NRC-CNRC

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Environmental Benefits of Life Cycle Design of Concrete Bridges

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Outline

- Introduction
- Life cycle design of concrete bridges
- Environmental and economic benefits of HPC bridges
- Case study
- Conclusions

Introduction

- Highway bridges: critical links in Canada's transportation network
  - Enable personal mobility
  - Transport of goods
  - Support economy
  - Ensure high quality of life

- Design life = 50 -100 years requiring:
  - Inspections, maintenance
  - Rehabilitation
  - Replacement of components (deck, walls, bearings)
  - Replacement of superstructure
  - Replacement of substructure

Introduction

- State of highway bridges
  - Extensive deterioration
  - Reduced safety, serviceability, and functionality
  - Increased traffic disruption and user costs
  - Increased risk of fatalities/injuries
  - Increased maintenance
- Causes
  - Aging bridge network: average service life = 45 years
  - Increased traffic volume and load
  - Aggressive environment (snow, freeze-thaw, deicing salts)
  - Variations of environmental loads due to climate change
  - Inadequate funding for maintenance and renewal of bridges

Introduction

- Objectives : design long life bridges using high performance concrete
  - low maintenance costs
  - minimized traffic disruption
  - minimized environmental impacts
  - optimized maintenance strategies
  - sustainable bridges

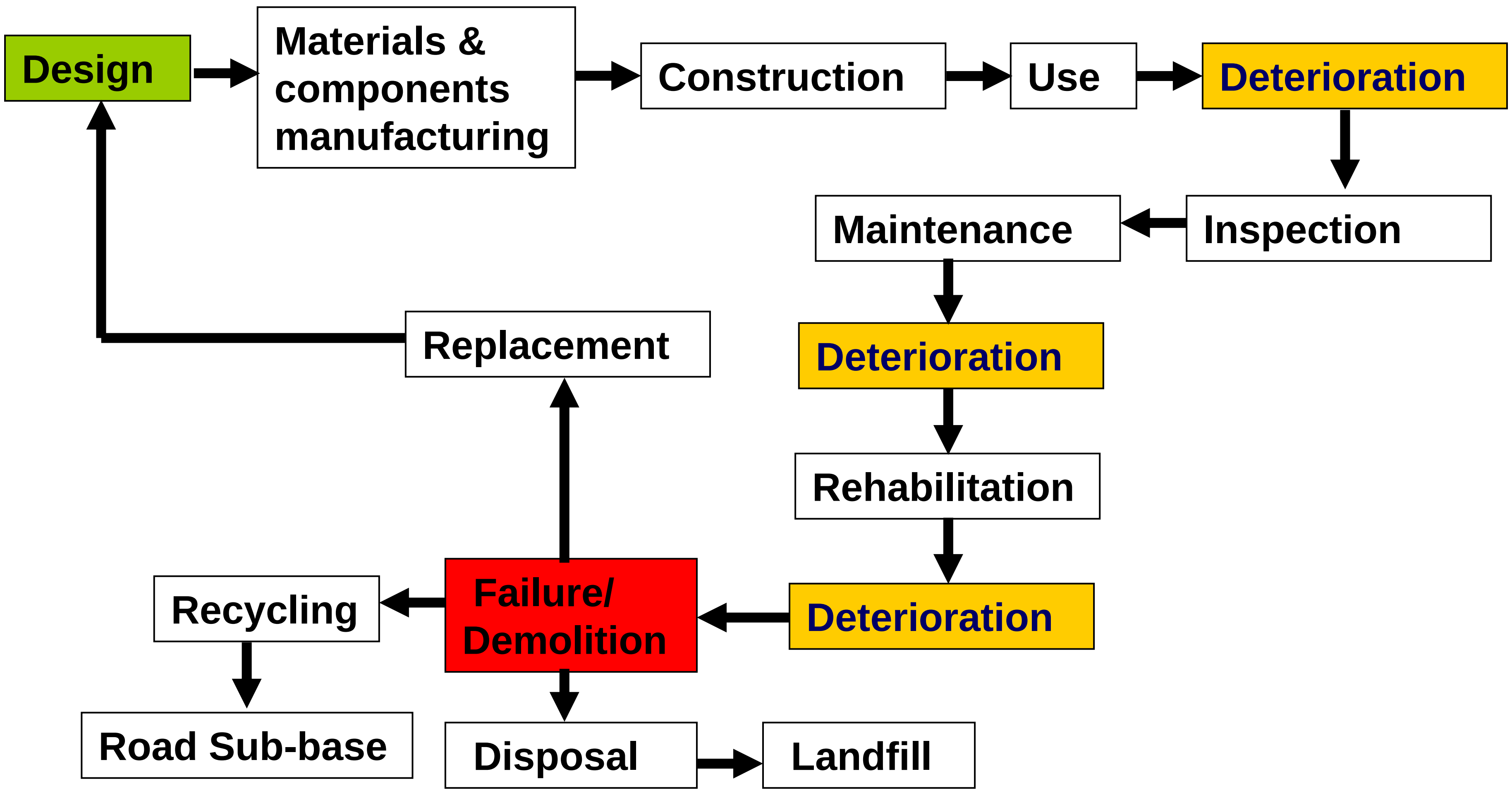
Introduction

Examples of Sustainable Bridges

- Bridge Ponte Fabricio (or Ponte Quattro Capi)
  - oldest bridge in Rome (built in 62 BC)
  - 2 arches + central pillar
  - 62 m span; 5.5 m width
  - Built of Tufa, volcanic tuff and travertine

- Inca Rope Suspension Bridge in Peru (14^{th}-15^{th} century)
  - 67 m span; 37 m above the river
  - Built of woven grass for cables reinforced with branches
  - Cables are replaced every year by local villagers

Life Cycle of Highway Bridges

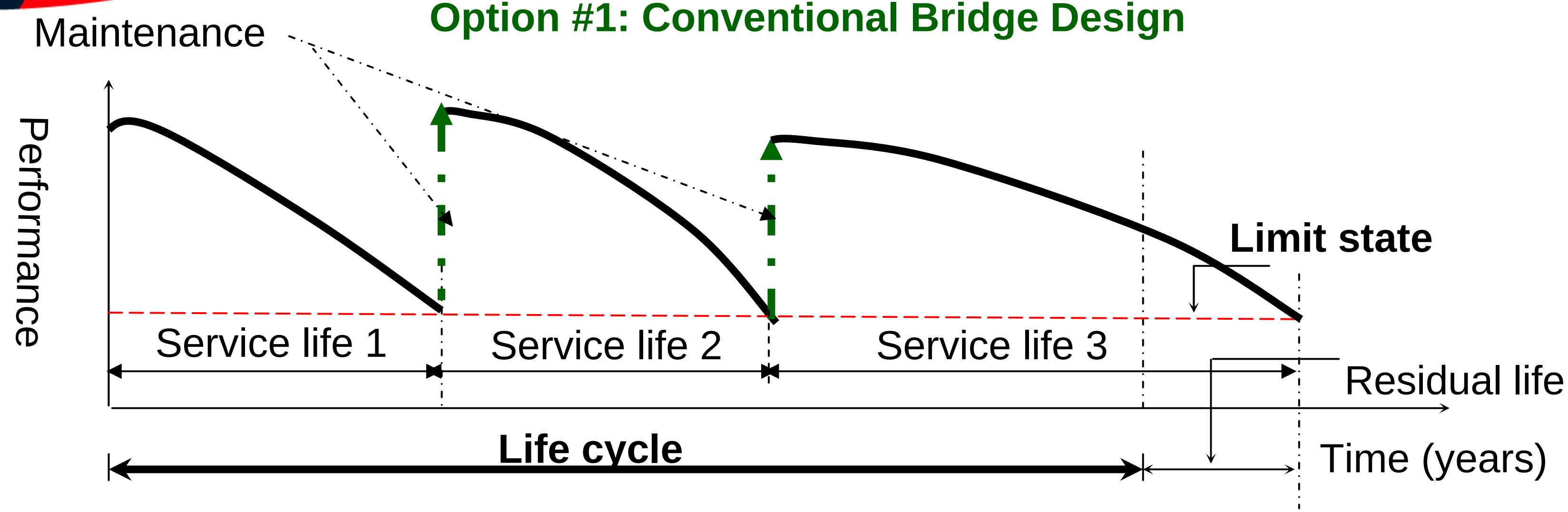


Life Cycle Design of Concrete Bridges

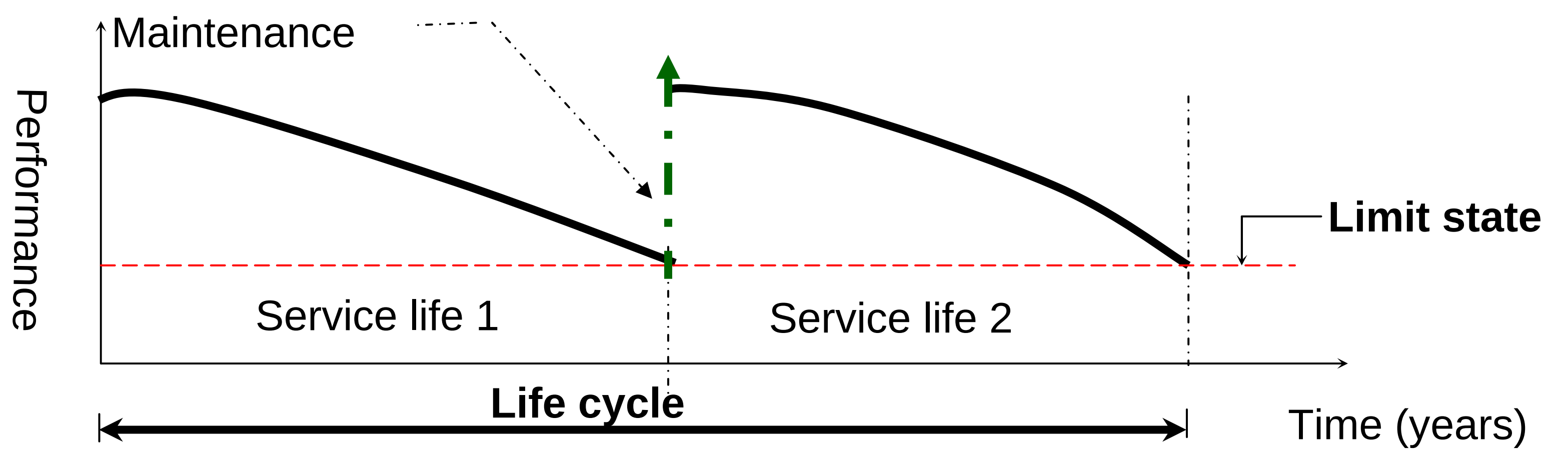
- Life cycle design of bridges = complex decision problem
  - Optimized designs for initial bridge and subsequent maintenance, rehabilitations, and replacement stages
  - Need life cycle performance models to predict bridge deterioration and service life
  - Need models to predict environmental impact
  - Multi-objective optimization problem
    - Minimize cost
    - Maximize service life
    - Minimize environmental impact (GHG emissions, waste)

Life Cycle Design of Concrete Bridges

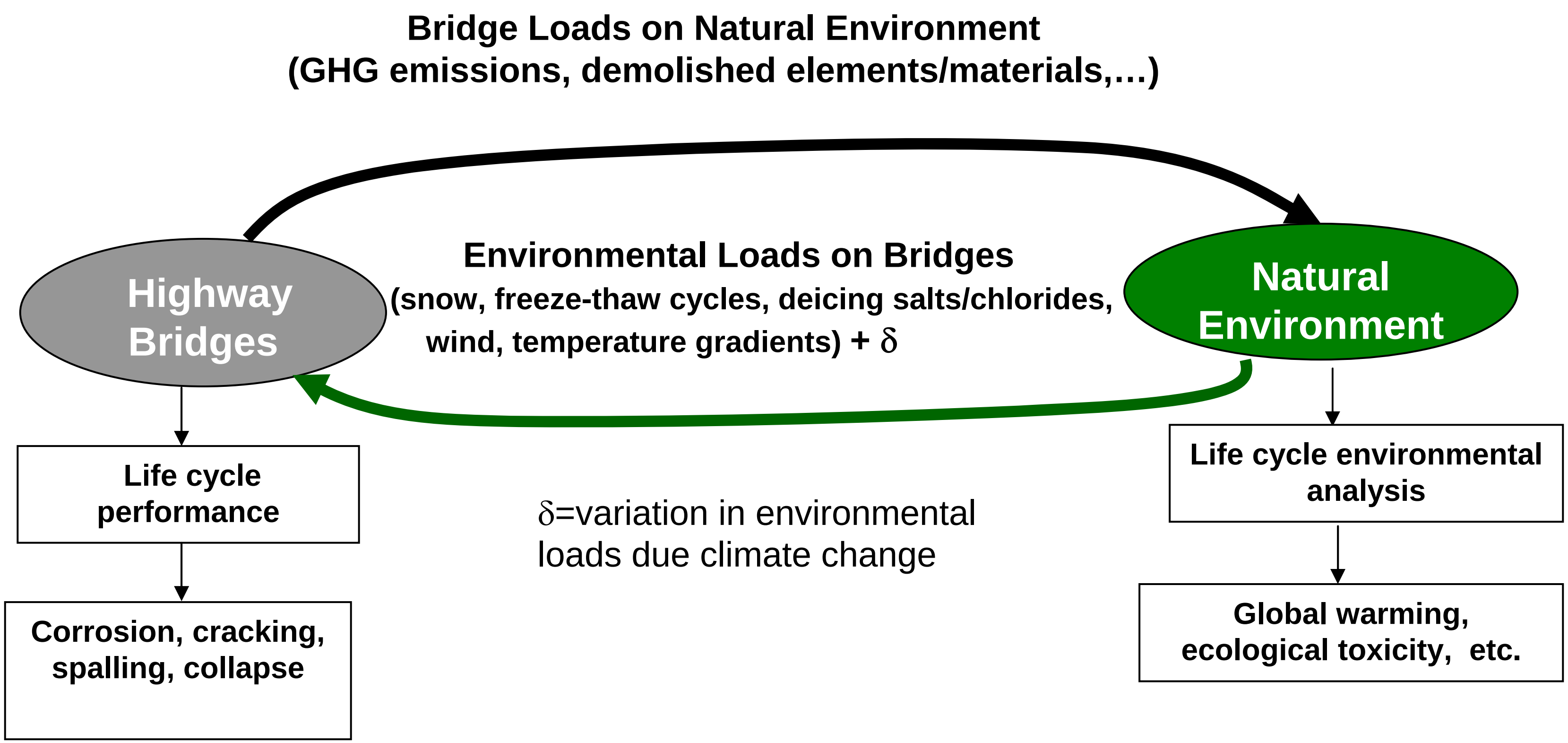
Option #1: Conventional Bridge Design



Option #2: High Performance Concrete (HPC) Bridge Design



Life Cycle Design of Concrete Bridges



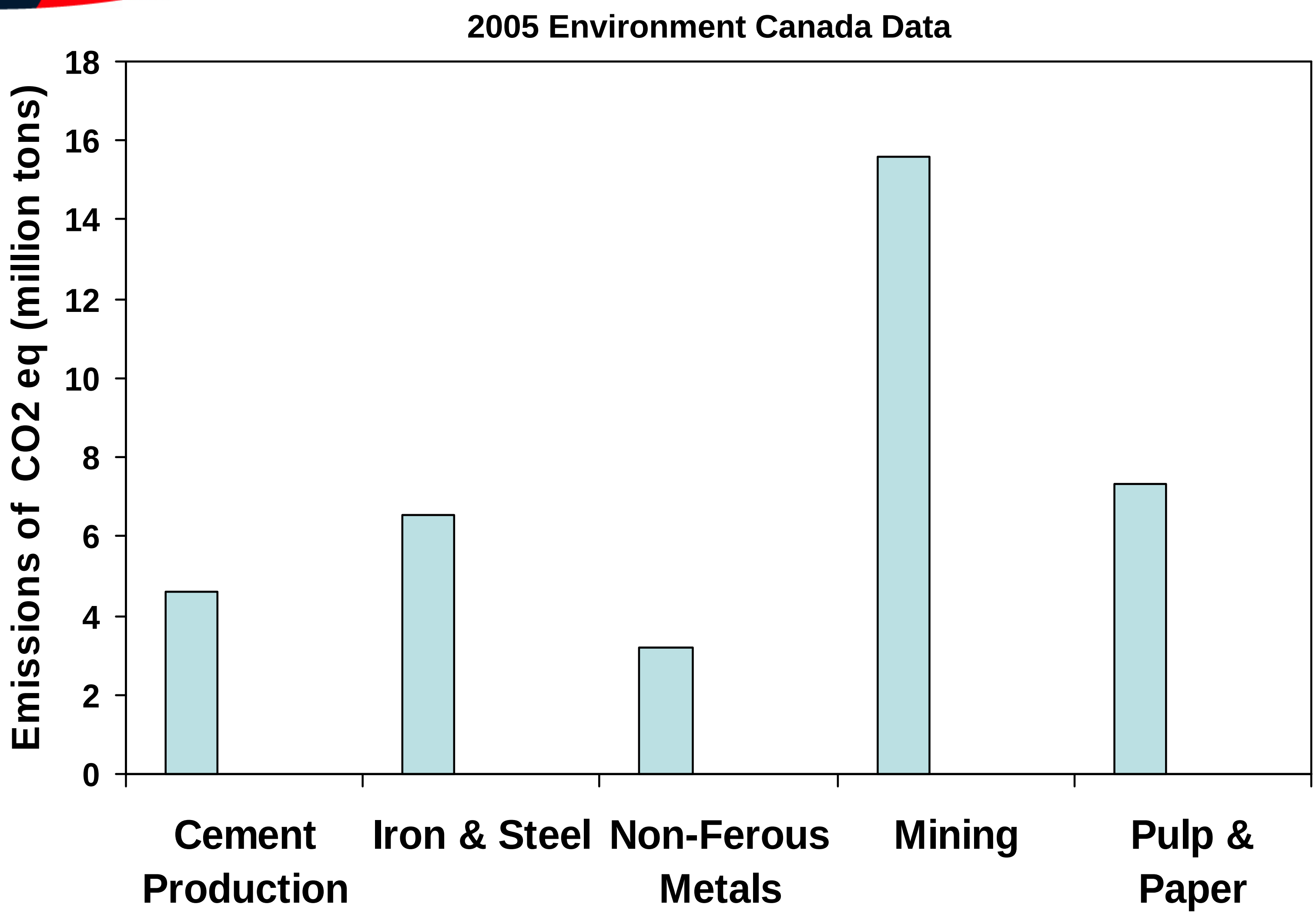
Complex Interaction between highway bridges and natural environment

Environmental & Economic Benefits of HPC Bridges

- Cement
  - Cement =critical component of concrete
  - World cement production= 2 billion tons in 2004; 7.5 billion tons in 2050
  - Production of 1 ton cement leads to 0.8 -1.0 ton of CO_2 emissions
  - World cement production accounts for 5% of world CO_2 emissions
  - World cement production consumes 2% of world energy

- Reinforced Concrete vs. Cement
  - Cement constitutes only 5% to 18% of concrete (by weight)
  - Aggregate (course and fine) make up 65%-70% of concrete
  - Concrete is made of readily available local materials (aggregate & water)
  - Enables to recycle industrial waste (fly ash, slag)
  - Low energy requirements for aggregate and water
  - Reinforcing steel is made from recycled steel

Environmental & Economic Benefits of HPC Bridges



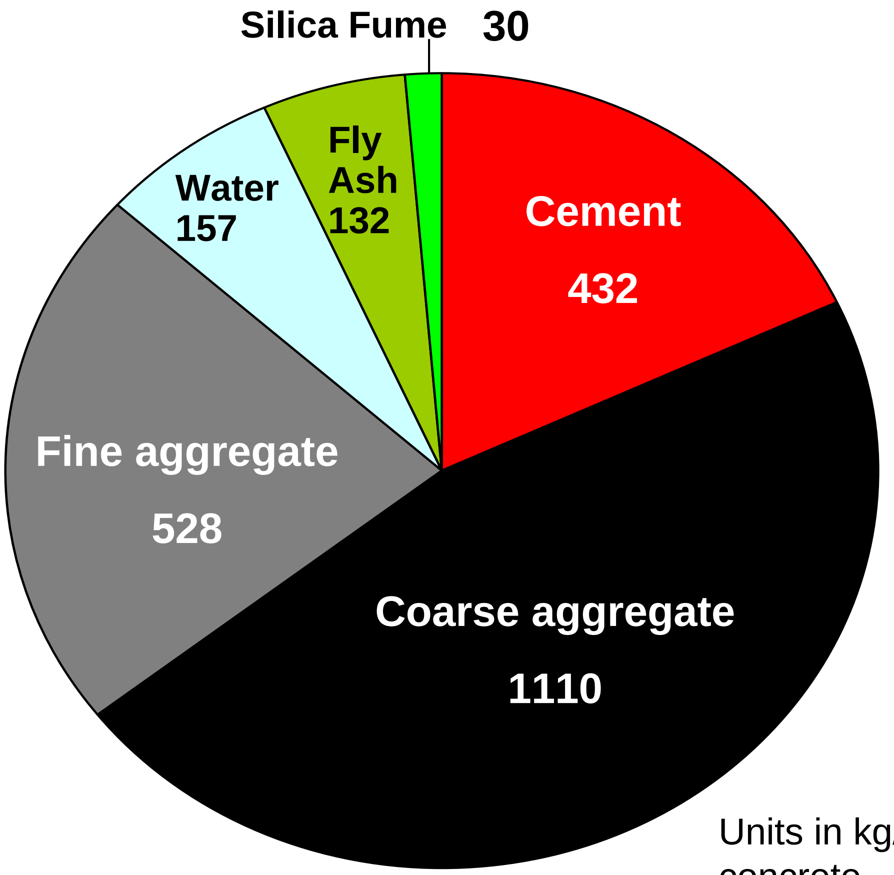
Environmental & Economic Benefits of HPC Bridges

Mix design of high performance prestressed concrete bridge girders:

w/cm=0.27

f'c=69 MPa

Chloride permeability=1010 coulombs



Units in kg/m^3 of concrete

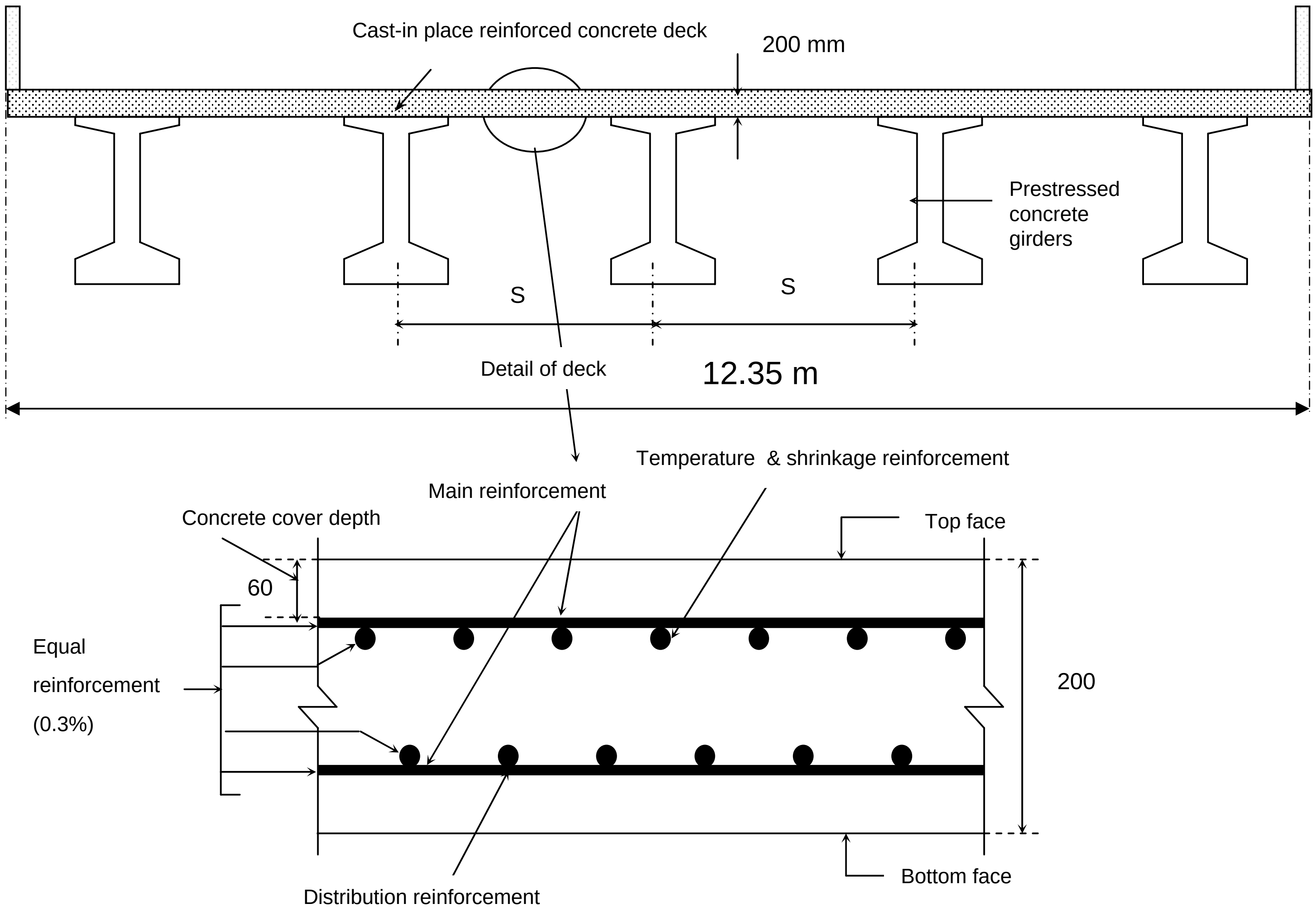
Environmental & Economic Benefits of HPC Bridges

- Incorporate industrial waste having cementitious properties in concrete
  - Fly ash: by-product of thermal power generating stations
  - Slag: by-product of processing iron ore to iron & steel in blast furnace
  - Silica fume: by-product of silicon and ferro-silicon metal production

- Benefits
  - Increased strength and reduced permeability
  - Reduced consumption of cement
  - Reduced GHG emissions
  - Reduced volume of land-filled materials
  - Reduced life cycle cost

Case Study: Life Cycle Design of Bridge Decks

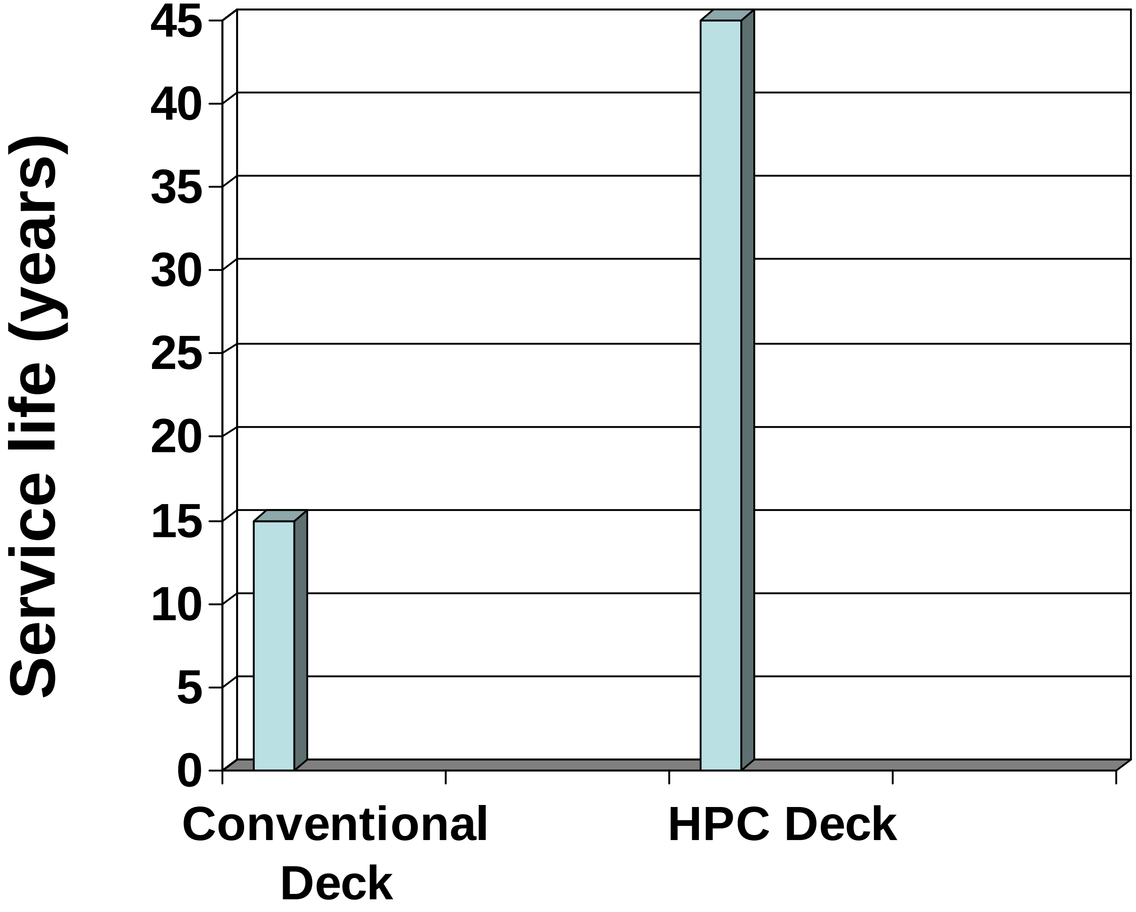
Bridge length = 35 m



Case Study: Life Cycle Design of Bridge Decks

- Two bridge deck design options
  - Conventional deck using normal concrete
  - High performance concrete deck using fly ash, slag, silica fume
  - Life cycle =30 years; Discount rate = 3%
- Service life
  - Time to onset of corrosion
- Environmental impacts
  - CO_2 emissions
  - Construction waste materials
- Costs
  - Owner costs (construction + maintenance)
  - User costs (delay, accident, vehicle operation)

Case Study: Life Cycle Design of Bridge Decks



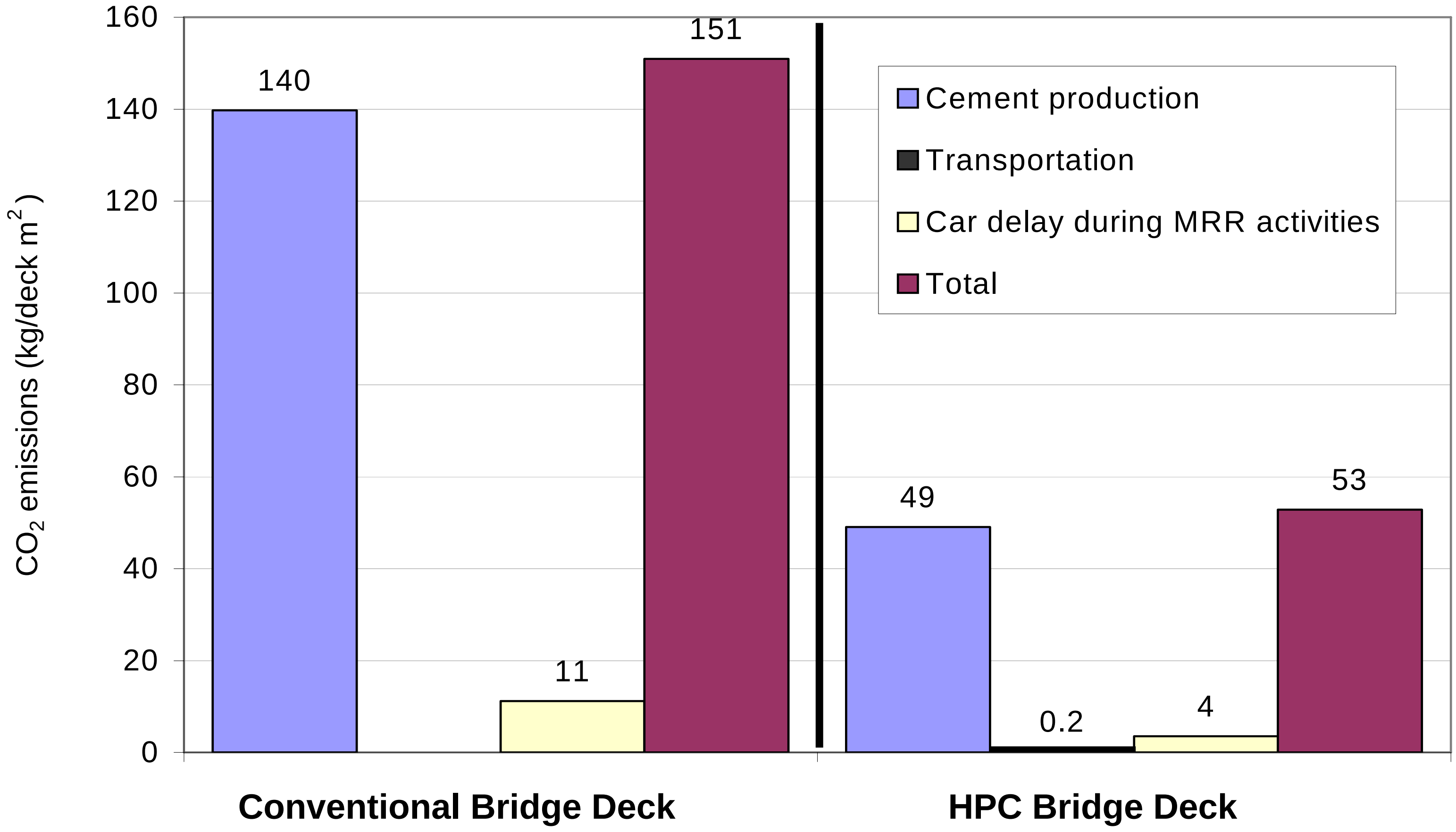
Case Study: Life Cycle Design of Bridge Decks

Life cycle = 30 years

- Conventional bridge deck
  - –Service life = 15 years
  - –Requires
    - 4 detailed inspections;2 replacements of asphalt overlay + routine inspection every 2 years
    - 4 patch repairs and 1 replacement at 15 years
- High performance bridge deck
  - –Service life = 30 years
  - –Requires
    - 2 patch repairs + routine inspection every 2 years

Case Study: Life Cycle Design of Bridge Decks

CO_2 emissions over life cycles of bridge decks



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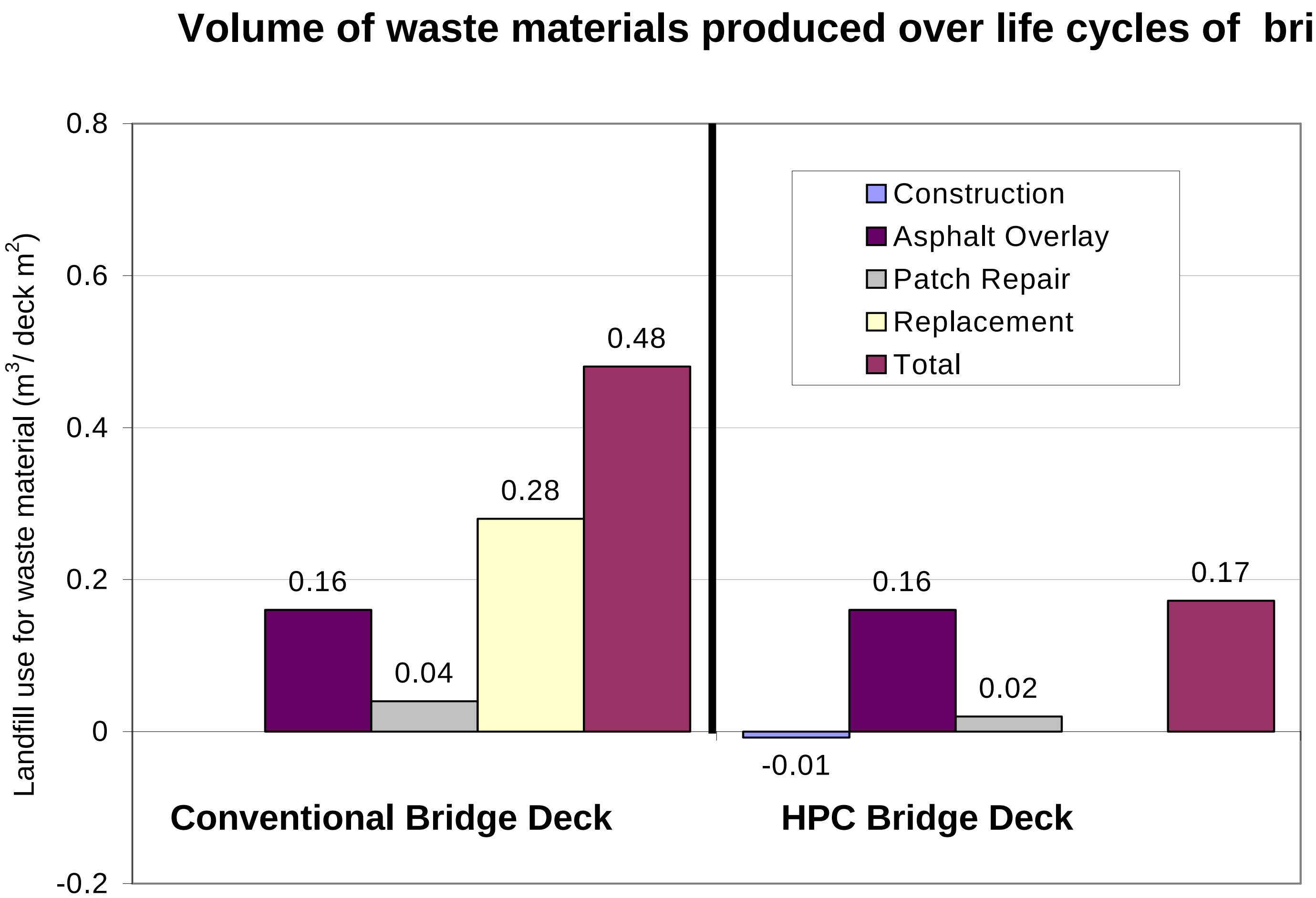

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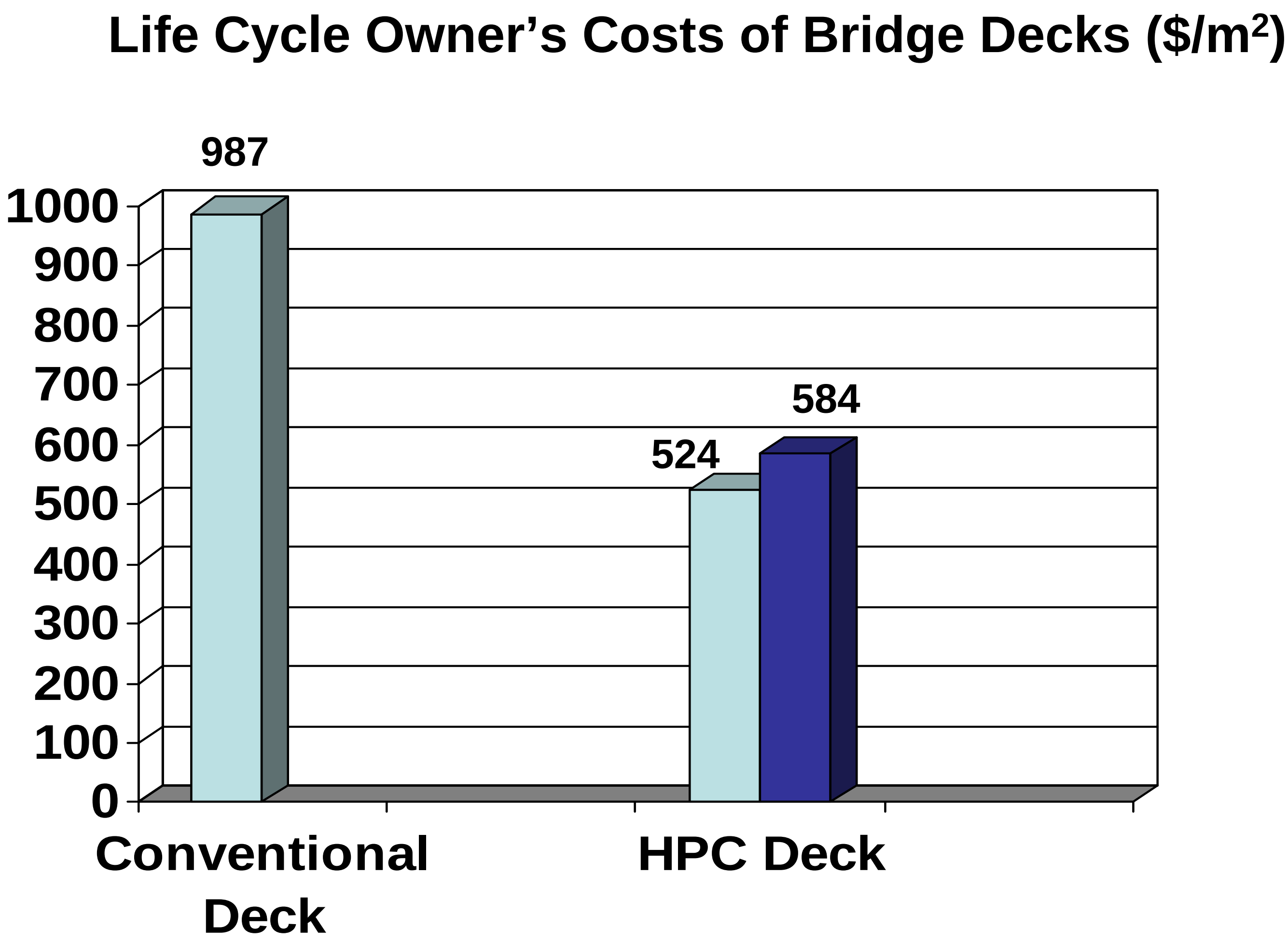

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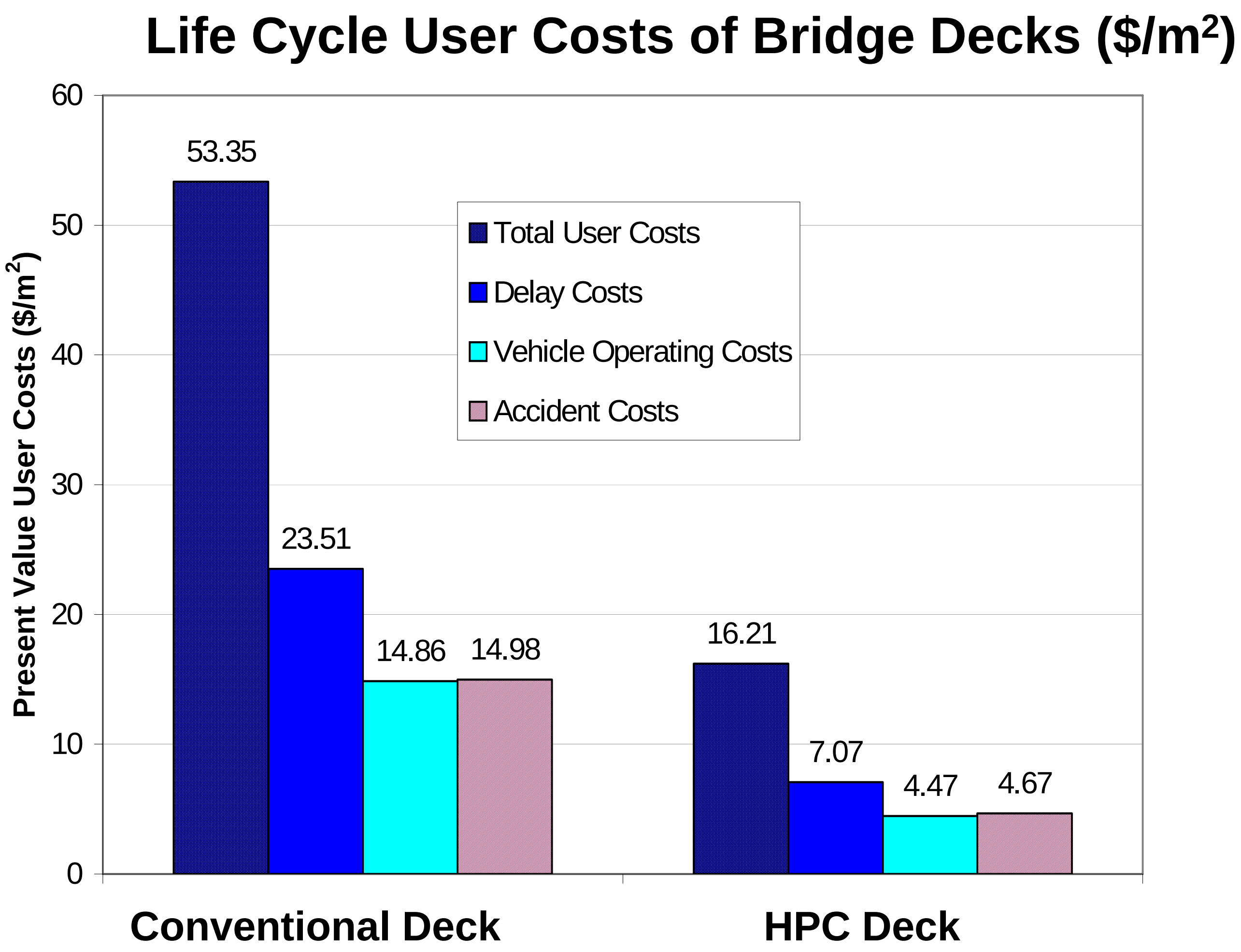

Case Study: Life Cycle Design of Bridge Decks

Summary

- Service life
  - Conventional bridge deck = 15 years
  - HPC bridge deck = 30 years
- Life cycle CO_2 emissions
  - Conventional bridge deck = 151 kg/m^2
  - HPC bridge deck = 53 kg/m^2
- Life cycle production of waste materials
  - Conventional bridge deck = 0.48 m^3/m^2
  - HPC bridge deck = 0.17 m^3/m^2
- Life cycle costs
  - Conventional bridge deck = \$1040/m^2
  - HPC bridge deck = \$560 /m^2

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Conclusions

- Life cycle design of highway bridges using HPC yields:
  - long service life bridges
  - low maintenance costs
  - Reduced energy and materials consumption
  - Reduced CO2 emissions
  - Reduced volume of land-filled materials
  - Recycling of industrial byproducts
  - Reduced life cycle costs for owners and users of bridges