INFRASTRUCTURE HYPER-SYSTEMS

- Telecommunications
- Electric Power
- Gas and Oil Storage and Delivery
- Transportation
- Water Supply
- Food and Agriculture
- Medicine and Health Care
- Chemical Industry
- Banking and Finance
- Emergency Services
- Government

Natural Environment

Human Elements

Engineered Elements
# PERFORMANCE OF INFRASTRUCTURE HYPER-SYSTEMS

<table>
<thead>
<tr>
<th>Performance Category</th>
<th>Engineered Elements</th>
<th>Socio-Technical Elements</th>
<th>Nature</th>
</tr>
</thead>
</table>
| Operational & Utility Limit States | • Safety  
• Efficiency  
• Security                                    | • Organizational Efficiency  
• Multi-Hazards Risk Management  
• Fiscal Responsibility               | • Sustainable  
• Env. Friendly  
• Hazardous Waste (Chemical, bio etc.) |
| Engineering Limit States     | • Serviceability & Durability  
• Safety & Stability of Failure  
• Conditional Events (w/ very long return) | • Inspection & Evaluation  
• Maintainability  
• Adaptability                         | • Aging  
• Deterioration  
• Recyclable                           |
| Societal Objectives          | • Pride in Engineering & Science  
• Quality in the Engineered Products & Services | • Aesthetics  
• Quality of Life  
• Affordability                    | • Harmony  
• Protection  
• Educate                           |
Engineering of Hyper-Systems

- Unobservable, non-stationary, highly dynamic, heterogeneous hyper-systems governed by many complex mechanisms of uncertainty and risk.
- Paradigms: Performance-Based Engineering, Integrated Asset Management, Proactive Health Management, Intelligent Systems, others?
- Paradigms serve as anchors for problem-focused research, technology development and applications.
- Research and demonstrations on actual infrastructure test-beds are essential. We are unable to reliably model, identify and simulate infrastructure hyper-systems.
The Commodore John Barry Bridge Field Test-Site as a Hyper-System Microcosm
BRIDGE HYPER-SYSTEM:
• Observe and Conceptualize
• Constraints and Objectives
• Analytical Modeling:
  Deterministic
  Physics-Based
  Soft (Numerical)
  Non-Deterministic
  Probability
  Soft (Statistical)
• Experiment
  Physical Modeling
  Field Monitoring
  Controlled In-Output
• Perturb, Control
• Asset Management
3D FEM of Commodore Barry Bridge

- **Design Drawings**
  - PP27
  - Drawings
  - Floor System
  - Lower Chord at PP27
  - Plan View at PP27

- **Structural Model**
  - PP27
  - PP 27 and Floor System
  - PP 27 – Plan
  - Wind Linkage
  - Wind Linkage
  - Moment Release (Axis 3)
  - Axial Force Release (Axis 1)

- **CAD Model**
  - PP27
  - Floor System
  - Lower Chord at PP 27
  - Panel Point 27

- **Photograph**
  - Verticals and Diagonals
  - Upper Chord at PP27
  - Floor System

**Notes:**
- **Floor System**
- **Upper Chord at PP27**

**Keywords:**
- PP27
- Lower Chord at PP27
- Plan View at PP27
- Wind Linkage
- Wind Linkage
- Moment Release (Axis 3)
- Axial Force Release (Axis 1)
FE Model of Commodore Barry Bridge Through Truss

3D Model Statistics
Nodes: ~8,000, DOF’s ~50,000
Frame Elements: ~5500
Shell Elements: ~3,000

Scalability/Interpretation Issues in Modeling Large Systems:
1. Conceptualizing Sub-Systems, Local Behaviors, Initial, Boundary and Continuity Conditions (known and unknown movement systems)
2. Mitigating Input, Analysis & Output Errors
3. Simulating dynamic, moving and non-stationary inputs and behaviors
4. Integrated modeling of socio-technical and natural elements
5. Incorporating different mechanisms/levels of uncertainty
Ambient Vibration Testing For FEM Calibration

45 Accelerometers Utilized

Vert. Accel.
Lat. Accel.
Long. Accel.

Mode 1
f=0.250 Hz

f=0.252 Hz

Mode 2
f=0.365 Hz

f=0.360 Hz

Mode 3
f=0.579 Hz

f=0.581 Hz

Mode 4
f=0.606 Hz

f=0.602 Hz

Mode 5
f=0.666 Hz

f=0.679 Hz

Mode 6
f=0.693 Hz

f=0.716 Hz

Mode 7
f=0.867 Hz

f=0.880 Hz

Mode 8
f=0.966 Hz

f=0.970 Hz

Mode 9
f=1.037 Hz

f=1.037 Hz

Mode 10
f=1.145 Hz

f=1.232 Hz
Static and Crawl Speed Load Test

South Hanger Strains (L1)

Strain (microstrain)

Panel points

Time (sec) and Position of Load

Strain (microstrain)

Static Test Data For Stringer b/w PP25-PP26

Crawl Speed Test Data for Influence Line Generation

Single Crane During Crawl Speed Test
Synchronization of Truck Images and Response

Monitored Truck

PP27 North Lower Hanger Flange Strain Average (uE)

PP27 South Lower Hanger Flange Strain Average (uE)

High-Speed:

Red Line: Current Time
Oct 30, 2002 10:00:33

Low-Speed:

Temperature (deg F)
Collection System

Field Collection
- Measurement sys. calibrations
- Installation quality
- Operator training
- Synchron. and formatting
- System redundancies

Elementary Data Checks
- Time-range validity
- Sensor-range validity
- Repeated readings
- Sampling frequency
- Data smoothness
- Other

Online-Real Time Presentation
- Visual verification
- Real-time I/O correlation
- Logical consistency

Data Transfer
- Headers
- Handshake
- Receipts

Data Tagging

Secondary Data Check
- Time-series analysis
- Frequency analysis
- Visualization tools

Database Safety
- Integrity
- Data change tracking
- Backup and safety
- Authorization protocols

Tertiary Data Check
- Data interpretation
- Data presentation
- Correlations
- Multivariate correlation
- Fuzzy and ANN models

Legacy Data Access
- Raw data
- Interpretations

Authorized Access / Firewall

Online via Internet

Data Quality Assessment, Processing and Archival
<table>
<thead>
<tr>
<th>Intelligent Bridge Application:</th>
<th>Tracking, Mapping, Integrating Multiple Images, Data, Information &amp; Heuristics</th>
<th>Identify Patterns</th>
<th>Test Patterns Retrospectively</th>
<th>Plan of Action, Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Management:</td>
<td>Live roads, wind, temperatures, movements and bridge responses: (a) to live loads, and, (b) intrinsic responses</td>
<td>Load &amp; response amplitudes and patterns at critical locations, given changes in intrinsic conditions, environment, and history. Establish indicators of normalcy</td>
<td>Evaluate response amplitudes, damage indicators &amp; normalized influence coefficients against measured &amp; simulated benchmarks</td>
<td>Intercept causes of deterioration, alert &amp; direct experts for closer inspection, maintenance &amp; repair when needed, alarms if damage is detected</td>
</tr>
<tr>
<td>Structural Health Monitoring, &amp; Modeling of the Loading Environment</td>
<td>Map-track traffic along roadway in real-time together with roadway &amp; weather conditions.</td>
<td>Check for anomalies in the movements of vehicles given traffic, weather &amp; roadway conditions. Check LP of vehicles against outstanding tickets &amp; warrants</td>
<td>Citations; Safety risks for any detected anomaly given the traffic, roadway &amp; weather conditions</td>
<td>Advise/Alert via smart-signs &amp; vehicle com systems, intercept for enforcement &amp; or accident avoidance, e-citations</td>
</tr>
<tr>
<td>Operational Safety:</td>
<td>Monitor physical characteristics and driving patterns of individual vehicles 24/7/365 at the vicinity of bridge &amp; tunnel entry points</td>
<td>Identify vehicle type, LP, transponder and driving patterns in conjunction with the composition &amp; volume of traffic</td>
<td>Identify vehicles that have to be inspected (red), &amp; those (yellow) that should be inspected for future patterning</td>
<td>Alert vehicle by smart-signs &amp; security personnel before entry. Direct to hardened lanes</td>
</tr>
<tr>
<td>Security:</td>
<td></td>
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<tr>
<td>Profile Vehicles for Inspection at Bridge, Tunnel, Garage Entries</td>
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</table>
NSF-FHWA-(NIST?-FEMA?-USGS?)

• An international nexus (e.g. SAMCO) for a critical mass of multi-disciplinary champions from academe-government-industry for problem-focused research, tech development, standards, demos for infrastructure innovation

• A meta-database on major infrastructure systems construction and renewal projects, research, technology, materials, resources.

• Develop/coordinate access to actual infrastructure test-beds for observations, data collection, research and demonstrations.