SUSTAINABILITY OF CONCRETE BRIDGES

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What is Sustainable Development?

- "*Sustainable Development meets the needs of the present without compromising the ability of future generation to meet their own needs*"- United Nation's World Commission

Sustainable Development of Concrete Bridges

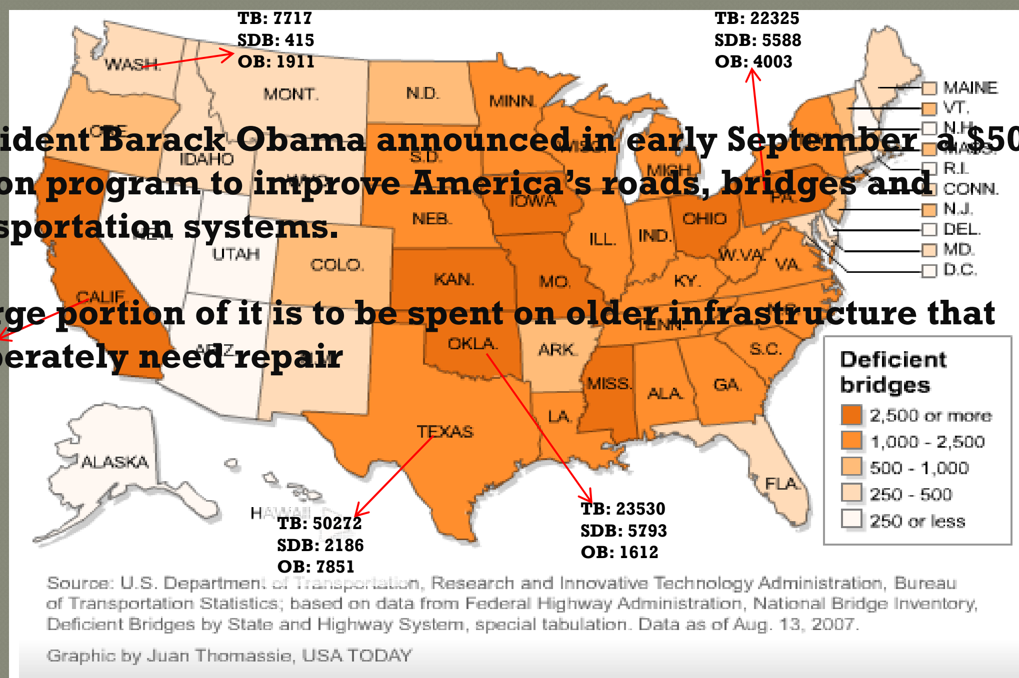
- To concrete bridge engineers, Sustainable Development means:
  - *"Designing , constructing and maintaining context sensitive bridges with long term durability, low life-cycle impacts, sensitivity in selection of materials and methods and a minimal impact on the environment throughout the bridge life."* - Dr Tess Ahlborn

Importance of Concrete Bridge Sustainability

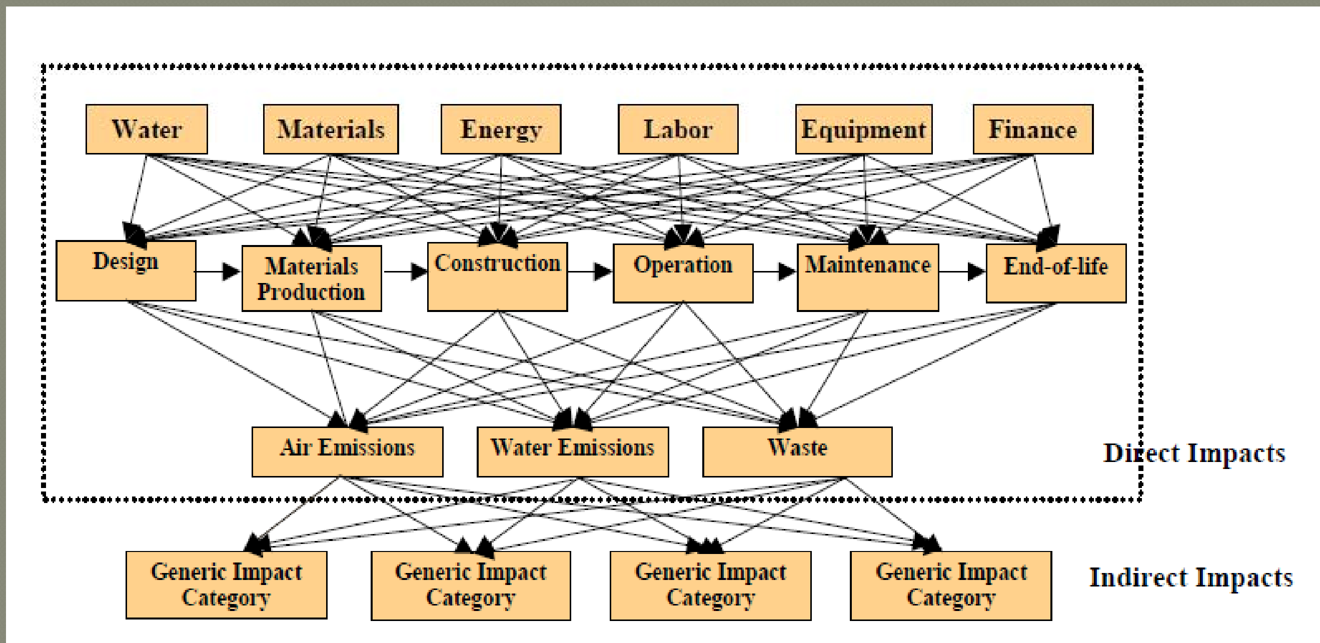
Out of 597876 bridges in USA, more than a quarter are rated as either structurally deficient or obsolete

President Barack Obama announced in early September a $50 billion program to improve America's roads, bridges and transportation systems.

A large portion of it is to be spent on older infrastructure that desperately need repair



Importance of Concrete Bridge Sustainability



Various Impacts of Bridges on Environment – M Myint Lwin

Importance of Concrete Bridge Sustainability

- According to the ASCE code of ethics,
  - *"Engineers should hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties"*
- Concrete is the number one building material
- Ranked 2nd to water as the most consumed substance
- Making concrete bridges sustainable is of paramount importance

Importance of Concrete Bridge Sustainability

- Sustainable bridge design
  - Create balance between the impact of bridge on society, environment & economy
  - Minimize the amount of waste material
  - Lessen the social impact of construction congestion
  - Decrease the cost /year of service over the life cycle of the structure
- Eventually, sustainable design clearly makes a positive public perception of the engineering solutions

Life Cycle of Concrete Bridges

- Life cycle plays an important role in evaluating the sustainability of a bridge
- Two important terms,
  - Life Cycle Cost (LCC)
  - Life Cycle Assessment (LCA)
- LCC includes cost of planning, designing, construction, and maintenance; used for cost benefit analysis and cost comparison

Concrete Bridges are Vulnerable

- Exposed to weather: tropical, freezing, high moisture, chemicals
- Substructure subject to tidal ebb and flow, soil, contaminants
- Freeze and thaw, deicing salts, traffic load and impacts, naval loads and impacts
- Extreme events

Life Cycle of Concrete Bridges

- LCA focus on the environmental impacts of natural resource extraction, raw material production, product manufacturing, operation, maintenance and final disposal
- LCA also addresses the decommissioning or reuse of the structure
- A comprehensive summary of the environmental impact of the bridge can be gained through LCA

Sustainable Bridge Design Process

- Design process must address performance needs and future repair/inspections
- Extended service life of bridges is of immense importance
- Escalating the service life of major bridges from 75 to 120 or 150 years without major repair work would obviously greatly reduce the resources needed on an annual basis

Sustainable Bridge Design Process

- Sustainable development and service life are clearly interrelated
- Following measures are important to evaluate the bridge performance and extend service life:
  - Durability
  - Best Practice
  - Higher Strength
  - Serviceability
  - Prevention of Deterioration
  - Preservation Methods
  - Critical Deficiencies in Data Collection
  - Vulnerabilities/Security
  - Operational Efficiency
  - Resiliency against Extreme Events

Sustainable Bridge Design Process

- Following measures are important to achieve extended service life,
  - Proper detailing of joints
  - Strict QA/QC
  - Usage of high performance materials
  - Adaptability of functionality
  - Scour monitoring system
  - Consider redundancy
  - Better drainage system
  - Cross frames
  - Single vs. multi load paths
  - Engineering judgment and flexibility in design & detailing
  - Assess the ability to reopen the bridge soon after the event
  - Ways to alert the public

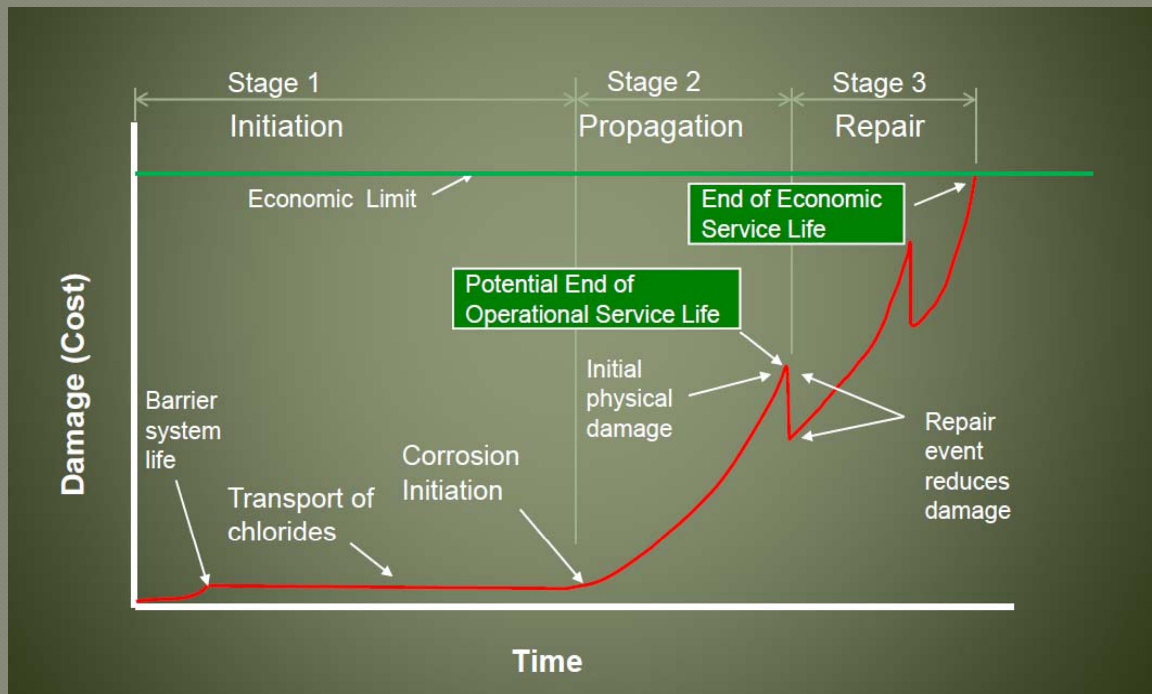
Sustainable Bridge Design Process

- Condition inspection should be given proper importance:
  - Qualifications of the inspectors need to be reviewed
  - Inspection is repetitive and tedious, so there is a need to keep inspectors interested
  - Different inspection teams should inspect a bridge during different cycles
  - A peer exchange programs for the inspectors can be introduced

Sustainable Bridge Design Process

- Quality control and quality assessment are essential to providing durable structures
  - Requirements of the Contract Documents enforced during construction
  - Proper training of the construction workers for better understanding of the plan and specifications.
  - Performance-based specifications should be used to facilitate innovative technology
  - Value engineering policies needs to be reevaluated so that contractors can come up with and implement innovative approaches and materials

Sustainable Bridge Design Process



Service life simulation

Major Issues Related to Sustainability and Life Cycle of Concrete Bridges

- Bridge Deterioration Issues
- Bridge Monitoring and Condition Assessment Technologies
- Improved Decision Making

Bridge Deterioration Issues

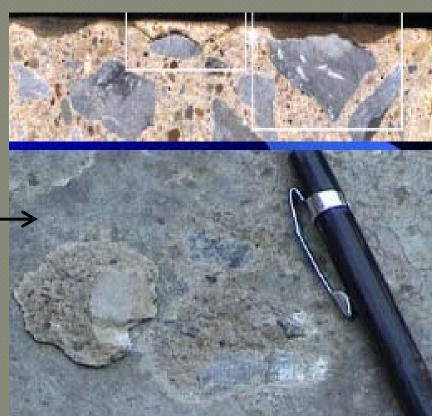
- Deteriorations may include
  - Scaling
  - Spalling
  - Popouts
  - Mortar Flaking
  - Delamination
  - Shrinkage Cracking
  - Abrasion damage
  - Alkali-Aggregate Reactivity
  - Corrosion of Reinforcement

Bridge Deterioration Issues

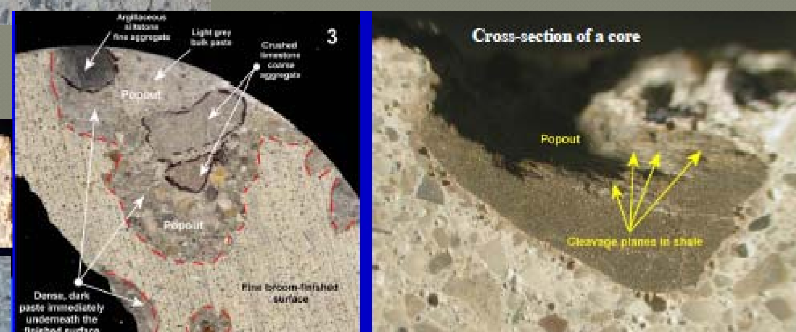
- Common causes of these deteriorations
  - Inadequate concrete production
  - Inadequate finishing techniques
  - Inadequate construction practices
  - Not conforming to applicable codes
  - Poor air entrainment
  - Softening of surfaces
  - Poor quality aggregates (high water absorptive and low strength)

Bridge Deterioration Issues

Scaling



Mortar Flaking

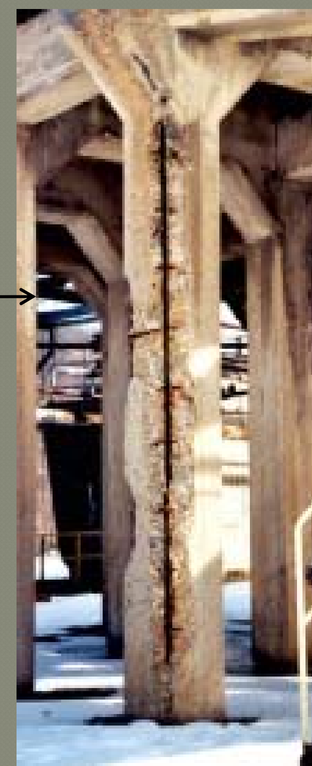


Popout

Bridge Deterioration Issues

Delamination

Corrosion of Reinforcement

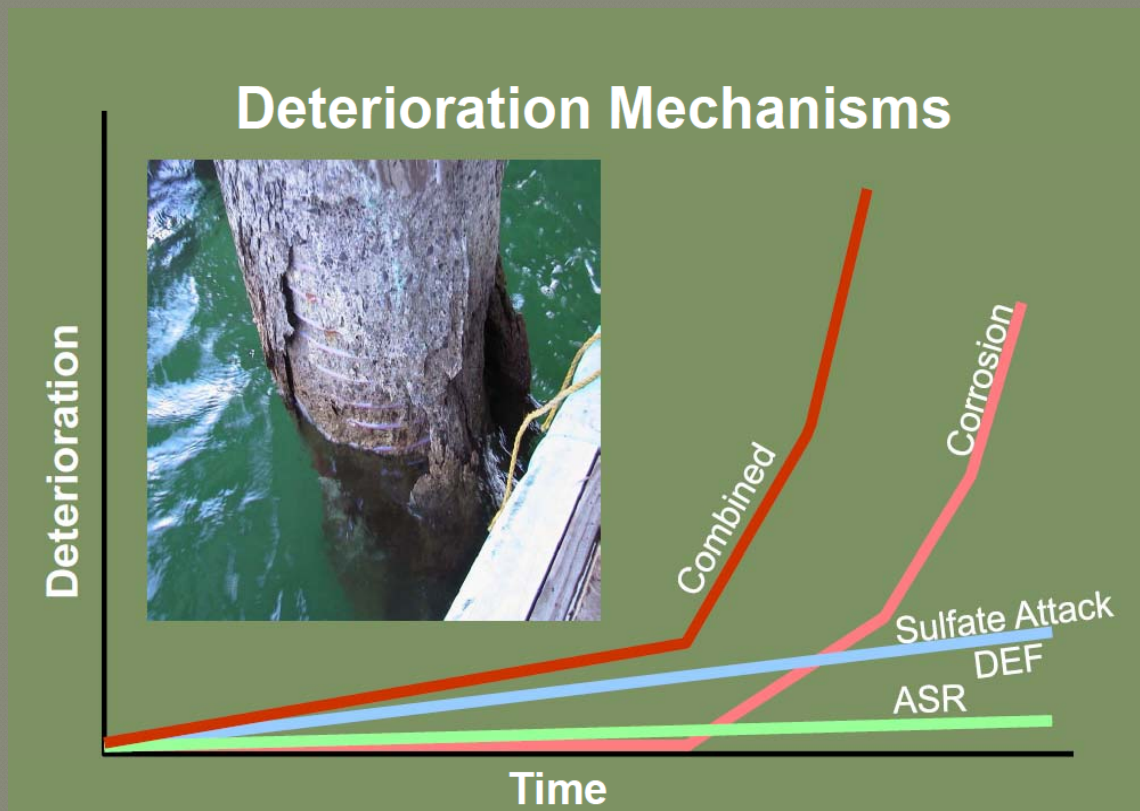


Shrinkage Cracking

Bridge Deterioration Issues

Admiral Clarey Bridge, Pearl Harbor, HI

Bridge Deterioration Issues



Bridge Monitoring and Condition Assessment

- Critical deficiencies that adversely affect the condition assessment
  - Load information
  - Overload linked to deterioration
  - Not taking bridge maintenance issues seriously/improper inspection
  - Qualifications of inspectors

Bridge Monitoring and Condition Assessment

- Bridge health monitoring objectives
  - To validate design assumptions and parameters
  - To provide early warning for failure
  - To detect anomalies in loading and response
  - To provide real time information for safety assessment
  - To provide evidence for prioritizing bridge inspection, rehabilitation, maintenance and repair
  - To monitor repair and reconstruction
  - To obtain in situ data for research

Bridge Monitoring and Condition Assessment

- Monitoring could be for short or long-term
- Can also be triggered by specific events
- Covers sensing, signal processing, data management, system identification, information technology
- Requires collaboration between civil, mechanical, electrical and computer engineering, among others

Bridge Monitoring and Condition Assessment

- Commonly used sensors for bridge health monitoring:
  - Fiber optic
  - Wireless sensors
  - Strain gages
  - Acoustic emission
  - Accelerometers
  - Moisture indicators
  - Chloride indicators
  - Ground penetrating radar (GPR)
  - GPS/video monitoring

Bridge Monitoring and Condition Assessment

- Future needs on bridge monitoring
  - Monitoring system that minimize post-processing and use established triggers for data collection
  - Inspector training on sensors
  - Sensors capable of assessing unknown foundation details
  - Wireless sensor communication reliability needs to be improved
  - New construction to be instrumented rather than monitoring system being added at a later date

Bridge Monitoring and Condition Assessment

- The envisioned future for bridge health monitoring:
  - *"An array of inexpensive, spatially distributed, wirelessly powered, wirelessly networked, embedded sensing devices supporting frequent and on demand acquisition of real time information about the loading and environmental effects, structural characteristics and responses"*

    -J.M. Ko et.al.

Bridge Monitoring and Condition Assessment

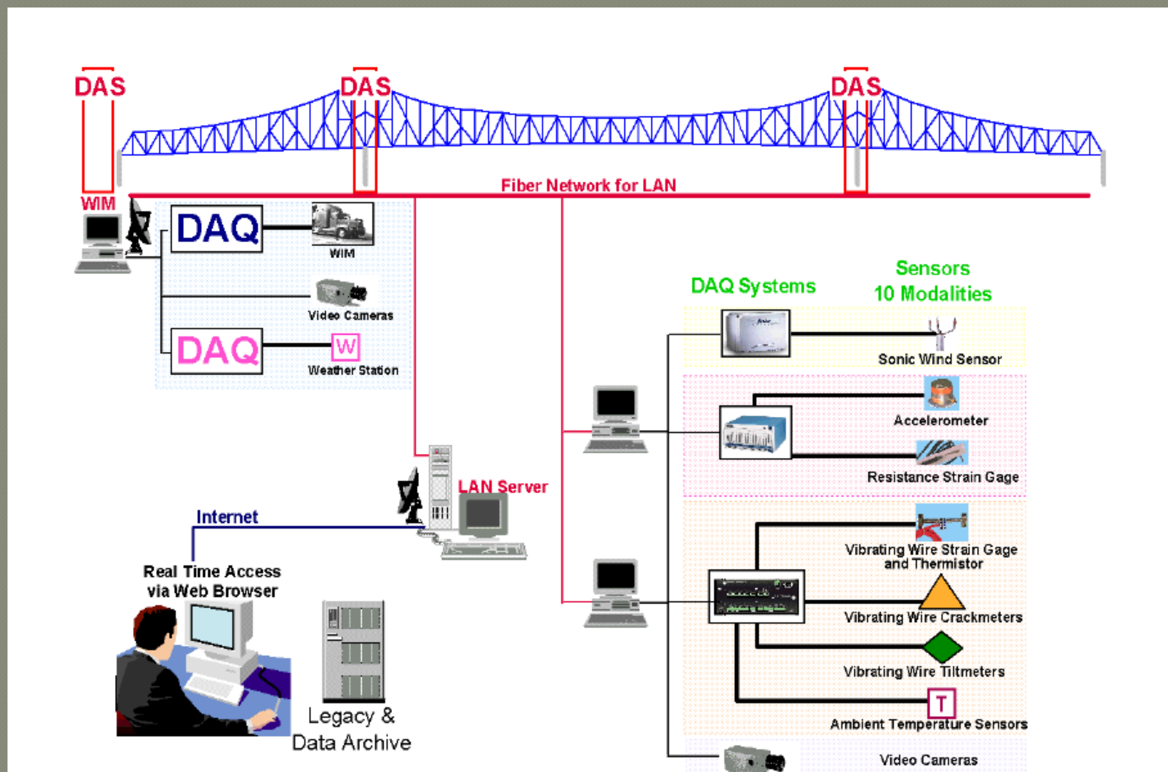
Bridge Monitoring and Condition Assessment

Holes drilled into the bridge

Inserting the tubes containing fiber optics

- A. Kerrouche et. al.

Bridge Monitoring and Condition Assessment



A schematic diagram of real time monitoring & data acquisition system

Bridge Monitoring and Condition Assessment

- Current bridges where successful implementation of health monitoring systems have been reported:
  - Great Belt Bridge in Denmark
  - The Confederation Bridge in Canada
  - The Tsing Ma Bridge in Hongkong
  - The Commodore Bridge in Japan
  - The Seohae Bridge in Korea

Improved Decision Making

- Innovative solutions are required that would respond to the economic and social well being
- Design concepts that can assist designers in creating the most sustainable bridge solutions are required
- Can be achieved through improved decision making

Improved Decision Making

- For improved decision making it is necessary to have:
  - Better record keeping so that bridge deterioration issues can be better understood
  - Coordination and communication between designers and contractors
  - Coordination and communication between maintenance personnel and designers
  - Coordination and communication between organizations (ASCE, ACI, PCI, AASHTO, FHWA)
  - A national database
  - A documentation of the maintenance, rehabilitation, and repair measures that are working and not working
  - Incorporation of knowledge from throughout the world

Conclusions

- Engineering design practices will have a significant impact on sustainable future of concrete bridges
- A paradigm shift is necessary to reach the goals of extended service life and a sustainable bridge structure
- Sustainability should involve owners, regulators, the public, academia, designers and builders

Conclusions

- *"A truly sustainable concrete bridge will meet context-sensitive concerns for the society it serves, optimize materials used, reduce environmental impacts through innovative technologies and efficient systems, improve durability to withstand the environment of the future and have lower life-cycle costs than other structural system"* - Dr Tess Ahlborn