

*12th Annual Pennsylvania Concrete Conference
Hershey, Pennsylvania - February 1, 2011*

Sustainable Concrete Pavements Small Steps, Big Gains



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Presentation Outline

- Sustainability concepts
- Sacramento Sustainability Conference – Some Highlights
- Specific sustainability applications
 - Optimizing pavement design
 - Concrete materials considerations
 - Concrete mixture



***Focus of presentation:
Not factors that involve pavement type selection process
But, factors that can come into play after the concrete
pavement selection is made – during the design &
construction phase***

What is Sustainability?



“Meet[ing] the needs of the present without compromising the ability of future generations to meet their own needs”

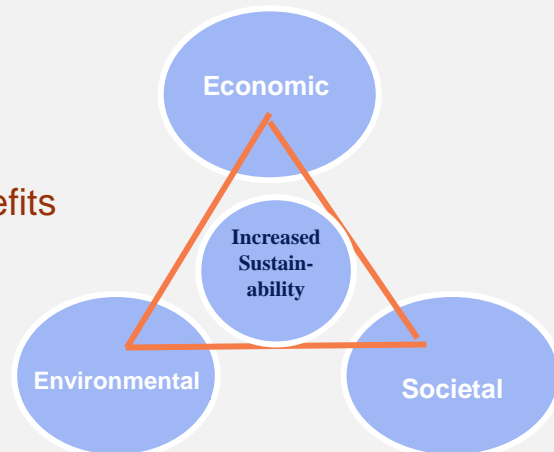
—World Commission on Environment and Development, 1987

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

Sustainable Infrastructure

➤ Must address

- Economic benefits
- Environmental benefits
- Societal benefits



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

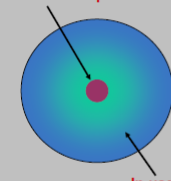
Sustainability - Construction Phase vs. Use/Operation Phase (GHG Focus)

THE BUSINESS CASE:
SUSTAINABILITY ACCOUNTING

EXAMPLE:

	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
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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)

EXAMPLE:

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

Benefits

↑

↓

Costs

41
10.06.07 Concrete-Carbon-Sustainable cement-ICC

CFMIRP-41

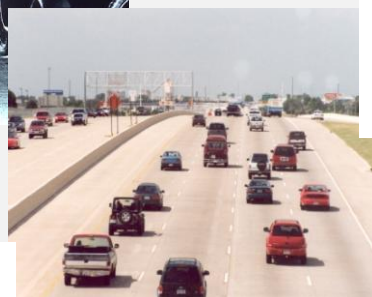
Sustainable Concrete Pavements - Making the Construction Phase More efficient

- This is where good engineering meets sound materials technology meets good construction practices by minimizing energy and resources use, cost, & GHG (CO₂) emission
 - By optimizing key 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

2005 on
Long life - 40+ years

Resulting from improvements in design, construction & material technologies & continuing to evolve



Long-Life Concrete Pavements Current US Expectations

- Original PCC surface service life – 40+ years
 - Pavement failures and material degradation
 - Pavement failures for cracking, faulting & rutting
 - Pavement and surface texture characteristics with minimal intervention activities to correct for ride & texture, for joint resealing, and minor repairs
- But, are we really doing our part to design & construct sustainable long-life concrete pavements?**

**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
- State DOT 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 (LCA, etc)
- For the construction phase
 - Minimize environmental impacts
 - Conserve resource
- 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

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 100% reliance on portland cement
 - Use less OPC & more “greener” cementitious materials
- Make construction more efficient (improve practice)
 - Use processes less damaging to the environment

Conference & Practice Highlights:

Pavement Design Optimization

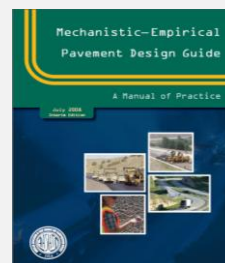
Reducing Portland Cement Use

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 without compromising performance

- 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

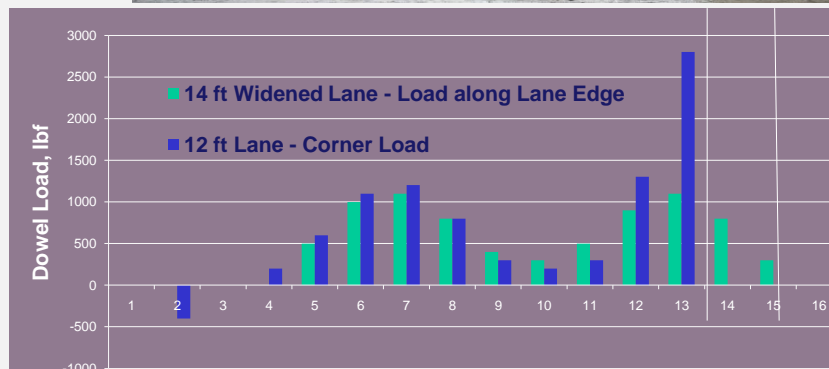
		Thickness [cm] ▼ E _{v2} - Bearing value [MN/m ²]				
Zelle	Bauklasse	SV	I	II	III	
	Äquivalenz 10-1-Achsübergänge in Mo.	B	> 32	> 10 - 32	> 3 - 10	> 0,8 - 3
	Dicke des Frostsch. Oberbaues ¹⁾	55	65	75	85	55
		65	75	85	55	65
		75	85	55	65	75
		85	45	55	65	75
Tragschicht mit hydraulischem Bindemittel auf Frostschuttschicht bzw. Schicht aus frostunempfindlichem Material						
1.1	Betondecke	27				
	Vliesstoff					
	Hydraulisch gebundene Tragschicht (HGT)	18				
	Frostschuttschicht	42				
	Dicke der Frostschuttschicht	-	33	43	-	25
1.2	Betondecke	27				
	Vliesstoff					
	Verfestigung	20				
	Schicht aus frostunempfindlichem Material	47				
	Dicke der Schicht aus frostunempfindlichem Material	8	18	28	38	15
1.3	Betondecke	27				
	Vliesstoff					
	Verfestigung	25				
	Schicht aus frostunempfindlichem Material	48				
	Dicke der Schicht aus frostunempfindlichem Material	8	18	28	38	15

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



- 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)

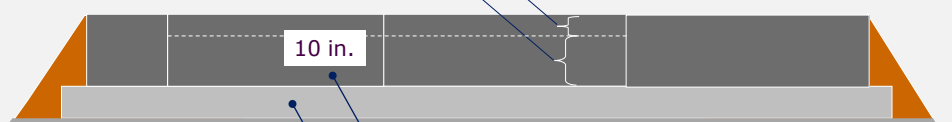
- Two-lift construction to maximize the use of locally available/recycled materials
 - The lower lift can be made with materials that might not perform well in a surface layer
 - The top lift can be designed to withstand the harsh environmental and loading conditions at the pavement surface

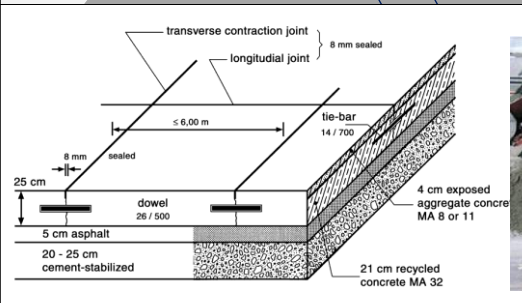
Typical European Section (Less PCC thickness than in US)


Top lift w/ exposed aggregate
Bottom lift w/ recycled aggregates

Emergency Lane

10 in.







Sacramento Conference Paper

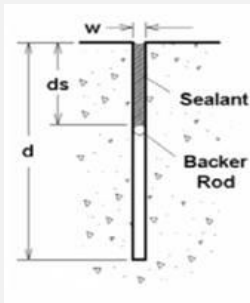
Implementation of Narrow Contraction Joints in Louisiana: A Cost Benefit Analysis Study

Tyson Rupnow, Ph.D., P.E.
Mark Martinez, P.E.
Zhongjie Zhang, Ph.D., P.E.



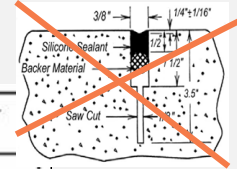
Study Details

➤ 98-6P: Evaluation of Narrow Transverse Contraction Joints



w (in)	d (in)	ds (in)	Sealant	Backer Rod
1/8	2.5	---	no	no
1/8	3.5	---	no	no
1/8	3.5	1/2	yes	no
1/8	3.5	1/2	yes	yes

w = joint width d = joint depth ds = sealant depth



Field Results & Conclusions

- Tested after construction (6 months)
- Tested nine years alter for long term data
- Joint condition after 9 years was good for all joints
 - Slightly lower IRI for the test sections
- Construction savings: \$2.5 million/year
- Rehab and fuel savings: \$678,000 /year
- Cumulative savings at year 7: about \$32 million



Conference Highlights:

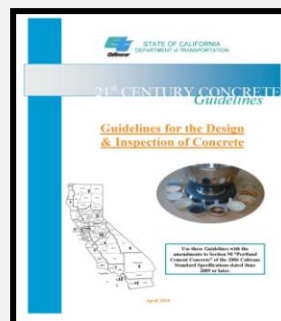
*Pavement Design Optimization
Reducing Portland Cement Use
Optimizing Concrete
Improving Construction Practices*

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 (ASTM C595)
 - Performance-based cements (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.)



Reducing Cement By Using Pozzolan and Slag

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

Blended cement use is allowed & is common

However, **ASTM C1157 performance** cements not widely used yet

Greener Cements

ASTM C1157 Performance Cements

- ASTM C 1157 offer equivalent performance to 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 (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 - City of Denver

- Side by side comparison of ASTM C150 I/II and ASTM C1157 GU cements
- No noticeable performance differences
- Winter construction
- Aligns with Denver's Greenprint CO₂ reduction initiatives

Other examples also presented – Colorado & Utah

Study Summary

- Performance cements (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 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

**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-CO₂ 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, 2010

CSA A3001-08 Types of Hydraulic Cement				Blended PLC – 2010 Amendment
Portland cement type	Blended hydraulic cement type*	Portland-limestone cement type†‡		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

**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

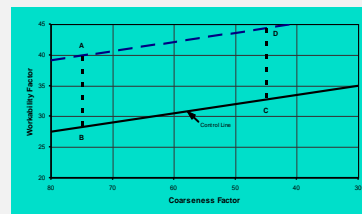
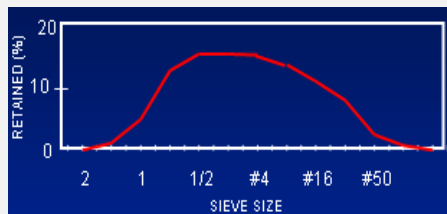
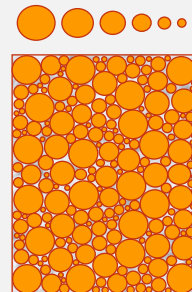
- PLC with 12% limestone performance, when optimized for equal strength → portland cement (Type PC)
- Blended PLC with 12% limestone and 15% slag performance → PC with 23% less clinker
- PLC also performs well with (further) additions of SCM at the ready-mixed concrete plant (less CO₂ emissions).
- PLC or blended PLC together with (further) SCM additions at the concrete plant
 - Reduces the clinker content of paving mixes by up to 50%
 - CO₂ reductions → 1 to 1½ tons per concrete truck!

Conference Highlights:

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

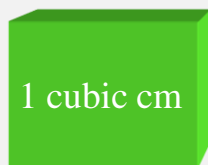
Reducing Paste (Cement) Optimizing Aggregate Gradation

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

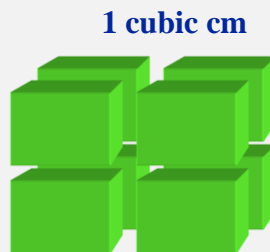


Reducing Paste (Cement) Use Larger Aggregate Size

- Larger the Particle Sizes:
 - Less surface area to coat(reduced paste & water demand → better concrete)



6 sq. cm surface area



12 sq. cm surface area

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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, 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

