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Tendencias Hacia una Construcción Sustenable en los Pavimentos de Concreto

Norbert Delatte, P.E., Ph.D, F.ACI

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Concrete Pavements

Societal, Ecological & Economical Implications

Presentation Originally Developed By

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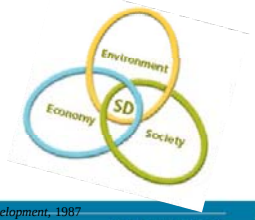
What is Sustainable Development ?

The most commonly cited definition

"Meets the needs of the present without compromising the ability of future generations to m[illegible] their own needs".[3]

Triple Bottom Line:

- **Environmental Impact**
- **Social Impact**
- **Economic Impact**



[3] *UN World Commission on Environment and Development*, 1987

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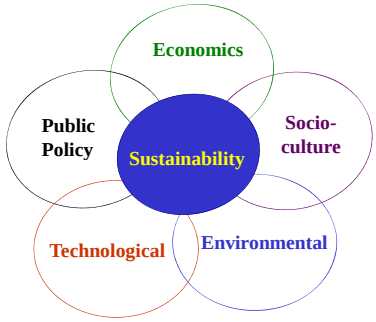
Sustainable Infrastructure Levers



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Social Benefits of Concrete Paving

- Safety
  - Transportation Safety
  - Better Visibility
  - Security and Impact Resistance
- Comfort
  - Transportation Comfort
  - Acoustical

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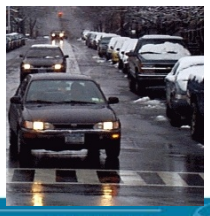
Decreased Hydroplaning Potential

- Hydroplaning occurs when there is tire separation from the pavement surface by a layer of water, which causes loss of vehicle steering and braking control.
- Factors include:
  - Tire wear
  - Driver Speed/Experience
  - Pavement Surface Characteristics
    - Texture
    - Rigidity



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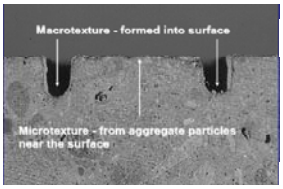
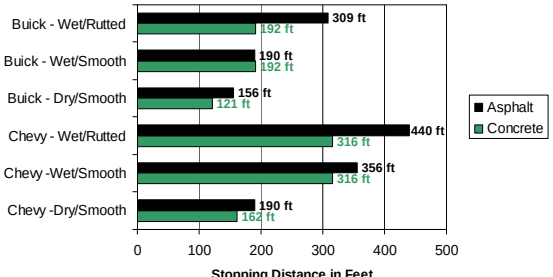
Hydroplaning

Concrete pavement is a moldable material when first placed and it can be textured to provide good friction characteristics and wet weather performance.



- Microtexture
  - Fine-scale roughness due to texture on the concrete surface.
- Macrotexture
  - Measurable striations or grooves formed in the plastic concrete by hand operated tining brooms or automated machines.

Improved Stopping Distance

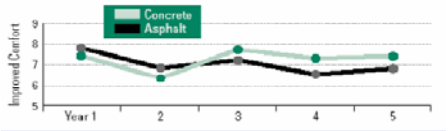


1 ft = 0.3 m

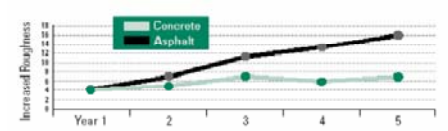
Values do not include hydroplaning.

Enhanced Ride and Comfort

Riding Comfort Index



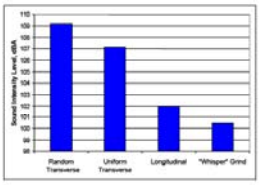
Profile Ride Index



NSTPW 5 Year Study Comparing Performance of Adjoining PCCA and ACP structures build in 1994.

Quietness of Ride

Most research to date shows that longitudinally tined, astro-turf drag textures, and diamond grinding provide the quietest new construction techniques for concrete pavement, while diamond grinding provides the quietest rehabilitation strategy.



Sound Level Intensities for Different Concrete Pavement Textures in Arizona

Visibility

Concrete light reflective surface provides better visibility in urban and rural environments.

Solar Reflectance of Various Pavement Types

Pavement Type	Solar Reflectance	
	New	Weathered
Asphalt	0.05 - 0.10	0.10 - 0.15
Gray Porland Cement Concrete	0.35 - 0.40	0.20 - 0.30
White Portland Cement Concrete	0.70 - 0.80	0.40 - 0.60

Night time photograph Of concrete pavement and asphalt pavement.

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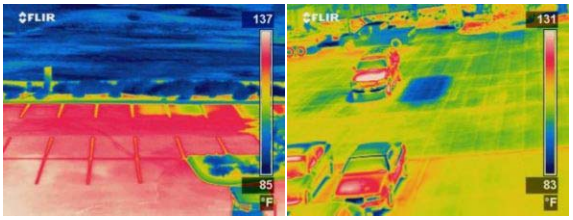
Before and After... Concrete



These photos show the heat levels generated by an asphalt pavement (left) versus the cooler effects of the concrete overlay placed over it (right).

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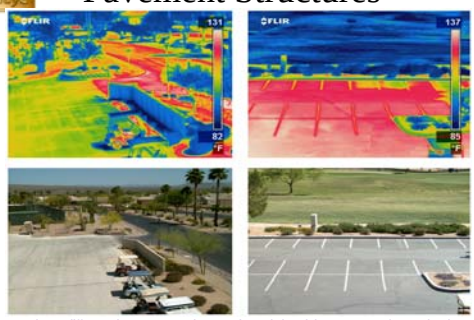
Pavement Structures



There was a 30-degree difference in temperatures between the asphalt and the concrete surfaces. The photo on the top right was taken of an asphalt parking lot adjacent to a golf course. Note the 85-90 degree temperature of the grass and the 135 degree temperature of the asphalt; the photo below it represents the same scene.

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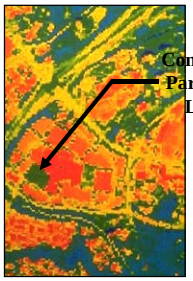
Concrete Pavements and Sustainable Development

"Cool Communities"
- Reduce Heat Island Effect

LEED™ Certification
- Concrete can assist in attaining necessary credits



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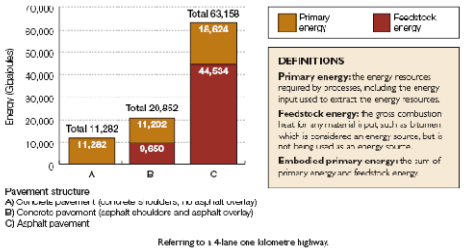
Reduced Energy Consumption – Comparative Embodied Primary Energy



Pavement structure
A) Concrete pavement (concrete shoulders, no asphalt overlay)
B) Concrete pavement (asphalt shoulders and asphalt overlay)
C) Asphalt pavement

Referring to a 4-lane one kilometre highway.

Note: Concrete pavement option has feedstock component due to its asphalt shoulders and overlay as part of the maintenance and rehabilitation schedule.

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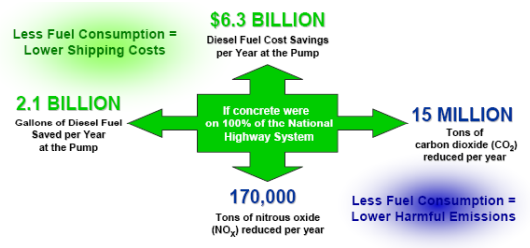
Reduced Carbon Dioxide Emissions



References:
1. Smith, Tim, "Truck Fuel Savings – What Does it Mean for YOU?", Cement Association of Canada, December 2, 2005.
2. "Federal-Aid Highway Length – 2004 – Miles By Type of Surface", FHWA, HM31, October 2005.
3. "Table 1-11 Number of U.S. Aircraft, Vehicles, Vessels, and Other Conveyances", Bureau of Transportation Statistics, US Department of Transportation, http://www.bts.gov/publications/national_transportation_statistics/2003/html/table_01_11.html

Assumptions: Total Asphalt Distance= 94,267miles; Truck Mileage = 15 mpg on Concrete, 14.2 mpg on Asphalt; Truck Travel = 94,267 miles/year/truck (underestimate); Total Number of Trucks in US = 5,626,030; Fuel = $3/gallon

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Reusable and Recycling Paving Material

- White topping
- Concrete Pavement Restoration Techniques
  - Diamond Grinding
  - Partial Depth Repair
  - Full Depth Repair
- Bonded Overlays
- Concrete pavement is 100% recyclable material
  - Granular Fill
  - Base Course for new pavement
  - Aggregate for new concrete pavement.

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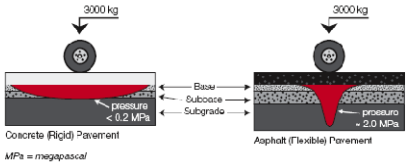
Utilize Less Granular Fill Material

Concrete acts as a bridge over the subgrade. Inch for inch, much less pressure is placed on materials below concrete than asphalt. Twice as much granular fill is needed in asphalt versus concrete pavements with equivalent designs.



2.0 MPa = 290 PSI, 3000 kg = 6600 lbs.

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Use of Industrial By-Products

- SCMs
  - Fly Ash, Slag Cement, and Silica Fume
    - Enhanced workability with slag cement and fly ash.
    - Increased durability with SCM use in concrete pavement and bridge mix designs.
    - Reduction in CO_2 emissions and disposal of by-products to landfills
    - Viewed as an FHWA best management practice BMP

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Additional Cementitious By-Products

- Class C Fly Ash
  - **Self-cementing properties for soil stabilization**
- Cement Kiln Dust
  - **Cementing properties for soil neutralization, stabilization and solidification.**

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Other Concrete By-Products

- Recycled Aggregates
  - Coarse and Fine
- Recycled Concrete
  - Can be crushed and recycled

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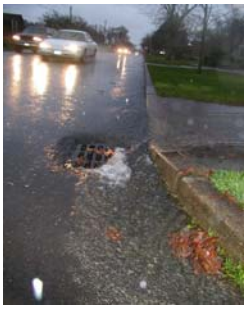
Impervious Pavement Surfaces

Traditional at-grade asphalt and concrete structures such as streets, sidewalks, parking lots, and pedestrian plazas are nearly 100% impervious, and therefore generate a high volume and rate of stormwater runoff.

This runoff must be collected, conveyed, treated, detained, and disposed of.



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Asphalt Pavement First Flush

First 12 to 25 mm of rainfall

- Contains contaminants
  - EPA requires collection and treatment prior to release
- US Geological Survey study
  - High concentration of polycyclic aromatic hydrocarbons (PAH)
    - Attributed to asphalt parking lot runoff
    - Runoff from asphalt-based sealants 10 times higher
    - Runoff from coal-tar based sealants 65 times higher

Source: http://water.usgs.gov/nawqa/asphalt_sealers.html

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http://ehp.niehs.nih.gov/members/2005/113-7/focus.html

Awash in toxicants. Chemicals used in paved surfaces can be toxic to fish, wildlife, and possibly humans. Images: Photodisc; PhotoAlto (inset)

"If you look at the asphalt used in a parking lot, the top coat is quite toxic. So if you have a heavy rain [soon] after the parking lot goes in, it's not unusual to see fish kills downstream."

--- Melinda Lalor, professor of environmental engineering at the University of Alabama at Birmingham

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Innovations in Concrete Pavement

- Innovations in paving technology have made it possible to pass rainwater though the pavement section and into the subgrade and underlying soil.
- In some cases, this can eliminate the need for additional stormwater management facilities, including catch basins, pipes, manholes, ponds, swales, drywells, and sumps

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What is Pervious Pavement ?

- Reduced-Fines Concrete Mix
  - Coarse Aggregate
  - Fine Aggregate (optional)
  - Portland Cement
  - SCMs (Fly Ash, Slag Cement)
  - Water
  - Admixtures
- Intended for use as an open-graded drainage material

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Typical Pervious Mix Design

- 315 – 360 kg/m^3 Portland Cement
- Fly Ash / Slag Cement cementitious materials acceptable
- 1 m^3 Coarse Aggregate
  - Aggregate size will affect drainage rate
- Sufficient water to display a wet, metallic sheen on the aggregate
- 0.25 – 0.35 W/C Ratio

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Engineering Properties

- 15% to 35% Air Void Content
- 1600 to 2000 kg/m^3 Density (unit weight)
- 2.8 to 28 MPa strength*
  - Introduction of small amount of fine aggregate can increase strength to 28 MPa (+/-)
  - Compressive strength typically *not* used as acceptance criteria.
  - Air void structure and unit weight are used instead.

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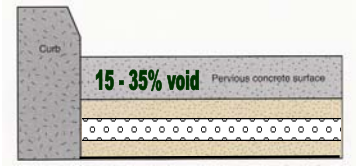
Typical Design for Pervious Concrete



- Pervious concrete: 10 – 15 cm
- Open-graded stone subbase: determined by local hydrologic conditions (15 – 45 cm typical)
- Geotex prevents movement of fines into stone bed
  - **Perforated pipe to capture and transport water (optional)**

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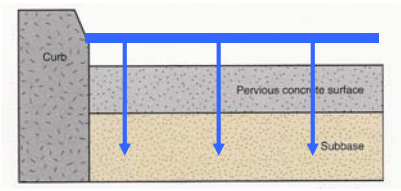
Transport of Stormwater

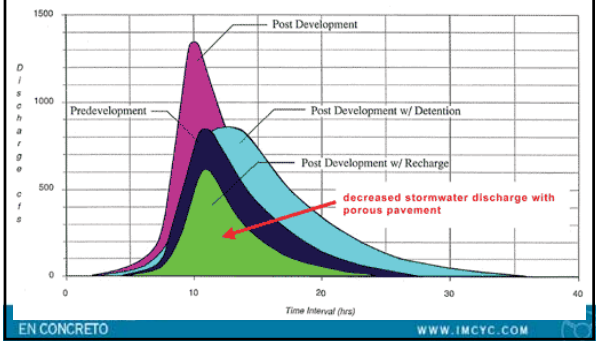


- Water drains through pavement into stone bed and infiltrates slowly into underlying soil mantle
  - 3 – 12 mm/hr acceptable
  - Total drawdown time should not exceed 5 days

Pervious Concrete Properties

- Drainage rate very high
- Equivalent of 7 to 11 m of rain per hour!
  - *More than half of all rainfall is provided in rain events that total one-half inch or less.*
- 15 cm section with 20% voids holds 2 – 3 cm of rain water

Controlled Flow

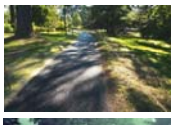


Chicago's Alleyways Program

- Pervious pavements is used in Chicago as an alley paving material for
  - Stormwater Management
  - Reduced Urban Heat Island Effects
  - Material Recycling
  - Energy Conservation and Glare Reduction

Applications for Porous and Pervious Pavements

- Low Volume Roads
- Subdivision Roads
- Median Strips
- Parking Lots
- Walkways
- Playgrounds



Reducing Storm Water Run-Off and Preventing Erosion

- Pervious pavements are recognized by the FHWA as runoff substitute for
  - Low-volume and emergency access roads
  - Highway Vehicle Crossovers and Road Shoulders
  - Boat Ramps, Bus Stop Pads

Route 23 Sussex, New Jersey

Economic Benefits of Concrete Pavement

Concrete provides many long-term economic advantages compared to other pavement materials

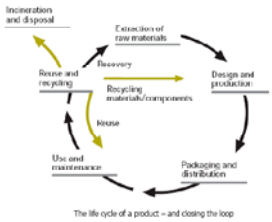
- Life Cycle Cost Analysis

Life Cycle Cost Analysis

The concept of Life Cycle Cost Analysis (LCCA) is to combine the incurred cost and accrued benefits over different periods of service lifetime in a consistent manner.

LCCA is especially useful when project alternatives that fulfill the same performance requirements, but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings.

Sustainable Product Life Cycle



The life cycle of a product – and closing the loop

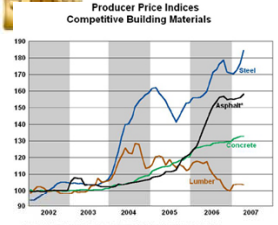
- Rethink the product and its functions.
- Reduce energy and material consumption.
- Replace harmful substances
- Recycle
- Reuse
- Repair

Key Factors to Include in LCCA

- Agency Costs
  - ✓ Initial Construction Costs
  - ✓ Future Construction or Rehabilitation Costs
  - ✓ Maintenance Costs Recurring Throughout the Design Period
  - ✓ Salvage or Residual Value at the End of the Design Period
  - ✓ Engineering and Administrative Costs
  - ✓ Traffic Control Costs
- User Costs
  - ✓ Travel Time
  - ✓ Vehicle Operation
  - ✓ Accidents
  - ✓ Discomfort
  - ✓ Time Delay and Extra Vehicle Operating Costs During Resurfacing or Major Maintenance

Economic Benefits of Concrete Pavements

- First Cost
  - Affordable and competitively priced
  - Less excavation needed
  - Minimum subbase preparation
  - One pass completion



First Costs Have Risen Dramatically in the Last Five Years

CONSTRUCTION MATERIALS COSTS

MATERIAL	2004-05	2005-06	Past 9 Months*
Copper	+33.4%	+3.9%	+36.9%
Drywall	+20.0%	+18.2%	+21.2%
Concrete	+5.5%	+8.6%	+5.5%
Steel	+8.0%	+13.0%	+13.6%
Lumber	-1.0%	-1.7%	-5.1%
Asphalt	+18.3%	+17.8%	+43.1%
Acoustical Ceilings	+7.0%	+7.0%	
Carpet	+8.0%	+8.0%	

Reduced Material Costs

- Concrete and cementitious materials are locally manufactured reducing the requirement to ship heavy building materials and the associated environmental, economic and societal impacts of transportation
- Ready-mixed concrete and and precast concrete are made to order materials that contribute little waste to job sites.

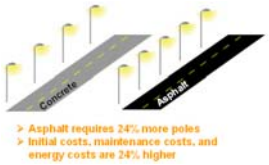
Maintenance

- Proven fewer repairs
- No annual resealing needed
- No business interruption

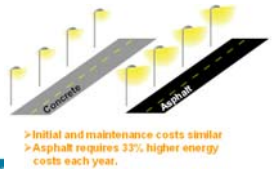
Durability

- Concrete is not affected by seasonal weakening of the subgrade during spring thaw, as many asphalt pavements.
- High Performance Concretes and Ultra High Performance Concretes have design lives greater than 100 years.

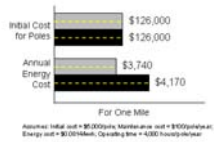
Illumination of Streets and Highways



- Asphalt requires 24% more poles
- Initial costs, maintenance costs, and energy costs are 24% higher

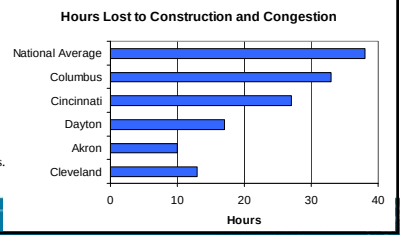


- Initial and maintenance costs similar
- Asphalt requires 33% higher energy costs each year.



User's Costs – Time Delay

Traffic congestion continues to worsen in American cities of all sizes, creating a $78 billion annual drain on the U.S. economy in the form of 4.2 billion lost hours and 2.9 billion gallons of wasted fuel — that's 105 million weeks of vacation and 58 fully-loaded supertankers.



Texas Traffic Institute, 2005 figures.

Reduced Fuel Costs

In 1989, the FHWA found that savings in fuel consumption for heavy vehicles was up to 20% with concrete pavements.

More recently, the National Research Centre of Canada showed that 0.8 to 6.9% reductions in fuel usage for semi-tractor trailers existed with concrete pavements.

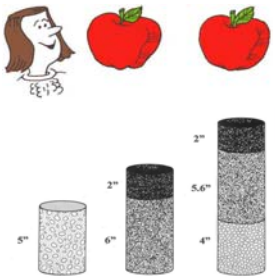
Reduced Traffic Delays

The cement and concrete industries have developed methods for rapid maintenance and restoration of highways.

Roadway owners can use both fast-track reconstruction techniques such as pre-cast concrete pavement panels or rapid setting concrete mixtures to minimize user delays.

Concrete vs. Asphalt

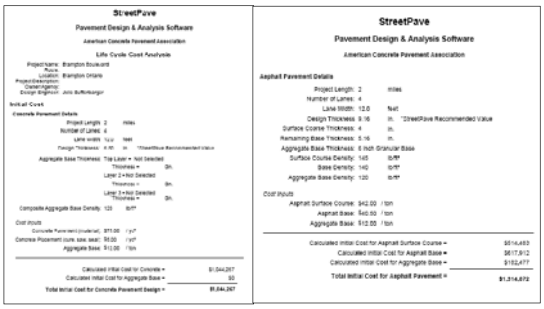
- Apples-to-apples comparison of pavement design should always be considered
- Quantification in $ allows for a better business decision on pavement choice



Design Of Pavements

- Purpose
  - Residential
  - Collector
  - Minor Arterial
  - Major Arterial
- Average Daily Truck Traffic
- Realistic design requires realistic understanding of pavement needs

StreetPave Program

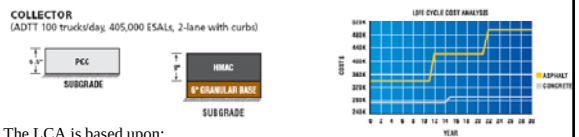


$1,044,267 $1,314,872

StreetPave – Collector Roads

Concrete: 600 psi, flexural; Reliability 80%; k-value 100; Design Life 30 Years.

Asphalt: MAAT 45 °F; Modulus of Resilience 3000 psi; Design Life 30 Years.



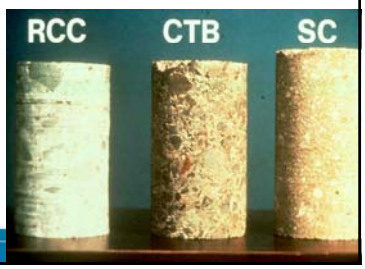
The LCA is based upon:

1. ENR August 2006 issue 20 City Average Prices
2. Initial Cost 1-mile 12' wide pavement with curbs place separately
3. Design Period 30 years
4. If integral curbs are placed with concrete pavement an additional $45 K can be saved on initial costs

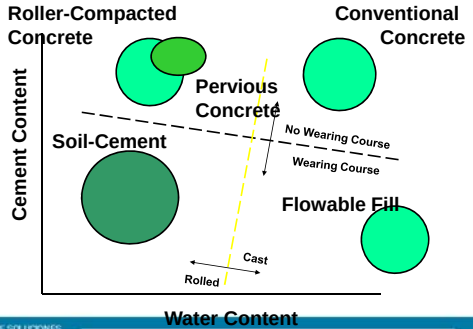
Roller-Compacted Concrete

Family of Cement Treated Materials

- Increasing cement content, strength, surface abrasion resistance
- Soil cement – SC
- Cement treated base – CTB
- RCC



Cement-Based Pavement Materials



Benefits of RCCP

- Fast construction with minimum labor
- High load carrying ability
- Early strength gain
- Durable
- Low maintenance
- Light surface reduces lighting requirements
- Economical

Rehabilitate, Rebuild, Reuse and Recycle

- Technologies enable the expanded use of recycled or waste materials in highways construction (FDR)
- Pursuit of less damaging (more "sustainable") and renewable materials and construction technologies

Materials

- Portland cement – generally less used than conventional concrete
- Fly ash, silica fume, other supplementary cementitious materials
- Coarse aggregate (may use aggregate blend)
- Fine aggregate
- Water

Disadvantages of RCC

- Rough surface – not sufficient for high speed applications without overlay
- Surface appearance

Conclusions

- Sustainability is now being recognized as a vital and central core to urban development.
- Analyzing the planning and design of civil infrastructure, which is consistent with the principle of urban sustainability and global sustainable development is a must for the future.
- Engineers are uniquely positioned to apply principles of sustainable development to infrastructure in initial construction and rehabilitation.

Conclusions

- Recycling industrial by-products and construction materials in infrastructure can help generate "green" infrastructure where use of virgin materials and large amounts of energy is avoided.
- Concrete pavement plays an important positive role in minimizing the impacts or our built civilization by providing social, environmental and economic benefits.

Other Resources

- American Concrete Pavement Association
- National Ready-Mixed Concrete Association
- Canadian Cement Association
- Portland Cement Association
  - www.concretethinker.com
- United States Green Building Council
- Canadian Green Building Council

In Closing, New Thinking Is Required

Einstein: "We will not solve problems by using the same kind of thinking we used when creating them"

" We do not inherit the earth from our ancestors; we borrow it from our children. "

- Native American proverb

Questions and Discussion