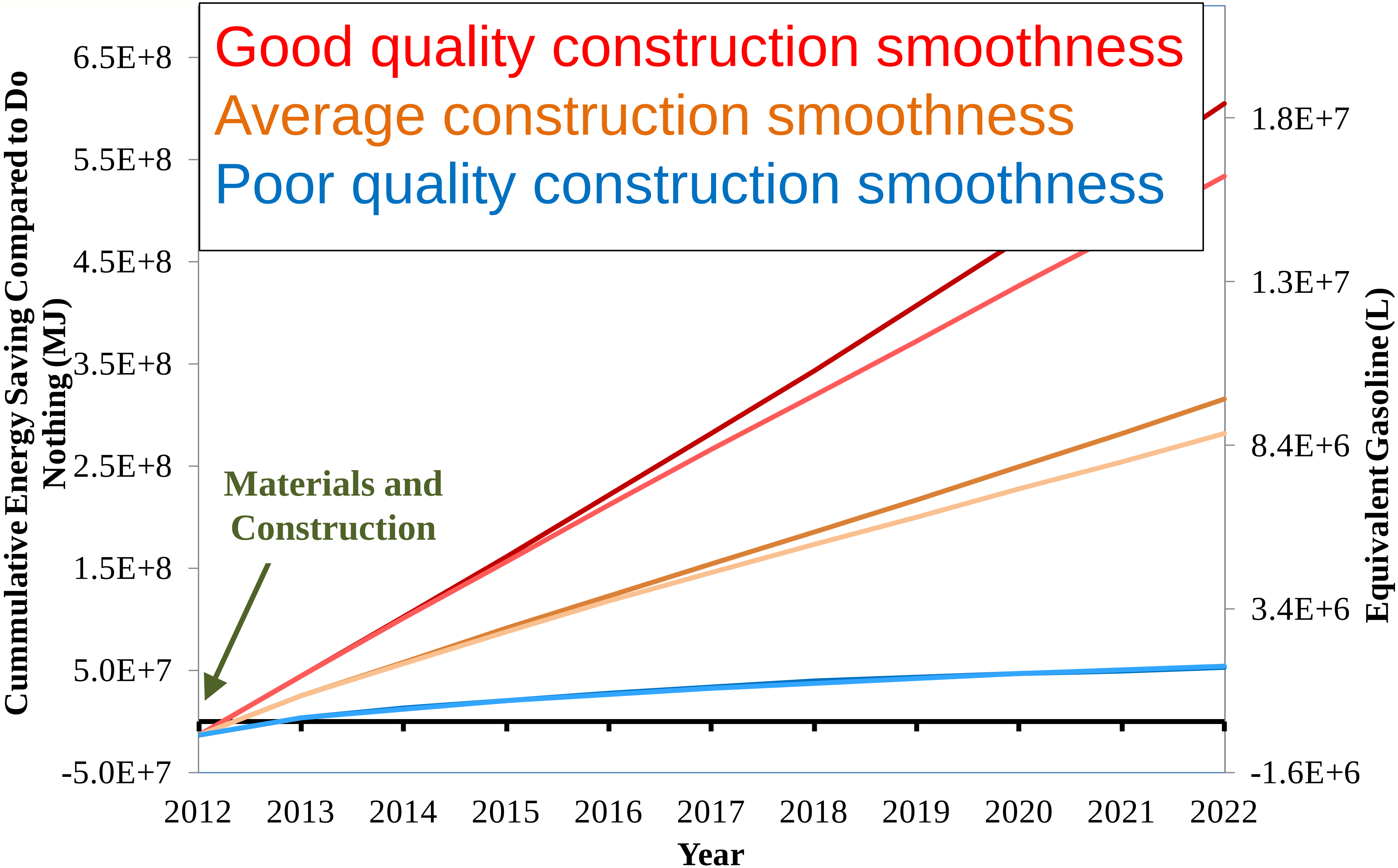
	Cars	Trucks	IRI
Lane 1 (Inner)	38%	0.2%	186
Lane 2	34%	8%	186
Lane 3	16%	42%	217
Lane 4 (Outer)	13%	49%	248



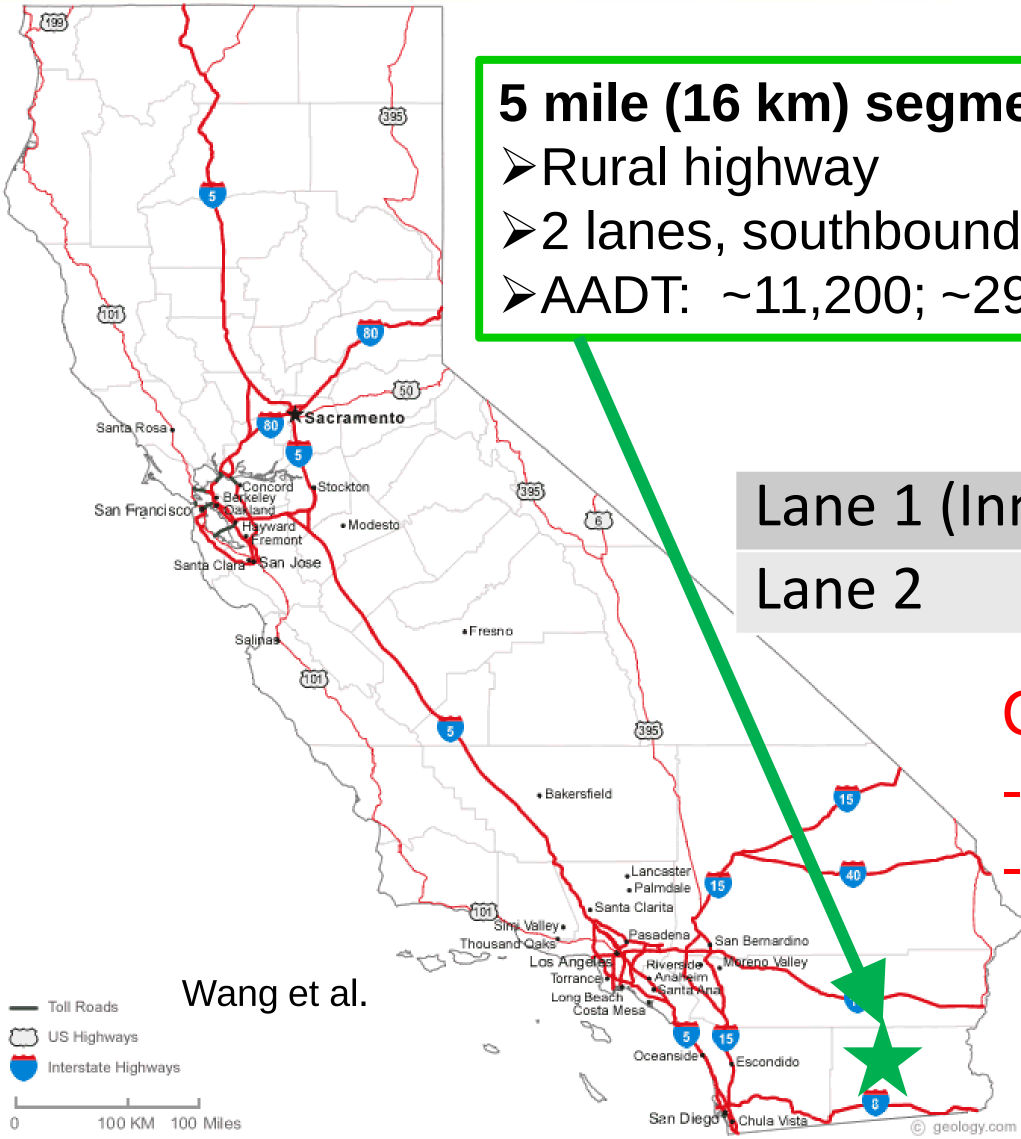
Wang et al.

Compare:
- Do Nothing
- 10 year CPR B
    - Slab replacement, grind

LA-5: Cumulative Life Cycle Energy Savings Compared to "Do Nothing" for Different Grinding Smoothness



Case Study 4 (IMP-86): Effect of Construction Smoothness



Wang et al.

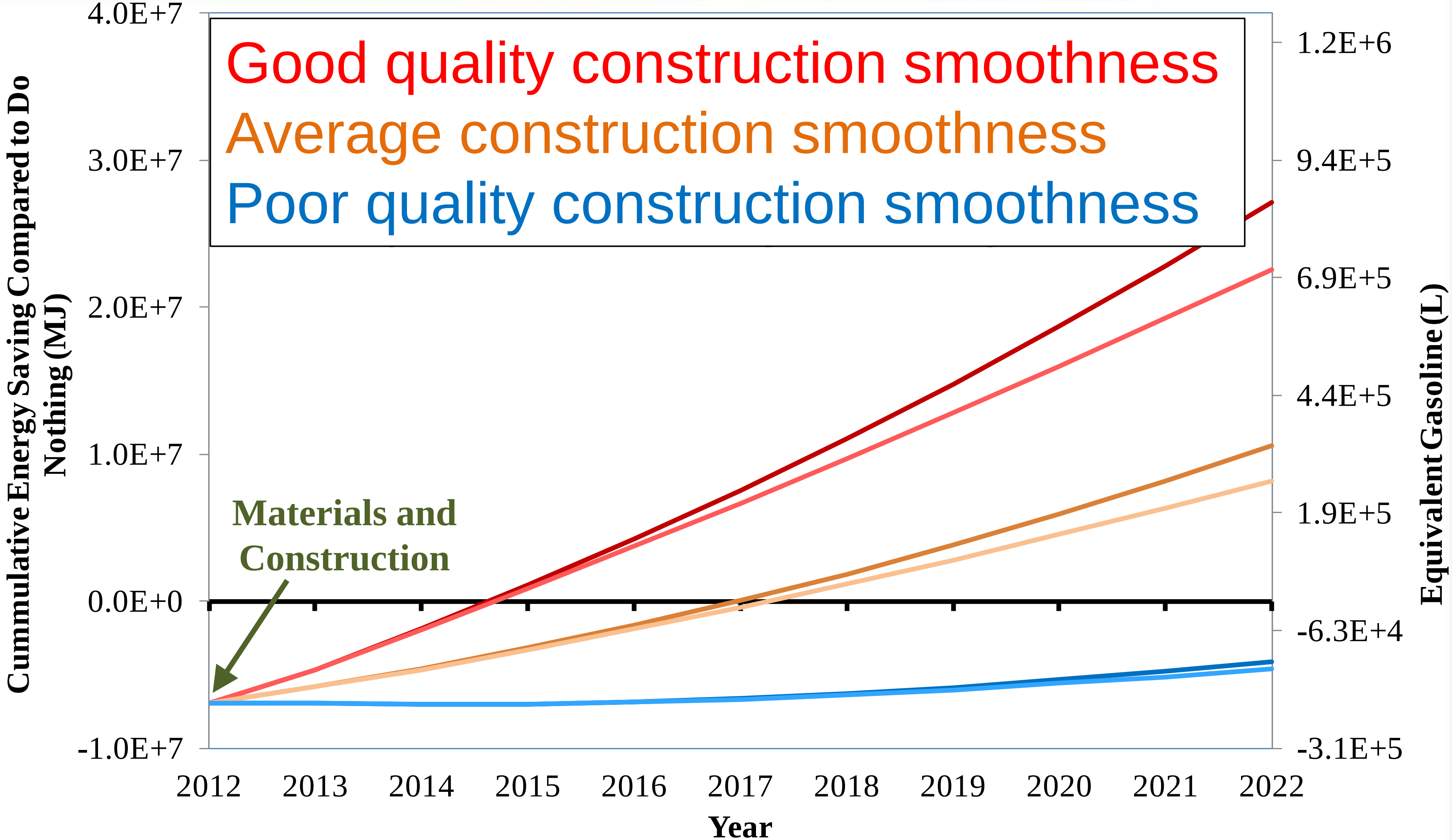
5 mile (16 km) segment in need of rehab

- Rural highway
- 2 lanes, southbound
- AADT: ~11,200; ~29% trucks

	Cars	Trucks	IRI
Lane 1 (Inner)	76%	8%	155
Lane 2	24%	92%	170

Compare:
- Do Nothing
- 10 year CPR B
    - Slab replacement, grind

IMP-86: Cumulative Life Cycle Energy Savings Compared to “Do Nothing” for Different Grinding Smoothness



Mechanistic-Empirical Design Methods

- Permit rapid evaluation of:
  - Materials
    - Increased recycled content
    - Materials with lower environmental impact
    - Changes in mix design
    - Locally available, lower quality specifications
  - Construction
    - Improved quality (smoothness and durability in particular)
    - Less variability
  - Pavement structures
    - Climate, traffic and subgrade specific designs
    - With materials and construction noted above

Process for Considering Sustainability in Pavement Design

Inputs:
- Project performance, cost, and sustainability objectives
- Project traffic, climate, available materials, and construction processes
- Agency design, LCCA, sustainability practices and policies

↓

Step 1: Develop generalized pavement type or rehabilitation approach alternatives

↓

Materials	Construction Specifications	Layer Combinations	Integration of Construction and Traffic	Construction Methods (chapter 5)

↓

Step 2: Develop pavement designs using ME or agency design procedures

↓

Step 3: Consider future maintenance and rehabilitation (chapters 4 & 7)

↓

Process for Considering Sustainability in Pavement Design (cont'd)

Step 4: Calculate and Evaluate:

- Performance
- Cost
- Environmental Impact
- Societal Impact

Step 5: Modify initial design using LCCA, LCA, and rating systems (to reduce cost and minimize environmental and societal impact while still meeting performance and agency objectives and policies)

Modified Alternative 1

Modified Alternative 2

Modified Alternative 3

Modified Alternative n

Step 6: Select preferred design alternative based on agency goals and policies.

FHWA Sustainable Pavements Program

- Concrete Pavement/Rehabilitation Types
- Sample Sustainable Design Strategies
- Future Directions/Emerging Technologies

Jeff Roesler

Selection of Concrete Pavement Types for Sustainable Design

- Select candidate pavement types based on material, construction, M&R, use, and end of life phases
  - New or rehabilitated concrete pavement

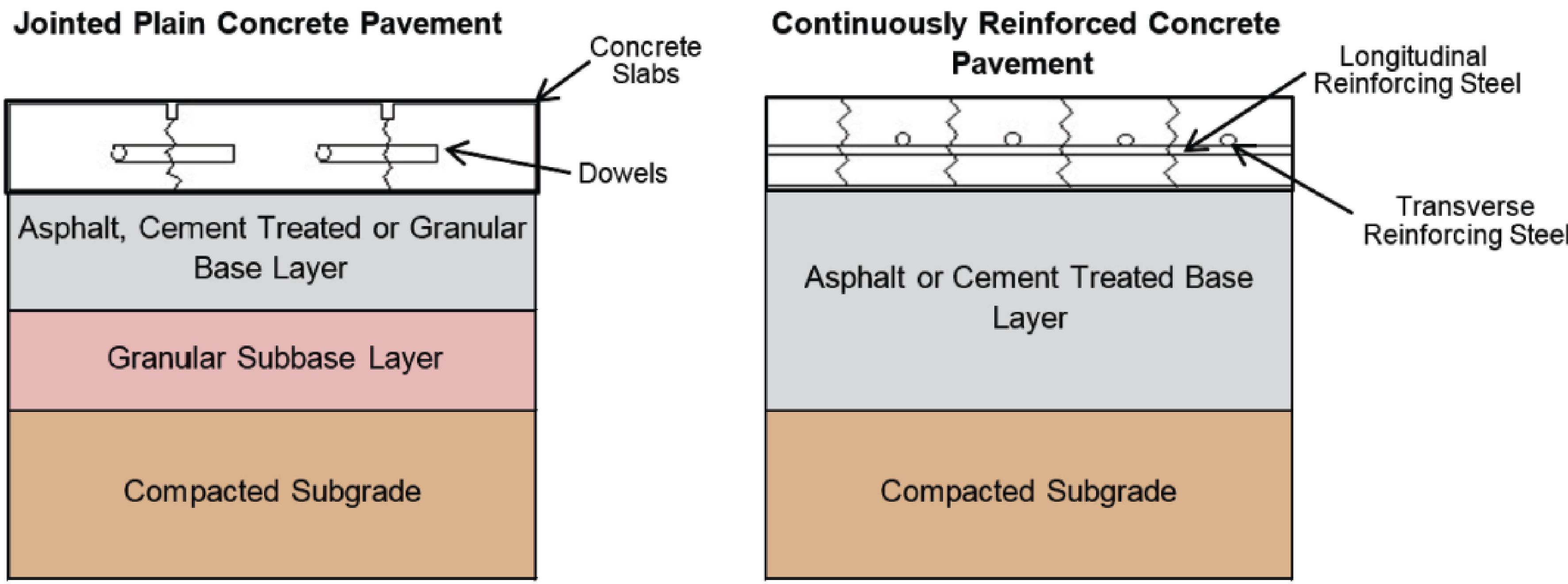
- Define pavement layers/materials and inputs

- Perform pavement structural designs

Sustainable Pavement Design Initial Evaluation

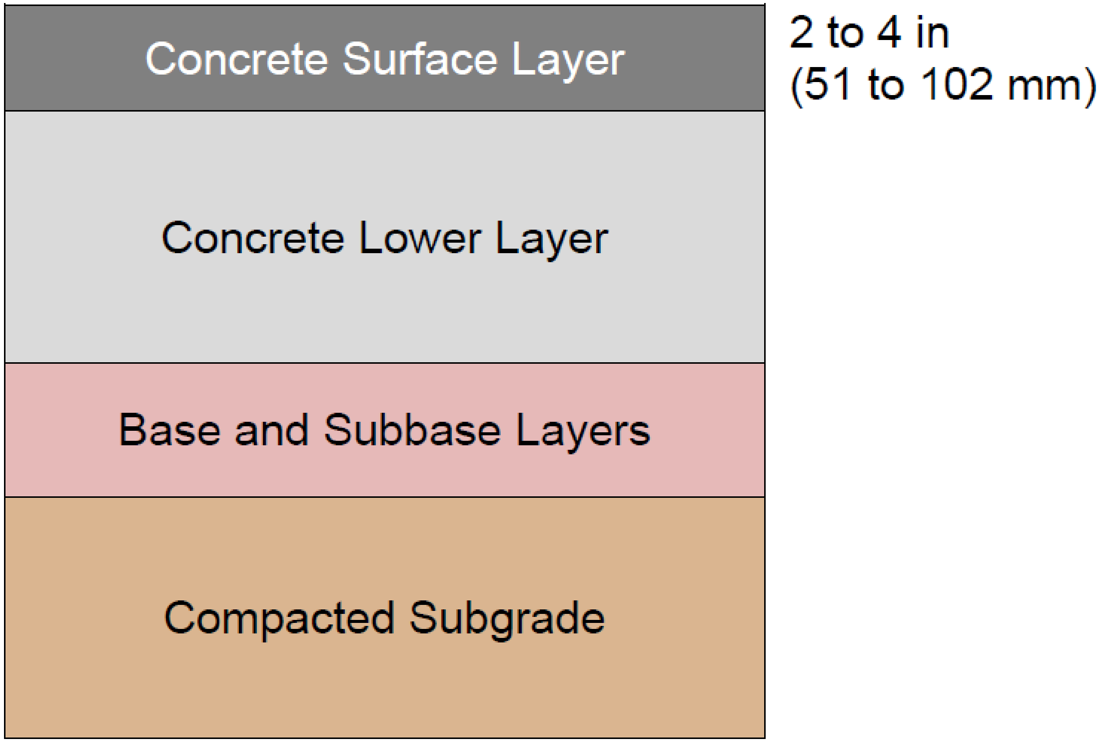
- Define goals / policies of agency or owner
  - Sustainability objectives & metrics
    - LCA, LCCA, rating system, etc.
  - Performance objectives
    - Structural (cracking, faulting)
    - Functional (smoothness, safety, noise)
  - Drainage
  - Design life / end-of-life
- Project constraints – traffic management
- Construction process

Concrete Pavement Types: New or Reconstructed



- Tradeoffs
  - Design life, smoothness, maintenance/repair, rehabilitation options
  - Initial vs. life cycle costs
  - Life cycle assessment (LCA) impact factors (e.g. GWP)

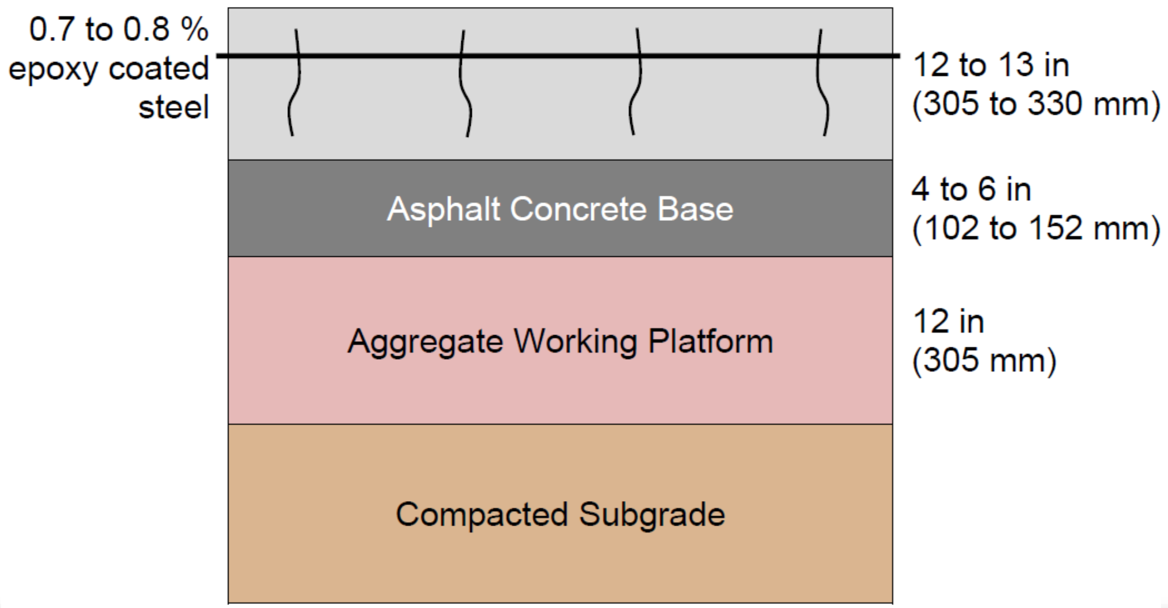
Composite Pavement Type: Two-Lift Concrete



- Considerations
  - Single lift paving vs. two lift
  - Recycled or marginal materials in bottom lift
  - Premium concrete surface, e.g., noise and friction

Longer Life Concrete Pavement

- Principal arterial
  - 30 to 60 year design life
- Durable concrete materials & reinforcement
- Non-erodible base layer & drainage
- Edge support – widen lane or tied shoulder

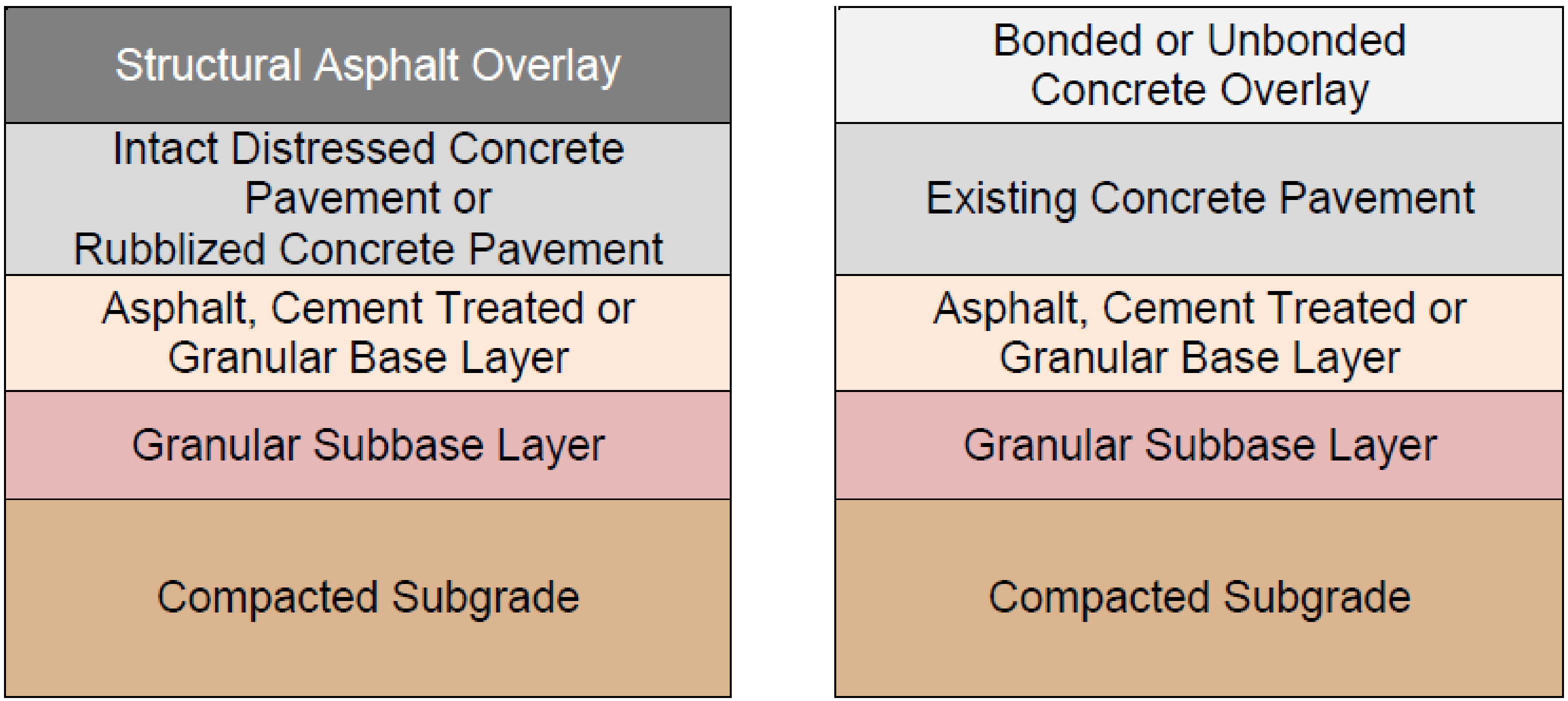


Long Life Example: CRCP

Concrete Pavement Types: Overlays of Concrete

Structural Asphalt Concrete Overlay

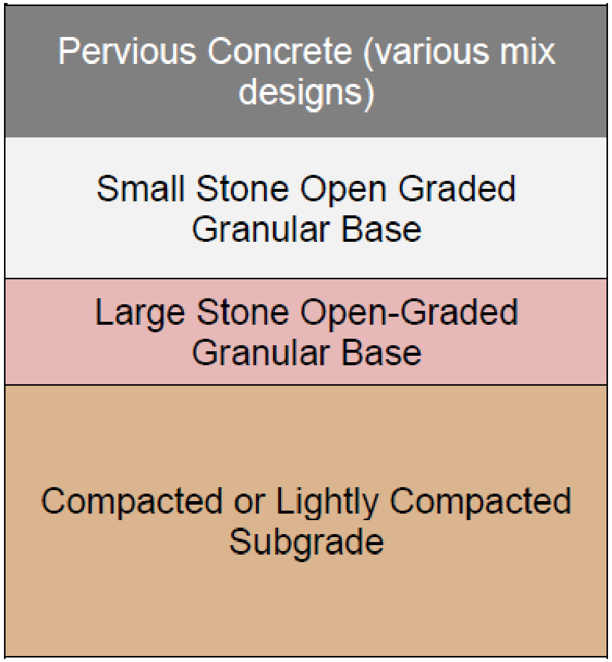
Structural (Bonded/Unbonded) Concrete Overlay



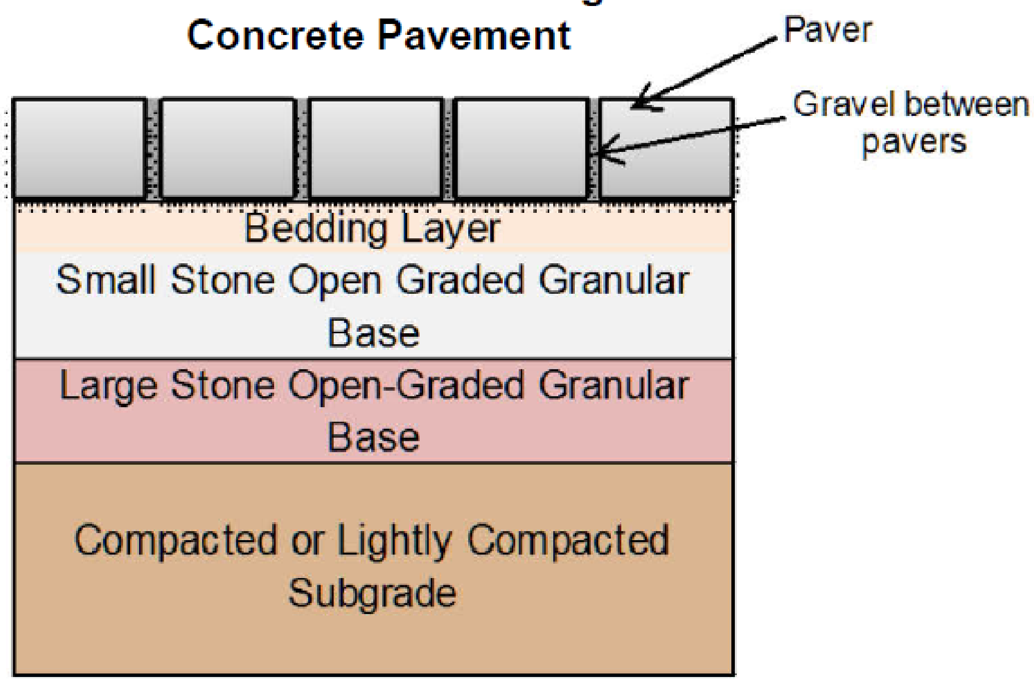
- Considerations
  - Design life, existing pavement condition, end of life, elevation restrictions, reflective cracking, traffic constraints, funding resources

Concrete Pavement Types: Stormwater Management

Pervious Concrete Pavement



Permeable Interlocking Concrete Pavement

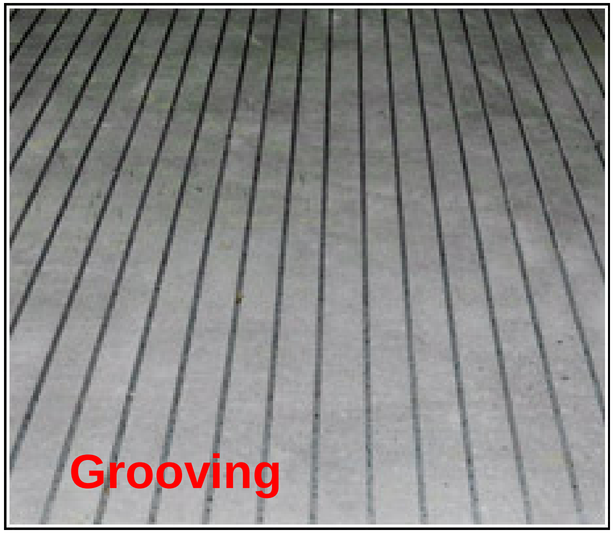


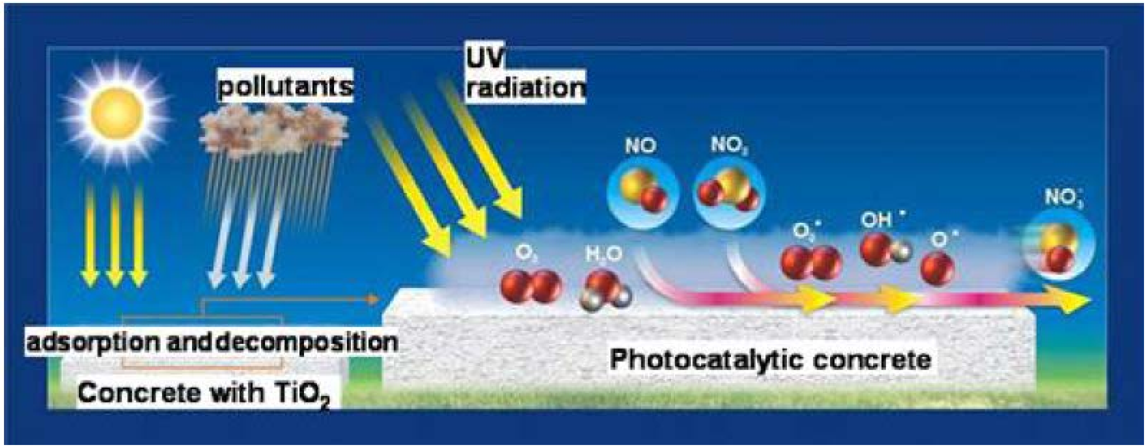
- Considerations
  - Management of stormwater discharge and peak flow
  - Lower speed roadways

Modular Pavement:
Precast Concrete Slabs

Concrete Pavement Surface Options

- Friction, noise, surface runoff
  - Tining
  - Diamond grinding and grooving
  - Turf drag
- Future considerations:
  - Urban Heat Island (Albedo)
  - Photocatalytic cement





Beeldens & Boonen (2011)

Layer and Material Type Selection

- Existing or new pavement structure
  - Proposed roadway cross-section
- Options for using recycled materials
  - subbase, base, shoulders, concrete layer

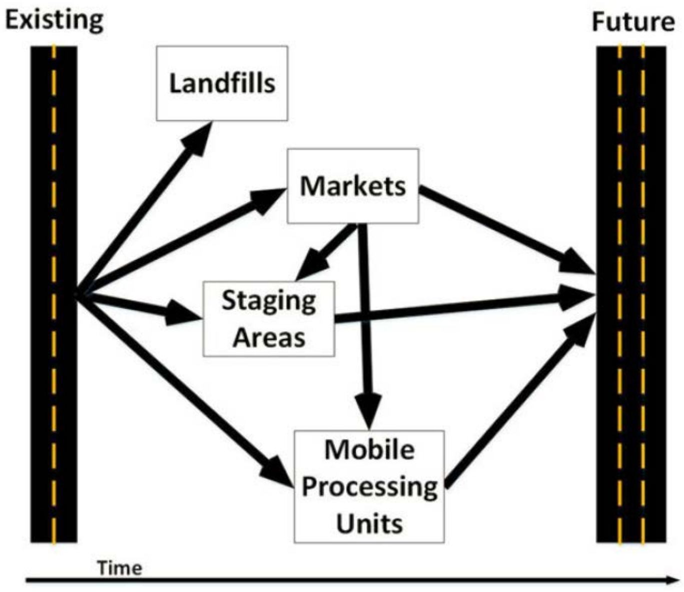


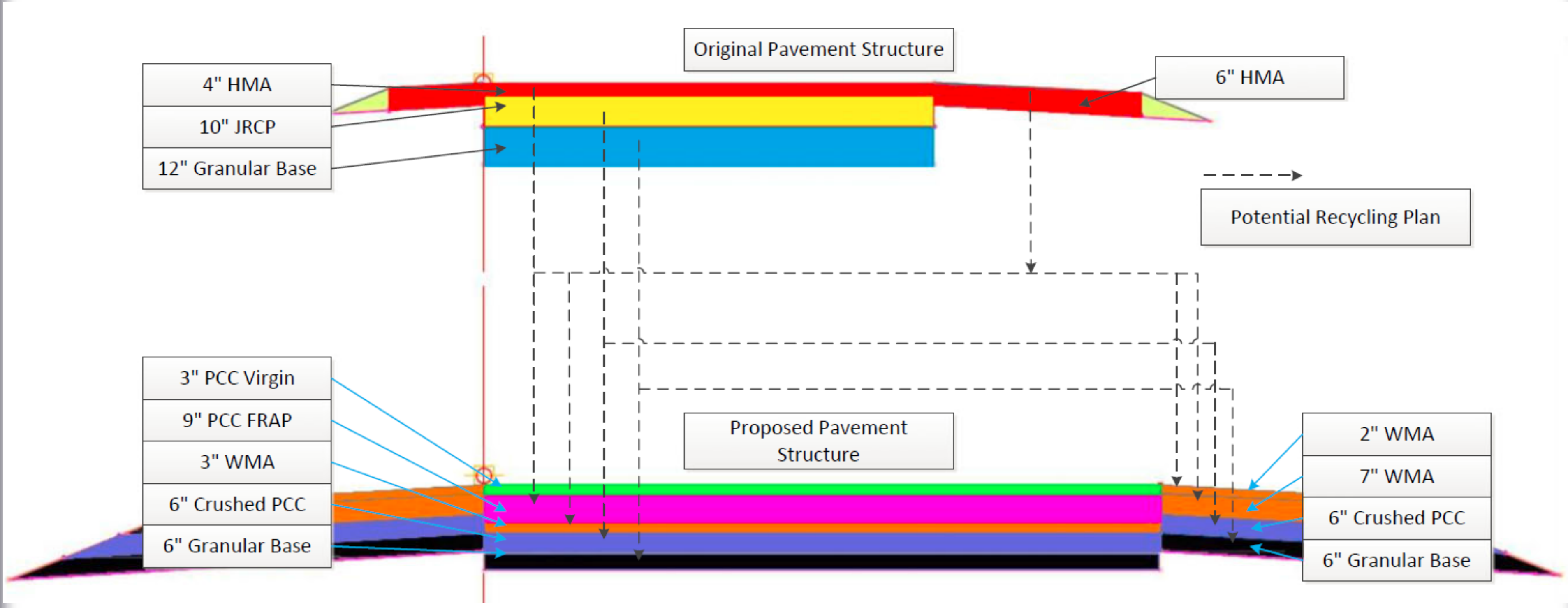
Fig. 1. Roadway reconstruction material processing and flow.

- Construction & Traffic Management Process
- Limit handling & hauling for more sustainable design

Local Materials/ Low-Impact Transportation

- Transporting materials has major environmental and social impacts
  - Consider materials specifications and whether designs can be developed to maximize use of local materials
- Consider adoption of a zero-waste approach that includes recycling of all pavement materials on-site or nearby
- Avoid compromising pavement longevity
- Reduce environmental impact of materials over the life cycle
  - Cannot just consider initial construction

Sustainable Pavement Design: Reconstruction Example

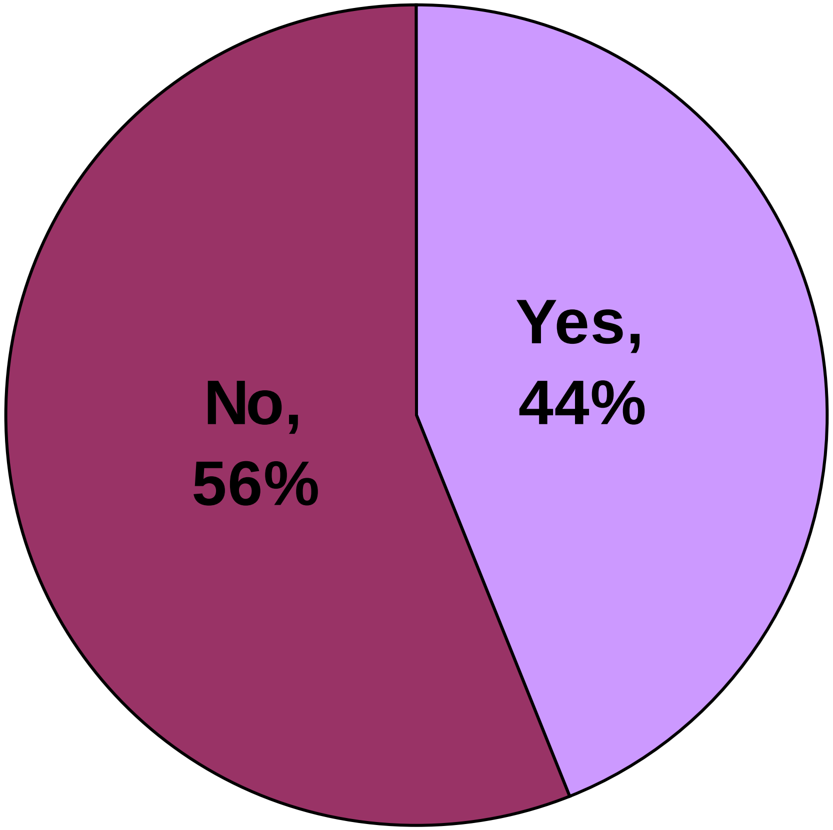


Accelerated Construction

- Can reduce cost and environmental impact
  - Less mobilization and demobilization
  - Less worker travel
  - Short intense pain vs. prolonged delays
- Techniques:
  - Designs and specifications to minimize thickness, speed construction
  - Continuous and full direction closures
  - Extensive traffic management planning, traffic monitoring and adjustments
  - Extensive public outreach
  - Provision of alternative transportation

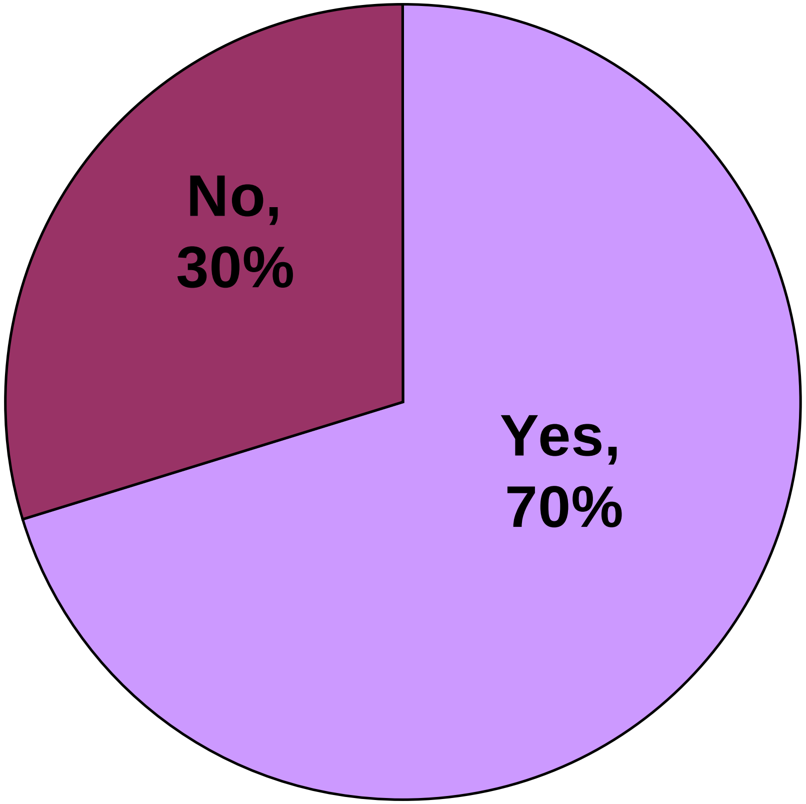
Public Perception Changes for Accelerated Construction

Before- construction



Do you support I-15 Devore "Rapid Rehab" approach?

After-construction

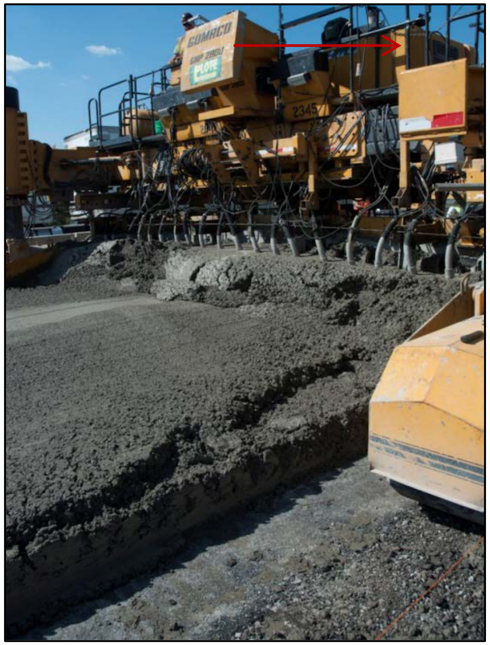


Do you support future "Rapid-Rehab" projects?

Lee et al. for Devore I-15 project

I-88 Tollway Example (September 2012)

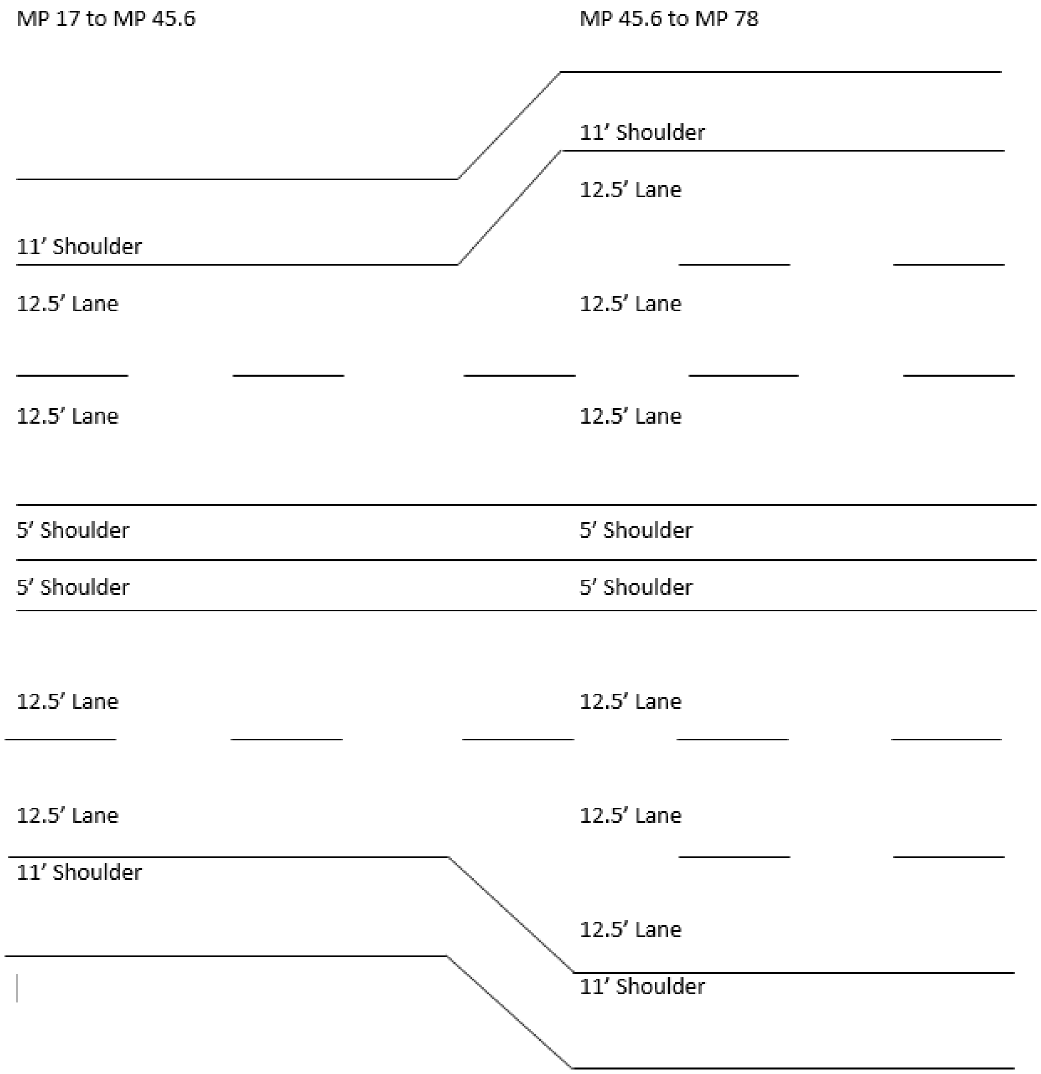
- Illinois Tollway's first two-lift pavement
- Bottom lift was a ternary blend (cement, slag, fly ash) with 21% coarse FRAP
- Bottom lift was 8 inches with 3.5-inch top lift
- Bottom lift had lower compressive and flexural strengths but similar fracture properties to the top lift



I-90 Existing Pavement Structure

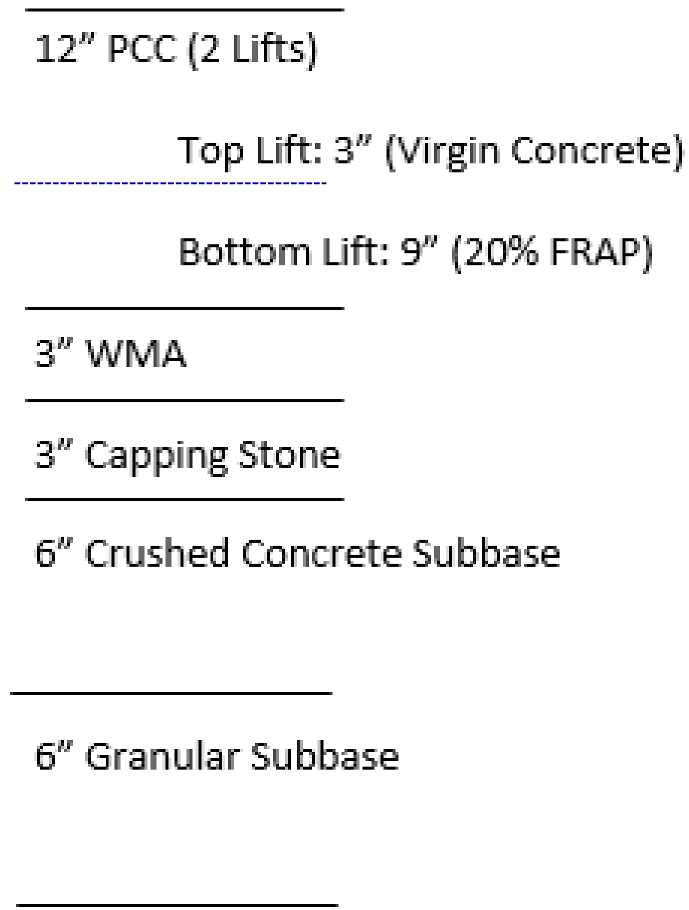
- Existing Roadway:
  - 4” HMA
  - 10” PCC (JPCP)
  - 12” Granular Subbase
- Shoulders (HMA):
  - 5 – 11 ft wide
  - 6 – 7” thick

ADT= 317,000 veh.
Trucks = 11%



I-90 Reconstruction Plan (2013-2015)

- Agency Goals/Constraints:
  - Recycle 100% of existing roadway
  - Maintain traffic revenue!!
  - Provide land for construction staging areas
  - Use:
    - Two-lift concrete
    - WMA
    - Recycled materials – FRAP, RAS, RCA, existing granular subbase

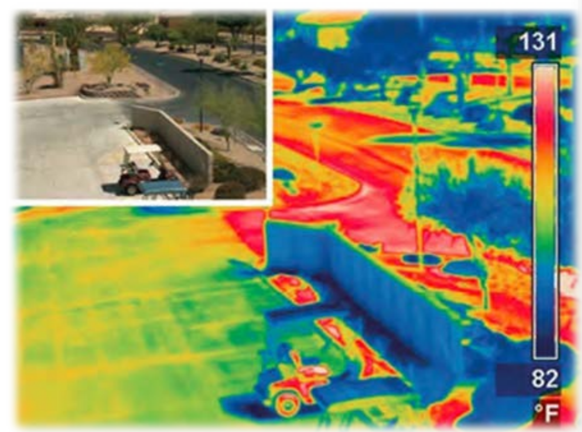


Use Phase Considerations

- Depends on roadway functional class (arterial, collector, etc.; rural vs. urban)
- Principal arterials
  - Smoothness - maintained
    - reduces environmental impact
  - Longevity
    - low level distress means less maintenance/repair
- Lower volume roads
  - Material and construction dominate environmental impact

Other Use Phase Factors

- Traffic
  - Fuel efficiency is correlated to smoothness
  - Also affected by texture, structural response
  - Noise, skid, pollution, and particulates
- Stormwater
  - Urban issues include flooding and stormwater treatment
  - Safety – splash/spray
- Aesthetics, *urban heat island* effect, artificial lighting, utility cuts, manholes



Summary of Design Considerations

- Achieve longer life, thinner pavement, or more efficient design for same life by integrating
  - Structural design
  - Materials selection and layers
  - Construction (& traffic) process
- Maximize use of recycled and locally available materials
  - Consider specifications changes
- Consider
  - Use phase impacts
  - End-of-life scenarios

Future Directions/Emerging Technologies

- Improved ME design capabilities
- Performance related construction specifications
- New materials including more recycled materials and multi-functional cements
- Integration of cost and environment impact in design criteria
- More consideration of future preservation, rehabilitation and recycling in design

FHWA Sustainable Pavements Program

- **Construction Considerations**
- **Strategies to Improve Sustainability of Concrete Pavement Construction Practices**

Mark B. Snyder

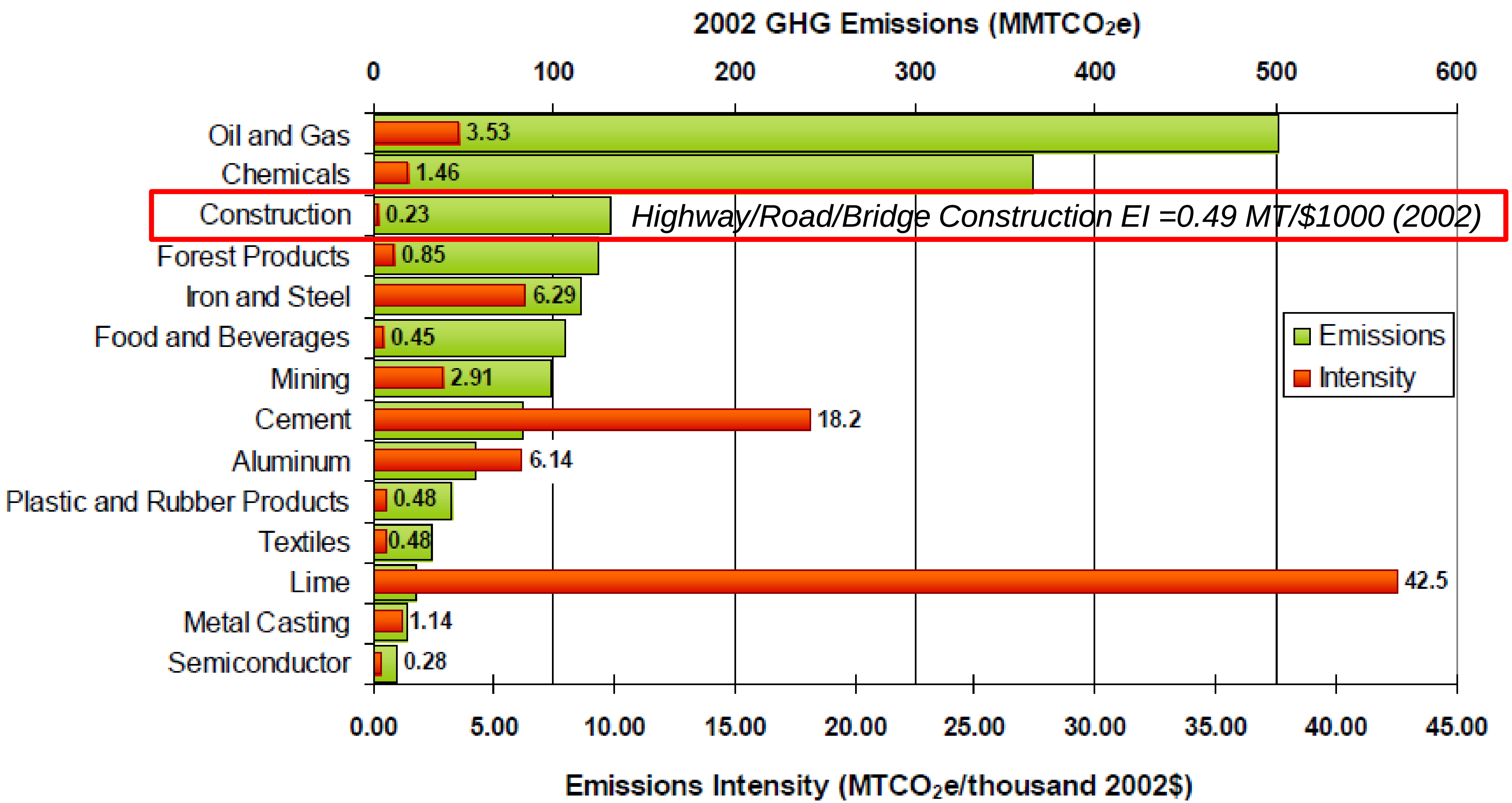
Key Construction Issues Impacting Sustainability

- Energy consumption
  - Transport of materials and construction operations
- Impacts on surrounding areas
  - Exhaust and particulate emissions (local and global), impact on wetlands and streams
  - Traffic delays, congestion and noise
- Impact of construction quality on pavement performance and overall service life
  - Surface texture (friction [safety], noise)
  - Roughness (impact on use phase fuel consumption)
- Economics of construction practices
  - Agency costs, user costs (construction-related, use phase)

Energy Consumption

- Construction: an *energy-intensive* process
  - Activities may include: excavation, earthwork, material processing and placement compaction/consolidation of paving layers, texturing, jointing
  - Equipment may include: excavators, haul equipment, crushers, mixers, graders, rollers, placers and pavers, and more.
- Energy consumption factors:
  - Internal: Operational efficiencies
  - External: Site operations and site conditions

Construction: Total Emissions and Emission Intensity



EPA (2009)

Quantifying Sustainability Impact of Traffic Delays

- Energy and emissions contribution of traffic delays due to construction activities are often ignored in pavement LCAs
- Impact on environment, associated with traffic delays, may be quantified using appropriate tools:
  - Traffic simulator to estimate driving schedule under changing roadway capacity
  - EPA's MOVES software to calculate additional emissions and energy consumption with changing driving schedules

Vehicle Emissions Simulations

- EPA's NONROAD
  - Emission modeling system for non-road equipment
  - Energy consumption
  - Emissions to air
    - HC, CO, NOx, PM, SO2, and CO2

- EPA's MOVES
  - Emission modeling system for mobile sources
  - Energy consumption
  - Emissions to air
    - 120+ emissions

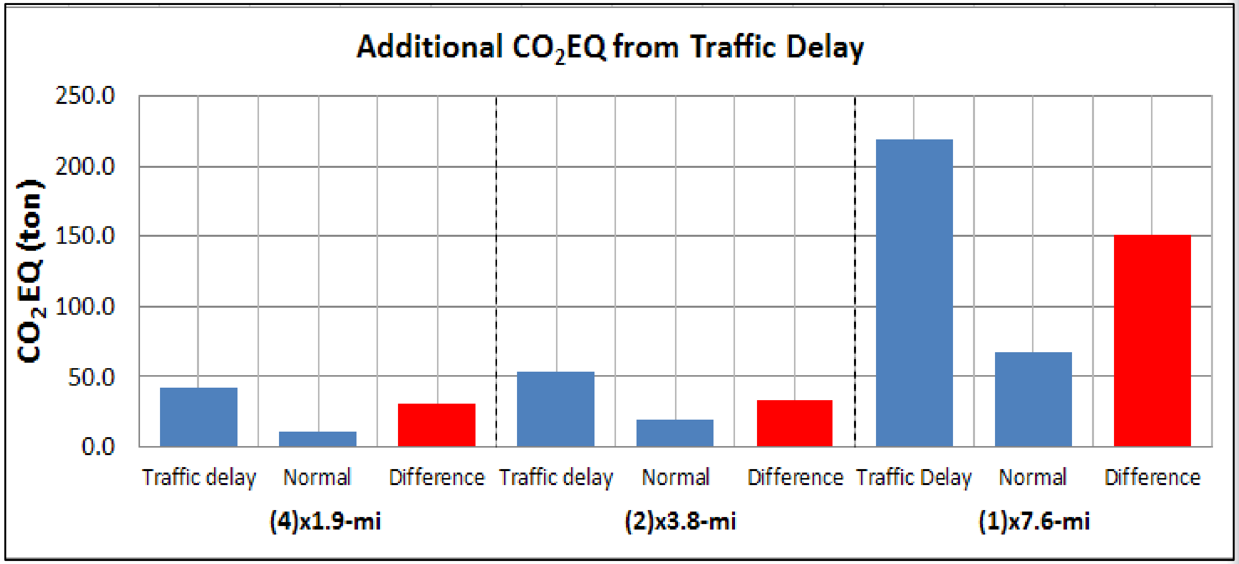
Also available: PE-2, GreenDOT

Case Study: Work Zone Scenarios and Impacts Using MOVES

- Traffic scenarios considered a 7.6 mi work zone (Kang et al., 2014):
  - Partition the project into 4 work zones and use night time closure to complete each
  - Partition the project into 2 work zones and use 16-hr closure between 10 pm and 2 pm
  - No partition with 32-hr closure starting from 9 pm and finishing 5 am

GWP due to traffic delay was 1.3 % (best case scenario) to 2.7 % (worst case scenario) of the total GWP including material and construction phases.

However , if no queue develops, there can be energy savings (Wang et al., 2014)



Impacts of Construction on Surrounding Areas

- Emissions from Equipment Exhaust
- Airborne Particulates from Construction Operations
- Noise Generated from Construction Operations
- Construction Impacts on Local Traffic, Residences, and Business Operations
- Construction in Streams, Wetlands, and Environmentally Sensitive Areas

Impacts of Construction: Traffic Delays and Congestion

- Work zones can cause user delay, increased fuel consumption, and compromised roadway safety
- Indirect economic and environmental impact result from construction activities due to reduction in roadway capacity and delays
  - Highway construction zones account for 24% of nonrecurring congestion equivalent to 482 million vehicle-hours per year (USDOT 2006)
  - Loss of highway capacity (60 million vehicles per day - Wunderlich and Hardesty, 2003)

Impacts of Construction Quality

Performance expectations from durable materials and effective designs will be unrealized with poor construction quality.

- Quality must be reflected in both structural and functional (e.g., friction, noise, IRI) characteristics.
  - Example: strong, durable pavements with poor ride may have high costs of fuel, vehicle maintenance, and damage to transported goods.
- Durability/longevity is a primary factor impacting pavement sustainability.

Economics of Construction Practices: Initial and Long-term, Agency and User

- Work zones cause 24% of nonrecurring U.S. congestion: 482 million annual vehicle-hours of delay (USDOT 2006) and $700M annual fuel loss (Antonucci et al, 2005)
- Construction changes to enhance sustainability often increase costs.
  - Examples: noise and pollution reduction, erosion control, improving local access during construction
- Costs must be weighed against expected benefits. High-cost changes may not be adopted, even with potential environmental and societal benefits.

Improving General Construction Sustainability: Fuel Use and Emissions

- Minimize haul distances
- Select appropriate equipment type and size
- Reduce idling times
- Retrofit/upgrade equipment and/or use hybrid equipment
  - Dual-fuel generators, grid electricity
- Use alternative fuels

Improving General Construction Sustainability: Alternative Fuels

Fuel Type	Emissions (lb CO_2)	GHG Reduction – 3% Fuel	GHG Reduction, 10% Fuel
Diesel	22.37/gallon	600 M lbs CO_2	2000 M lbs CO_2
Gasoline	19.54/gallon	186 M lbs CO_2	621 M lbs CO_2
Nat. Gas	11.7/1000ft^3	106 M lbs CO_2	353 M lbs CO_2

- Diesel (non-road): 3000-5000 ppm sulfur
- Ultra-low Sulfur Diesel (ULSD): <15 ppm
  - Lower energy content, higher price
- Biodiesel (B5 and B20)
  - Reduced PM, CO and HC emissions, reduced engine wear
  - Higher price, increased NO_x, lower power and fuel economy, hose/gasket degradation

Improving General Construction Sustainability: Erosion and Runoff

- Minimize extent and duration of disturbed areas
  - Construction phasing
- Use perimeter control barriers
  - Fences, straw bales, etc.
- Apply erosion control matting or blankets
- Re-vegetate ASAP
- Store/stockpile materials away (e.g., > 40 ft) from water courses.
- Cover stockpiles or provide barriers for rain events

Improving General Construction Sustainability: Noise Reductions

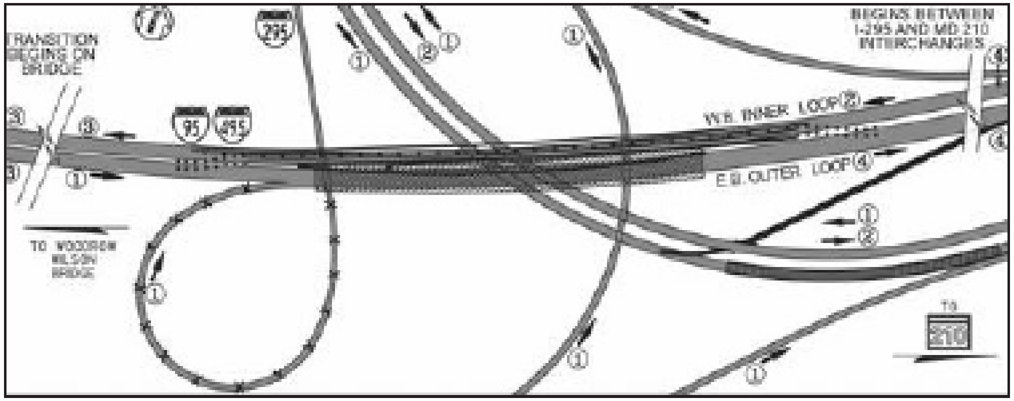
- Construction time restrictions
  - Reduced productivity? Increased emissions due to prolonged construction?
- Equipment maintenance/modifications
  - Requires capital investment

Improving General Construction Sustainability: Accelerated Construction

- Establish performance goals and measures for work zones
  - e.g., target work zone delay to be less than 6% of all traffic delays (The Netherlands); U.S. value estimated at 10%.
- Incorporate lane/road closure analysis strategies during project planning
  - Use project management programs such as FHWA's QuickZone, CalTrans' CA4PRS, and Dynasmart
- Implement effective road and lane closure strategies during construction
- Implement intelligent transportation systems (ITS) to provide alternative routes or modes to drivers

Case Study: QuickZone

- Quickzone is a software tool for traffic analysis that compares traffic impacts for work zone mitigation strategies and estimates traffic delays and cost
- Quickzone was used during the planning stage for Woodrow Wilson Bridge replacement project with an objective to minimize impact on road users
  - Duration of project was reduced from an estimated 6 months to 2 months
  - Efficient communication was created between the contractor and bridge management team



Case Study: I-15 Devore Selection of Closure Type Using CA4PRS

Construction Scenario	*Schedule Comparison*		Cost Comparison ($M)			Max. Peak Delay (Min)
	Total Closures	Closure Hours	User Delay	Agency Cost	Total Cost	
1 Roadbed Continuous	*2*	*400*	*5.0*	*15.0*	*20.0*	80
72-Hour Weekday Continuous	*8*	*512*	*5.0*	*16.0*	*21.0*	50
55-Hour Weekend Continuous	*10*	*550*	*10.0*	*17.0*	*27.0*	80
10-Hour Night-time Closures	*220*	*2,200*	*7.0*	*21.0*	*28.0*	30

Lee et al. from I-15 Devore project

Improving General Construction Sustainability: Contracting Alternatives

- Emissions control through contract-required EPA certification of equipment or emissions-reducing retrofit pollution controls.
  - Examples: MassDOT Central Artery, IDOT Dan Ryan, various NY Metro Transportation Agency projects
- Alternative bidding and contracting to encourage reduced GHG and other pollutant emissions
  - A + B (cost plus time) bidding to reduce project duration
  - A + B + C (C = environmental costs) bidding has been proposed (Ahn 2012)
    - Use LCA to estimate emission and energy consumption values for C

Concrete Pavement Construction: Overview

Concrete Pavement
Base Course (optional)
Subbase course (optional)
Subgrade Layer(s)

Construction Activity	***Fuel Factor***
Subgrade Preparation (grading and finishing)	0.300-0.700 gals/cubic yard
Base Layer Preparation (hauling, placement, and compaction)	0.400-0.600 gals/ton
Concrete Mix Production	0.09 gals/c.y.
Concrete Hauling (short)	0.60 gals/c.y.
Concrete Placement	0.267 gals/c.y.

(fuel factor source: Skolnik, Brooks, and Oman 2013)

Improving the Sustainability of Concrete Pavement Construction Practices

- Reduce use of virgin materials
  - On-site recycling
  - Two-lift paving
- Minimize construction fuel use and emissions
  - On-site recycling (foundation layers)
  - Match construction equipment and production capacities
  - Single-lift construction
  - Use of roller-compacted concrete (RCC)
  - Use of early-entry saws
- Conserve and protect water resources
  - Collect and re-use concrete wash water

Improving the Sustainability of Concrete Pavement Construction Practices

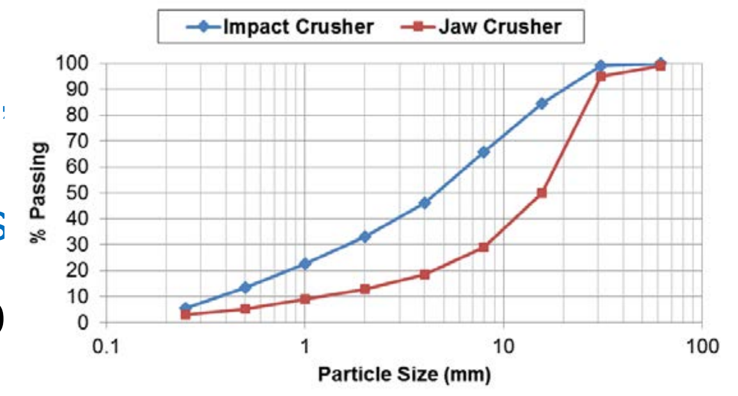
- Improve initial ride quality (reduce use phase fuel consumption and emissions)
  - Two-lift paving
  - Real-time profile (RTP) measurement and control
- Increase pavement service life
  - Improved construction QA (including dowel alignment)
  - Improved curing materials and practices
- Balance surface friction requirements with tire-pavement noise impacts

On-site Recycling

- Reduced project (material) costs
- Reduced haul costs
- Reduced fuel consumption
- Reduced GHG emissions
- Reduced consumption of resources
- Reduced use of landfills

Considerations for Concrete Recycling

- Many potential applications
  - Base/subbase materials (most common), new concrete and asphalt paving layers, riprap, fill and embankment, many others
- Suitability may be limited by quality o source concrete
  - Pavements vs building demolition debris
  - Materials-related distress (AAR, freeze-thaw)
- Production processes impact product quality
- Stockpile runoff and drainage effluent



Two-lift Paving

- Pros:
  - Potential improvement in initial ride quality, with resulting reduction in use-phase user costs, fuel consumption and emissions
  - Potential for improved use of local and recycled materials
- Cons:
  - Possible increased construction cost (slight)
  - More energy consumed in construction

Use of Roller-Compacted Concrete

- Pros:
  - Significant construction cost savings (primarily materials)
  - Lower fuel consumption and GHGs in construction
  - Adequate ride quality for low-speed pavements
- Cons:
  - Overlay or diamond grinding for higher-speed pavements (added cost, fuel and possibly material

Collect and Re-Use Concrete Wash Water

- Increased costs for collection and removal
- Reduced costs for remediation and clearing drains
- Eliminate localized vegetation kills
- Eliminate pH impact on local surface waters

Real-Time Profile (RTP) Measurement

- What is it?
  - An integrated system of profile data collection sensors and processing software that provides real-time profile feedback to the contractor.

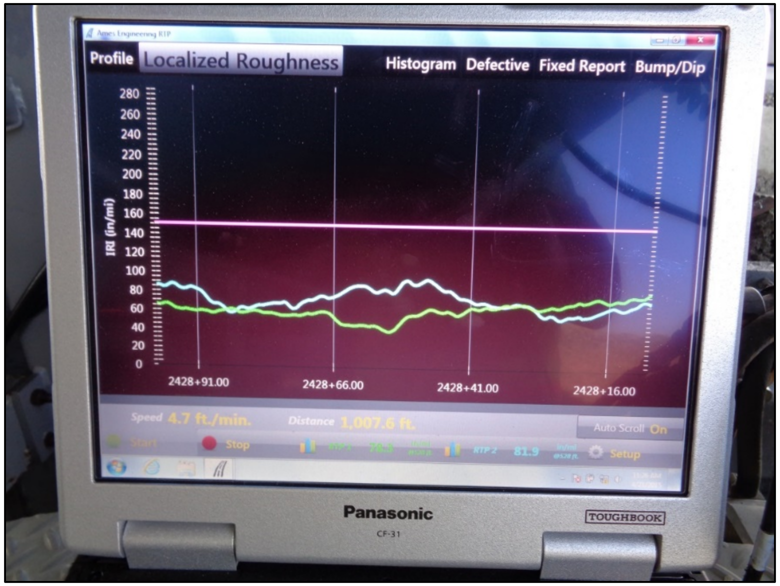


Photo credits: Gary Fick, SHRP2 R06E Contractor

Real-Time Profile (RTP) Measurement

- Pros:
  - Better ride quality, lower vehicle operating costs
  - Reduced need for construction corrections
  - Potential reductions in use-phase fuel consumption and GHGs
- Cons:
  - Capital cost of equipment

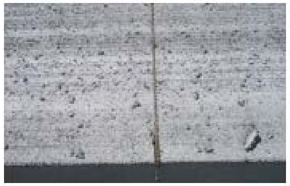
Photo credit: Gary Fick, SHRP2 R06E Contractor

Improved Construction QA

- Examples: Dowel alignment measurement, Super Air Meter (SAM)
- Pros:
  - Potential for increased service life, more time between M&R activities, lower user costs
- Cons:
  - Additional testing costs
  - Equipment costs

Texture to Balance Surface Friction and Noise Concerns

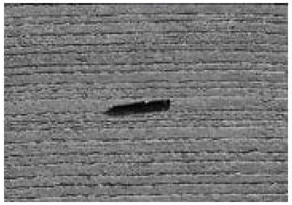
- Surface friction (sustainability through safety, reduced crash rates)
- Minimize generation of tire-pavement noise
- Texture type selection and proper construction prevent premature surface corrections ($) and safety problems



Turf Drag

Long. Tining

Exposed Agg



Trans. Tining

Diamond Grind

Photos courtesy of ACPA.

Remarks

- Construction has an impact on energy consumed and resulting local and global environmental impacts
- Pavement construction activities offer many opportunities to adopt practices that improve pavement sustainability
- The construction phase is a phase over which engineers and contractors have a great deal of influence
- Achieving specification targets and maintaining good construction quality are keys to reducing life-cycle impact
- Tools are available for sustainable management of pavement construction

Thank You!

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- **Please join us at these upcoming webinars!**

Schedule	Webinar Event
Aug 20 **1-3 pm EDT**	#4: Maintenance, Rehabilitation, and End-of-Life
Sep 9 **1-3 pm EDT**	#5: Use Phase, Livable Communities, and Path Forward