CAEE Departmental Seminar
8 March 2006
EDUCATION and RESEARCH NEEDS for ENGINEERING and MANAGEMENT of INFRASTRUCTURES

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Director of Intelligent Infrastructure Institute
www.Di3.Drexel.edu
Before the World Wide Web, there was the Library of Alexandria, which collected all that had been written <www.Di3.Drexel.edu>
"...The first microprocessor only had 22 hundred transistors. We are looking at something a million times more complex in the next generations—a billion transistors. What that gives us in the way of flexibility to design products is phenomenal."

—Gordon E. Moore

In 1965, Intel co-founder Gordon Moore saw the future. His prediction, popularly known as Moore's Law, states that the number of transistors on a chip doubles about every two years. This observation about silicon integration, has fueled the worldwide technology revolution and decreased costs of toys to traffic lights.

More Performance for Less Cost

Many are familiar with Intel's exponential increases in the number of transistors into our processors and other leading platform ingredients. These increases, as graph illustrates, have steadily and reliably lead to more computing performance measured in millions of instructions per second (MIPS).

Video: Conversation with Gordon Moore

You can also download the Moore's Law poster. [PDF]

Moore's Law

- Intel Silico
- Designing
- Platform 2
- Architect
- Intel Muse
- Moore's Law
Example of Information Explosion in Healthcare

The Healthcare Big Bang

More Data Over the Next 3 Years Than Previous 40,000 years Combined

Electronic Medical Record Digital Radiology/Cardiology

Personal Proteonomic Treatment
E-Health Initiatives/Linkages

Pharmacogenomics
Metabolic Pathways

Human Genome
Proteins
MIPs

SNPs

Combinatorial Chemistry
HTS
ESTs

Data Management Requirements [Petabytes]

1990 2000 2010

Source: UC Berkeley, School of Information Management and Systems
Bioengineering, Biotechnology & Biomedical Technology

- Advances in biotech have already significantly improved the quality of our lives
- More dramatic breakthroughs ahead
- Tissue engineering
- Regenerative medicine
- Drug delivery engineering
- Bio-inspired computing
- Protection from biological terrorism

Decoding of Human DNA >$2B
Micro/Nanotechnology

- **Draws on Multiple Fields**
  - Genetic and molecular engineering
  - Composites and engineered materials
  - Quantum scale optical and electrical structures

- **Potential Applications**
  - Environmental cleaning agents
  - Chemical detection agents
  - Creation of biological (or artificial) organs
  - Ultra-fast, ultra-dense, circuits

A factory large enough to make over 10 million nanocomputers per day might fit on the edge one of today’s integrated circuits. - Drexler and Peterson
Materials Science & Photonics

- Smart materials and structures, which have the capability of sensing, remembering & responding (e.g., to displacements caused by earthquakes and explosions; smart textiles provide cooling and heating).

- “As the physical sizes of optical sources decrease, while their power and reliability continue to increase, photonics based technologies will become more significant in engineered products and systems.”

Applications: fiber optics, precision cutting, visioning and sensing; photochromic windows.
Meanwhile: Some Remaining Challenges

- Infrastructures in Urban Settings
- Safety and Security of Information and Communications Infrastructures
- Technology for an Aging Population
- The Environment
- Social Concerns
The Environment

- Three quarters of the US population resides in areas with unhealthy air. [American Lung Association]
- In 2020, California will need 40% more electrical capacity, 40% more gasoline, and 20% more natural gas than in 2000.
- 50% of the world’s original forest cover has been depleted [Worldwatch Institute] and global per capita forest area is projected to fall to 1/3 its 1990 value by 2020. [Haque, 2000].
- 48 countries (2.8 billion people) face freshwater shortages in 2025 [Henrichsen, 1997]
- The wealthiest 16% of the world consumes 80% of the world’s natural resources. By the year 2020, there will be 8 billion people who will be further depleting the environment
A mix of 100 people in 2020 would look like the following:

- 56 would be from Asia, including 19 Chinese and 17 Indians
- 13 would be from the western hemisphere, including 4 from the United States
- 16 would be from Africa, including 13 from Sub-Saharan Africa
- 3 would be from the Middle East
- 7 would be from Eastern Europe and the former Soviet Union
- 5 would be from Western Europe

In contrast to the aging of the US, Europe and Japan, the most politically instable parts of the world will experience a “youth bulge”.
Critical Infrastructures - President's Commission on Critical Infrastructure Protection (1997)

- Telecommunications
- Electrical Power Systems
- Gas and Oil Production, Storage and Transportation
- Transportation
- Water Supply Systems
- Banking and Finance
- Emergency Services
- Continuity of Government Services

HUMAN - NATURAL - ENGINEERED SYSTEMS OF SYSTEMS
The sewers, the water, the gas connections, the electrical connections all went down together with one hole in the middle of Fifth Avenue, in Manhattan, NY.

Performance of Human-Nature-and-Engineered Systems
## PERFORMANCE OF INFRASTRUCTURE SYSTEMS

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Engineered Elements</th>
<th>Socio-Technical Elements</th>
<th>Nature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational &amp; Utility Limit States</td>
<td>• Safety</td>
<td>• Organizational Efficiency</td>
<td>• Sustainability</td>
</tr>
<tr>
<td></td>
<td>• Efficiency/Economy</td>
<td>• Multi-Hazards Risk Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Security</td>
<td>• Fiscal Responsibility</td>
<td></td>
</tr>
<tr>
<td>Engineering Limit States</td>
<td>• Serviceability &amp; Durability</td>
<td>• Inspectability</td>
<td>• Resilient</td>
</tr>
<tr>
<td></td>
<td>• Safety and Stability of Failure</td>
<td>• Maintainability</td>
<td>• Recyclable</td>
</tr>
<tr>
<td></td>
<td>• Substantial Safety at Conditional Events w/ very long return</td>
<td>• Adaptable/Re-usable</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Easily Renewable</td>
<td></td>
</tr>
<tr>
<td>Societal Objectives</td>
<td>• Achieving a Sustainable Economy</td>
<td>• Ensuring a Strong, Healthy and Just Society</td>
<td>• Living Within Environmental Limits</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Promoting Good Governance</td>
<td>• Using Sound Science Responsibly</td>
</tr>
</tbody>
</table>

- Safety
- Efficiency/Economy
- Security
- Organizational Efficiency
- Multi-Hazards Risk Management
- Fiscal Responsibility
- Inspectability
- Maintainability
- Adaptable/Re-usable
- Easily Renewable
- Resilient
- Recyclable
- Living Within Environmental Limits
- Using Sound Science Responsibly
CEE Education in North America (ASEE, 2004)

- ~240 CE Bachelors Programs in North America
- ~140 CE PhD Programs in North America
- ~40 Construction Technology Programs in North America
- 8142 Bachelors graduated (23.1% Woman)
- 3745 Masters graduated (25.2% Woman)
- 644 Doctoral degrees awarded (19.4% Woman)
- 43,590 CE Bachelors program registered

DEGREES AWARDED (2004)
1. Purdue University 176
2. Texas A&M University 157
3. Pennsylvania State University 154
4. Polytechnic Univ. of Puerto Rico 131
5. Univ. of Illinois, Urbana-Champ 128
6. North Carolina State University 124
7. Georgia Institute of Technology 121
8. California Polytechnic State Univ. 111
9. University of Florida 110
10. Virginia Tech 109
11. Univ. of Puerto Rico, Mayaguez 104
12. North Dakota State University 103
13. Michigan Technological University 101
14. Auburn University 94
14. Univ. of Minnesota, Twin Cities 94
16. Michigan State University 92
17. Clemson University 90
18. Ohio State University 87
19. University of California, Davis 83
20. Colorado State University 82
20. University of Kentucky 82
22. University of Washington 77
23. Iowa State University 72
ABET and ASCE Outcomes for civil engineering education

Apply knowledge of mathematics, science and engineering.
Design and conduct experiments, as well as analyze and interpret data.
Design a system, component or process to meet desired needs.
Function on multi-disciplinary teams.
Identify, formulate and solve engineering problems.
Understand professional and ethical responsibility.
Communicate effectively.
Understand the impact of engg solutions in a global/societal context.
Recognize the need for, and an ability to engage in, life-long learning.
Knowledge of contemporary issues.
Understand the techniques, skills, and modern engineering tools
Apply knowledge in a specialized area related to civil engineering.
Understand project management, construction, and asset management.
Understand business and public policy and administration fundamentals.
Understand the role of the leader and leadership principles and attitudes.
Why is civil engineering so different?

- Civil engineers design, construct and manage (operate, preserve, protect) constructed systems that are the backbones of many infrastructure system-of-systems.
- Disconnected design-construction-operation-maintenance.
- Lack of a systems approach, observation and measurement. We have NOT yet learned how to effectively observe and measure such large, complex system-of-systems.
- Lack of objective valuation and descriptions for condition, performance and health.
- Complex interactions/interdependency between natural, human and engineered elements of infrastructures defy modeling. Vulnerability due to hidden intersections between elements and systems are discovered mainly as a result of costly breakdowns.
- Barriers abound hindering effective technology research and integration through multidisciplinary “systems” research on actual infrastructures.
- Significant epistemic uncertainty prevails most critical decisions.
Sub-Systems Affecting Infrastructure Life-Cycle Performance

Constructed Systems at Intersection Shaping Infrastructure Life-Cycle Performance

Detached Design - Construction - Operation - Maintenance Systems

Integrated Design - Construction - Operation - Maintenance Systems
Auto and Construction: The Need for Metrics

Product-Oriented Approach

- 2001 Small Car
- Price: $12,000
- Performance Metrics!
- Warranty
  - Bumper-to-bumper: 5 years
  - Powertrain: 10 years

Process-Oriented Approach

- Hamilton Co. (OH) Bridge (1997)
  - Over 24 subcontractors for construction
  - Many Bureaus of ODOT and District 6
- Price: $1,000,000 - $2,000,000
- Performance Metrics: ??
- Warranty: None
### Lifecycle Limit States/Events - General

<table>
<thead>
<tr>
<th>Limit State</th>
<th>Utility and Functionality</th>
<th>Serviceability and Durability</th>
<th>Life Safety and Stability of Failure</th>
<th>Substantial Safety at Conditional Limit States</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit Events</td>
<td>Environmental impacts</td>
<td>Excessive: Displacements; Deformations; Drifts</td>
<td>Excessive: movements; settlements; geometry changes</td>
<td>Lack of multiple escape routes in buildings</td>
</tr>
<tr>
<td></td>
<td>Social impacts</td>
<td>Deterioration</td>
<td>Material Failure</td>
<td>Lack of post-failure resiliency leading to progressive collapse of buildings</td>
</tr>
<tr>
<td></td>
<td>Sustainability of functionality throughout life cycle</td>
<td>Local damage: Cracking, Spalling, Yielding</td>
<td>Fatigue</td>
<td>Cascading failures of Interconnected infrastructure systems</td>
</tr>
<tr>
<td></td>
<td>Financing Initial cost and life cycle costs</td>
<td>Excessive Vibrations</td>
<td>Localized or Member Level Stability failure</td>
<td>Failures of Infrastructure elements critical for emergency response medical, communication, water, energy, transportation, logistics, command and control</td>
</tr>
<tr>
<td></td>
<td>Operational capacity safety, efficiency, flexibility and security</td>
<td>Lack of Durability</td>
<td>Stability of Failure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feasibility of construction, protection and preservation</td>
<td>Special limit state that should govern aspects of global design, detailing, materials and construction</td>
<td>Incomplete or premature collapse mechanism(s) without adequate deformability and Hardening; Undesirable sudden brittle failure mode(s)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aesthetics</td>
<td></td>
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</tbody>
</table>
NEED FOR: Definitions and Data

**Health**: Condition of being sound in body, mind, soul; Commonly used indices: **CR, LR, SI, SF, (C/D), etc**

**Structural Reliability** $P(C > D)$ or $(1 - P_f)$

$2^{nd}$ Moment $RI$ “$\beta$”. Typically:

$0.000001 < (P_f) < 0.5$ or $4.75 > \beta > 0$

1. How to identify/incorporate Epistemic Uncertainty?
2. We need to extend reliability from safety to all of the critical limit states that govern lifecycle performance

**Management**: To direct and control, judicious use of means to accomplish an end. Asset Management?

**Performance**: Fulfillment of a promise
Typical Events Causing 500 Bridge Failures in the Last Decade


- Hydraulic Events
- Collision
- Overload
- Deterioration
- Fire
- Construction
- Ice
- Earthquake
- Fatigue
- Design Errors
- Soil
- Storm/Hurricane/Tsunami
- Other
Performance Indices for Bridges

- **Operational Safety, Security, Utility and Functionality:**
  - Safety - under adverse weather (ice, wind, roadway freezing)
  - Security Risks: Threats - Vulnerability – Consequences
  - Bridge versus Network operational capacities/demands
  - Geometric Restrictions: Lanes, Height/Width, Approaches
  - Criticality for the network, necessary for emergency response?
  - User costs and economic (GDP) impacts of bridge if closed

- **Safety:**
  - Load capacity rating (based on actual measured load distribution)
  - Vulnerability to Hazards (Manmade and Natural) and Risks
  - Redundancy and Toughness (especially for hazards)

- **Serviceability, Durability**
  - Condition rating and rate of decrease in condition rating
  - Deflections, Cracks, Debonding, Vibrations, Settlements
  - Drainage, Chlorides, Reactive aggregates, Rebar corrosion

- **Feasibility of Inspection and Maintenance**
Performance-Based Design and Evaluation under Uncertainty and Risk

Performance-Based Design Based on Uncertainty/Risk:

Establish the resistance envelope to meet the demands at each limit-event based on an acceptable risk of failure to perform at that event i.e.:

\[ P (\Phi \text{ Capacity} \leq \gamma \text{ Demand}) \]

Establish \( P \) for each limit-event and select Demand, actions, \( \Phi \) and \( \gamma \) based on an acceptable risk of failure to perform at that limit-event.
Search For Reality (Penrose, 2005)

- Mental World
- Physical World
- Platonic Mathematical World

Arrows indicate the relationship between the worlds:
1. From Platonic Mathematical World to Physical World
2. From Physical World to Mental World
3. From Mental World to Platonic Mathematical World
Reality by Structural Identification

1. Observation and conceptualization
2. A-priori modeling
3. Controlled experimentation
4. Processing and interpretation of data
5. Validate model, calibration, and parameter ID
6. Utilization of model for simulations, scenario analysis

Structural Identification
## Modeling Alternatives for Constructed Systems

### Physics-Based Models

**Mathematical Physics Models**
- $F=MA$
- $E=MC^2$

**Continua Models**
- Theory of Elasticity
- Field and Wave Eqns
- Idealized Diff. Eqns (Bernoulli, Vlasov, etc.)

**Discrete Geometric Models**
- Smeared-Macro or Element Level Models
- FEM-for Solids and Field Problems
- Modal Models:
  - Modal Parameters
  - Ritz Vectors

**Numerical Models**
- $K,M,C$ Coefficients

### Non-Physics-Based Models

**Semantic Models**
- Ontologies
- Semiotic Models

**Meta Models**
- Rule-based meta Models
- Mathematical (Ramberg-Osgood, etc.)

**Numerical Models**
- Probabilistic Models
  - Histograms to Frequency Distribution
  - Standard Prob. Distributions
  - Independent events
  - Event-based (Bayesian)
  - Time-Based (Markov)
  - Symptom-based
- **Agents**: Meta + Monte Carlo
- **Statistical (Data-Based)**
  - ARMA, ANN, others
  - Signal/Pattern Analysis, Wavelet, etc
EXPERIMENTAL TECHNOLOGY for FIELD RESEARCH

GEOMETRY MONITORING

CONTROLLED TESTING

NDE
MATERIALS and LOCAL CHARACTERIZATION

CONTINUOUS MONITORING

SURVEYING, MONUMENTING
GPS
CLOSE RANGE PHOTOGRAMMETRY
EXTENSOMETER / INCLINOMETER MEASUREMENTS
ANOMALOUS CHANGES IN GEOMETRY

PSEUDO/STATIC:

STATIC TRUCK TESTS:
BEHAVIOR & OPERATING/PROOF LEVEL RESPONSES
CRAWL TEST
UNIT INFLUENCE COEFFICIENTS
SERVO-CONTROL ACTUATORS
W/ROCK-ANCHORS
CAPACITY/FAILURE MODE
CONTROLLED DAMAGE-TEST DAMAGE INDICATORS

DYNAMIC:

MODAL TEST
IMPACT
HARMONIC
WIM+RESPONSE
FWD+RESPONSE
AMBIENT MONITORING
DYNAMIC PROPERTIES:
FREQ, MODE SHAPE,
MASS-NORMAL MODE SHAPE, DAMPING,
MODAL FLEXIBILITY,
FLEXIBILITY,
DEFLECTED SHAPES
EARTHQUAKE/BLAST MONITORING
TIME-HISTORY OF INPUTS/RESPONSES

CONTINUOUS MONITORING

SLOW-SPEED MONITORING
HIGH-SPEED MONITORING

ULTRASONIC PULSE VELOCITY
ULTRASONIC PULSE-ECHO
ACOUSTIC EMISSION
ELECTRICAL, ELECTROCHEMICAL METHODS
INTERFEROMETRY
IMPACT-ECHO
MAGNETIC METHODS
NUCLEAR MAGNETIC RESONANCE
TIME DOMAIN REFLECTOMETRY
ELECTRO-AcouSTICAL METHODS
ULTROSONIC RESONANCE SPECTROSCOPY
GAS PERMEABILITY
HEAT TRANSMISSION
OPTICAL METHODS

MATERIAL PROPERTIES,
DEFECTS, VARIABILITY,
CONDITIONS THAT MAY AFFECT DURABILITY

MOVEMENT
WIND, TEMPERATURE
AMBIENT INPUTS & INTRINSIC BRIDGE RESPONSES
SUDDEN CHANGES IN INTRINSIC FORCE DUE TO ACCIDENTS OR DAMAGE

TRAFFIC VIBRATION
EARTQuakes ANOMALIES IN RESPONSE PATTERNS
Bridge Test-beds Studied to Reveal Steel-Stringer Bridge Life-Cycle Performance

(1994-present)

1. HAM-126-088L
   - R.R. Cross Co. Hwy at Hamilton Ave.
   - Prototype Intelligent Bridge
   - Absolute Measurements for Intrinsic Forces
   - LIFECYCLE: DESIGN, CONSTRUCTION and COMMISSIONING

2. HAM-42-0992
   - R.R. Cross Co. Hwy at Reading Rd.
   - Instrumented Monitoring Proof of Concept
   - Incremental Parameter Measurements
   - LIFECYCLE: 10 Years Old, Excellent Condition

3. HAM-561-0683
   - Over Seymour Rd. at Paddock
   - Demonstrate Concepts and Tools for Damage Detection
   - LIFECYCLE: 50 Yrs OLD, DECOMMISSIONED

4. UCII Labs at UC

Cincinnati

Ohio River

Hamilton Bridge

- View Under the Deck
- Instrumentation of the Stringers
- Heat-Camber Instrumentation
- Pile Instrumentation
- RC deck Embedment Sensors
- Deck Pouring Operation
- Instrumentation at the Deck Pouring Operation

Reading Road Bridge


Site Design for Bridge Monitor System

Two Year Continuous Monitoring Results (Nov 94-Nov 96)

Ambient Temp. [DEGF]

ΔT = 111.4 F

Sampling: 1 sample / 6 hours

Δε = 359 με

Data Acquisition Cabinet for Teleremote On-Line Monitoring of In-Service Responses
Seymour Bridge

Bridge-Type Specific Management of Steel-Stringer Bridges in Ohio (1996-1998)

Damage Scenarios: Steel Superstructure

- One-Sided Flange Cut
- Two-Sided Flange Cut
- Web Cut
- Crossframe Cuts

Deflection, in.

Test (Baseline)

After X-Brace Cut

Modal Flexibility Based Deflections (BGCI)

- Welding/Restoration of BC's
- After X-Brace Cut at South Span

Transforming a bridge into a laboratory:
Contribution of Mechanisms to Stiffness

- **HAM-42-0992**
  - G: 34%
  - C: 44%
  - D: 17%
  - X: 6%

- **CLE-50J-0080L**
  - G: 52%
  - C: 41%
  - D: 17%
  - X: 6%

- **HAM-128-1006**
  - G: 22%
  - C: 52%
  - D: 16%
  - X: 10%

Legend:
- **Blue** = Girders
- **Red** = Composite Action
- **Tan** = Deck
- **Green** = X-Braces
Profile of T-Beam Bridges in Pennsylvania

1,651 Single Span T-beam Bridges in PA

- Total Number in USA > 32,000
- Total Number in PA > 2600
- Type Specific Design
  - Built Between ~1930 & 1950
  - Span ~20 ft - 40 ft
  - Width ~ 20 ft - 40 ft
  - Skew ~ 0 - 45 deg
  - Slab Thickness ~ 8-8.5 in
  - Beam Spacing ~ 5 ft on center
  - Beam Depth ~ 19 in - 40 in

Bridge ID: 46-0029-0300-2175
Length = 34 ft
Year Built = 1954
Skew = 45 deg

Condition Rating
<table>
<thead>
<tr>
<th>Deck</th>
<th>SuperStr</th>
<th>SubStr</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

Standard Design Dwgs.
STATISTICAL SAMPLING OF T-BEAM BRIDGES

Nominal Structural Parameters

<table>
<thead>
<tr>
<th>Span (Width Dependent)</th>
<th>Skew Angle (degrees)</th>
<th>SuperStructure Condition Rating</th>
<th>Year Built</th>
<th>Average Daily Truck Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ft to 55 ft</td>
<td>6 ft to 32 ft</td>
<td>16 ft to 32 ft</td>
<td>1929 to 1938</td>
<td>1939 to 1948</td>
</tr>
<tr>
<td>33 ft to 40 ft</td>
<td>22%</td>
<td>6 to 22</td>
<td>1948</td>
<td>551 to 1000</td>
</tr>
<tr>
<td>6 ft to 32 ft</td>
<td>64%</td>
<td>4 to 8</td>
<td>&lt; 1929</td>
<td>0 to 200</td>
</tr>
</tbody>
</table>

Condition Parameters

<table>
<thead>
<tr>
<th>Span (Width Dependent)</th>
<th>Skew Angle (degrees)</th>
<th>SuperStructure Condition Rating</th>
<th>Year Built</th>
<th>Average Daily Truck Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 ft to 32 ft</td>
<td>22%</td>
<td>0 to 7</td>
<td>1929 to 1938</td>
<td>1939 to 1948</td>
</tr>
<tr>
<td>23 ft to 37 ft</td>
<td>22%</td>
<td>6 to 22</td>
<td>1948</td>
<td>551 to 1000</td>
</tr>
<tr>
<td>6 ft to 22</td>
<td>19%</td>
<td>7 to 8</td>
<td>&lt; 1929</td>
<td>0 to 200</td>
</tr>
</tbody>
</table>

Entire 1,651 T-Beam Bridge Population

Statistical Representative 60 T-Beam Bridges

- Entire 1,651 T-Beam Bridge Population
- Statistical Representative 60 T-Beam Bridges
SAMPLE T-BEAM BRIDGES

Manoa Bridge, PA

Churchville Road Bridge, PA

Coring of the deck

Core Samples

Academy Road Bridge, PA
Details of the Swan Road Bridge Finite Element Model

Cross Section of the Model

Statistics of The Model:
Number of DOF = 108243
Number of Solid Elements = 22940
Number of Frame Elements = 7636

Reinforcement

Typical Solid Element Dimensions

Structural Details & Boundary Condition

UNIVERSITY
Regional Calibration: Deflections of the Swan Road Bridge & Test Results

Transverse Centerline Deflection of the Superstructure (Test vs. Models)

<table>
<thead>
<tr>
<th>Deflection (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.010</td>
</tr>
<tr>
<td>-0.020</td>
</tr>
<tr>
<td>-0.030</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>-0.040</td>
</tr>
<tr>
<td>-0.050</td>
</tr>
<tr>
<td>-0.060</td>
</tr>
<tr>
<td>-0.070</td>
</tr>
</tbody>
</table>

Section A-A

Section B-B

Deflection of the T-Beam "C" (Test vs. Models)

Truck and Sensor Locations:

Boundary Condition Idealization of Different Models:

- Model 1
- Model 2
- Model 3
- Model 4
- Model 5
- Model 6

K = 1000 kip/in
Comparison of Different Model Load Rating Results

- **H20 Truck**
  - a) AASHTO based BAR7 Analysis
    - Rating Factor: RI=1.27, RO=2.11
  - b) Field-calibrated FE Model
    - Rating Factor: RI=3.18, RO=5.32
  - c) Field-calibrated FEM w/o Parapet and Sidewalks
    - Rating Factor: RI=3.10, RO=5.18
  - e) Damage and Deterioration Case 1 (40% of concrete, only 80% of upper layer rebar)
    - Rating Factor: RI=1.16, RO=1.93
  - f) Damage and Deterioration Case 2 (Case e and only vertical restraints at the inner edge of the boundary)
    - Rating Factor: RI=1.05, RO=1.76

- **H20 Trucks**
Mechanisms Contributing To 2.5 - 5 Times Capacity Rating Relative to Current Practice

(Limit Condition: First Yield in Steel)

**Demand Mechanisms**
- Compression due to Pavement Thrust and Soil Pressure
- Boundaries Partially Restrained For Displacement and Rotation Due to Geometry and Dowels
- Reinforced Concrete Parapets
- Stiff Diaphragm Beams
- Lateral Load Distribution by Slab Is More Effective than simulated by DF
- Effective Force Redistribution Due To Cracking *Not Incorporated*

**Capacity Mechanisms**
- *Not Incorporated in RF*
  - Bi-axial Compression State of Concrete Stress due to Restrained Boundaries
  - Higher Yield Strength, Statistical Strength and Post-Yield Strain Hardening of Steel
  - Multiple Rebar Layers
  - Yield Line Capacity of Slab
Clermont Bridge
Non Destructive And Destructive Testing Of A Concrete Slab Bridge and Associated Analytical Studies (1990-1992)

Pratt Bridge

Camelback Bridge

Chord Failure

Load Transfer System
The Commodore John Barry Bridge
THE COMMODORE BARRY BRIDGE OVER DELAWARE RIVER:
STRUCTURAL IDENTIFICATION AND HEALTH MONITORING DEMO PROJECT


REAL-TIME MULTI-MODAL 500-CHANNEL HM SYSTEM DISPLAY
Uncertainty in Predicted Properties and Performance of Constructed Structures

- Errors $>100\%$ are common in predicted displacements of idealized reinforced concrete and steel structural models tested in the laboratory.

- Field experiments on bridges indicate a range of discrepancies between predicted and measured: $\sim 2-5$ times in service displacements, $\sim 5-10$ times in predicted stresses, $\sim 10-20$ times in predicted system load capacities.

- Many intrinsic load mechanisms and the changes these cause in the intrinsic force distributions are unknown.

- Actual failure modes of especially aged and deteriorated systems are often a complete surprise for even experienced engineers.
Types of Uncertainty Affecting Reliability of Scenario Analysis and Predictions Involving Infrastructures

- **Human Errors (HE)**
  - Inattention/Thoughtlessness
  - Inexperience
  - Omission (Forgetfulness)
  - Commission (Bad Design)

- **Random Phenomena (RP)**

- **Epistemic Uncertainty (EU)**
  - Less Understood Phenomena (LUP)
  - Unknown Phenomena (UP)
### (3) Controlled Experimentation

<table>
<thead>
<tr>
<th>Structural Complexity</th>
<th>Force and Excitation:</th>
<th>Data Acquisition:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Non-stationarity of boundary and continuity conditions</td>
<td>• Amplitude</td>
<td>• Spikes, Interferences and Spurious Energy Infiltration</td>
</tr>
<tr>
<td>• Changes in intrinsic stresses during tests $f_r$ (redundancy, deterioration, $t, T$)</td>
<td>• Spectral distribution</td>
<td>• Spatial Aliasing</td>
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<tr>
<td>• Nonlinearities: Many forms of material and damping nonlinearity, friction, intermittent contact and uplift</td>
<td>• Spatial Distribution and transmissibility</td>
<td>• Time Synchronization</td>
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<tr>
<td></td>
<td>• Directionality</td>
<td>• Hardware filtering options</td>
</tr>
<tr>
<td></td>
<td>• Dimensionality (1D, 2D or 3D)</td>
<td>• Noise &amp; bias in signal</td>
</tr>
<tr>
<td></td>
<td>• Duration and Non-stationarity</td>
<td>• Measurement Bandwidth</td>
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<tr>
<td></td>
<td></td>
<td>• Cabling and installation effects</td>
</tr>
</tbody>
</table>

### (2) A Priori Model(s)
- Analytical representation of physical members and connections
- Completeness of 3D geometry
- Soil-foundation, structural members, joints: stiffness and kinematics
- Mechanisms/Forms of Nonlinearity

### (4) Data and Processing
- Real-time data quality assessment, management and warehousing
- Error identification/Cleaning
- Different filtering, averaging, windowing options
- Data post-processing algorithms

### (5) Model Calibration, Parameter ID
- Parameter grouping
- Sensitivity, Bandwidth
- Modality of sensing
- Objective Functions, constraints
- Optimization
- Physical interpretation

### (6) Utilization
- Health/Performance Monitoring
- Damage detection, Prognosis
- Scenario Analysis and Vulnerability Assessment
- Performance-based Engineering
- Guidelines and Codes

Uncertainties associated with Sys-ID of constructed systems
Conclusions

CEE education and practice are at a crossroads

CEE’s have little knowledge about their products and no objective metrics. We cannot continue to rely on heuristics in such a fast changing highly dynamic interconnected world.

CEE practice recognizes the need for rapidly transitioning to performance based engineering - many academics don’t

We need a National St-Ld initiative for field research on common as well as unique constructed systems to rationally define and model their performance as components of critical infrastructures.

Education and continuing education should focus on technology integration and engineering/managing of large infrastructure systems.

We need to rethink how we may reduce/control the impact of politics and short-term thinking on CEE education, research and practice.

Advancing CEE education and practice is essential for societal quality of life. A National strategy for reforming CEE education and practice is essential for safe and effective functioning of any infrastructure.
Successful Attributes for the Engineer of 2020

- Possess strong analytical skills
- Practical ingenuity and creativity for innovative designs – engineers design, scientists search
- Good communication skills with multiple stakeholders
- Entrepreneurial, management skills, leadership
- High ethical standards, strong sense of professionalism
- Dynamic/agile/resilient/flexible
- Lifelong learners
- Ability to frame problems, putting them in a socio-technical and operational context
Critical Drivers for Education Reform

- Technology Leaps
- Globalization and Demographics
- The Changing Roles of Engineers
- Rapid Knowledge Growth
- New Fundamentals and Curriculum
- Practice What you Teach
- Pedagogy
- Diversity
- Scholarship and Value System
Challenges and Opportunity for Civil Engineers

Challenges:

- Civil and Environmental Engineering is slipping in its image, worth and societal standing while many civil engineers are in denial.

- Civil engineers have not been very successful as stewards of infrastructures and constructed systems for safe, effective, sustainable operation, preservation, protection, maintenance, repair, retrofit and replacement.

- Civil engineers should be transforming systems engineering and associated tools to more effectively address large infrastructure systems problems. We need to re-learn civil engineering by scientific observation, identification, simulation and control of actual operating infrastructure systems.

Opportunity:

- Properly educated/trained Civil and Environmental Engineers remain essential for leading and coordinating the multi-disciplinary teams and integrating technology and knowledge essential for effective engineering and management of large infrastructure systems.