An Innovative Procedure for Load Rating of Suspension Bridges

Hassan Sedarat
Iman Talebinejad
Alexander Kozak
Joyce Lee, Farid Nobari, Alex Krimotat
SC Solutions, Sunnyvale California

Outline:

- Bridges in the United States: Status and Condition
- Need for Load Rating of Bridges
- Proposed Procedure for Load Rating for Complex Bridges

Collapse of Silver Bridge (1967) – Ohio River

- First major bridge collapse since Tacoma Narrows Bridge collapsed on November 7, 1940
- 46 killed – 9 injured
- Stress corrosion cracking in the eyebar
- The bridge was carrying much heavier loads than originally designed for
- Poorly maintained

Congressional Action

- Establishment of the National Bridge Inspection Standards (NBIS)

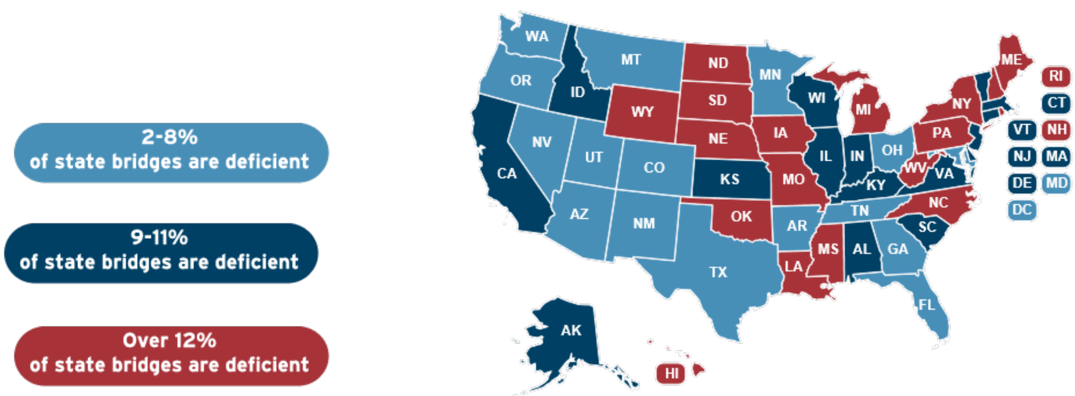
U.S. 35 - Silver Bridge (between Point Pleasant, West Virginia, and Kanauga, Ohio)

Silver Bridge, OH
Upon Completion in 1928

Silver Bridge, OH (46 deaths)
December 15, 1967
[Stress corrosion cracking in eyebar]

Status/Condition

- The average age of the nation's 607,380 bridges is currently 42 years
  - The nation has an entire generation of bridges, constructed in the 1950s and 1960s, that need major repair or replacement
- Per 2013 ASCE Report Card for America's Infrastructure :
  - Over 250 million daily crossings on 63,207 U.S. structurally deficient bridges in need of repair
- Per FHWA Estimate:
  - The current cost to repair or replace only the deficient bridges: $76 billion



Source:
All data is from the 2013 National Bridge Inventory, released in march 2013 by the Federal Highway Administration. Number includes all bridges classified as structurally deficient without taking into consideration the year a bridge was build or reconstructed.

Management Strategies

NBIS Mandates

- Bi-annual inspection and load rating
- Federal regulations requirements for inspection procedures
- Preparation and maintenance of bridge inventory records

Current Management Strategies:

- Visual Inspection Methods
- Non-destructive Evaluation Methods (NDE)
- Structural Monitoring Method (SM)
- Load Rating

Load Rating

- AASHTO Provides General Guidance for Simple Bridges
- Complex Bridges ?

Need for an Efficient Procedure for Complex Bridges

1. To address the demand calculations
   - calculation of dead load
   - live load or unknown overweight vehicles
   - distribution factor
   - increase in traffic volume
   - impact load
   - speed at which the vehicles travel

2. To address the capacity calculations
   - Construction deficiencies
   - Aging of material

Proposed Procedure:

- Combine Structural Monitoring with Load Rating

Proposed Procedure

Steps 1 and 2:
Finite Element Analysis
Flexibility Analysis
This is a one-time effort

Step 3:
Measure displacement of bridge using wireless accelerometers
Measurement in real-time

Step 4:
Estimate the response of the bridge in real-time
(without performing finite element analysis)

Step 5:
Calculate the C/D ratio of the estimated response for any desired bridge component
Or
Compare with Baseline Condition

A Unique procedure

Reliable tool for load rating and continuous monitoring of the bridge

- The New Carquinez Bridge (Alfred Zampa Memorial Bridge)
- Opened to traffic on November 11, 2003
- Superstructure: steel box girders

Implementation

Steps 1 and 2:
Finite Element Analysis
Flexibility Analysis
This is a one-time effort

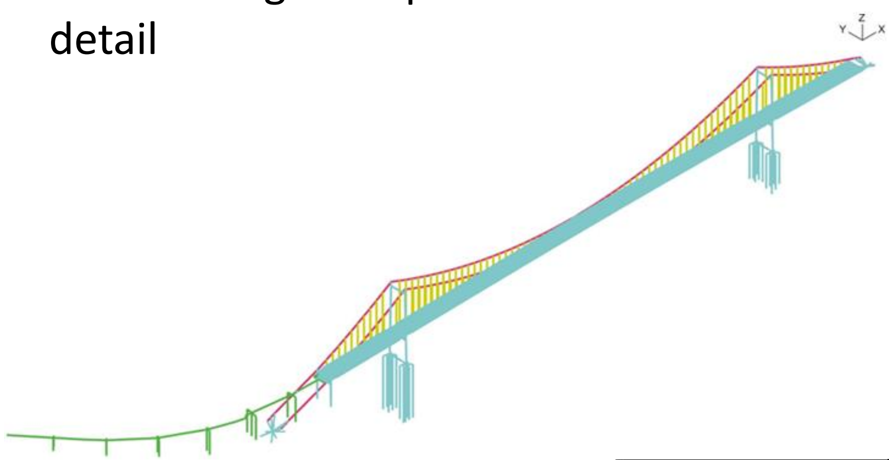
Step 3:
Measure displacement of bridge using wireless accelerometers
Measurement in real-time

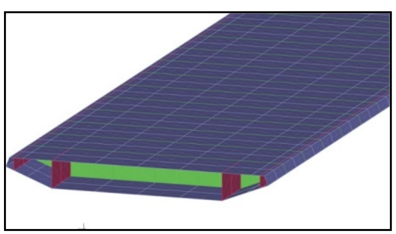
Step 4:
Estimate the response of the bridge in real-time
(without performing finite element analysis)

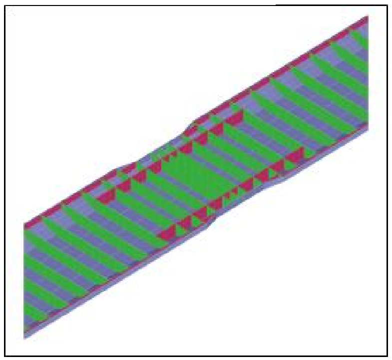
Step 5:
Calculate the C/D ratio of the estimated response for any desired bridge component
Or
Compare with Baseline Condition

FE model of the New Carquinez Bridge

- FE model: 28837 nodes, 98825 elements and 159,195 DOFs
- Construction sequence was simulated
- All the bridge components were modeled in detail





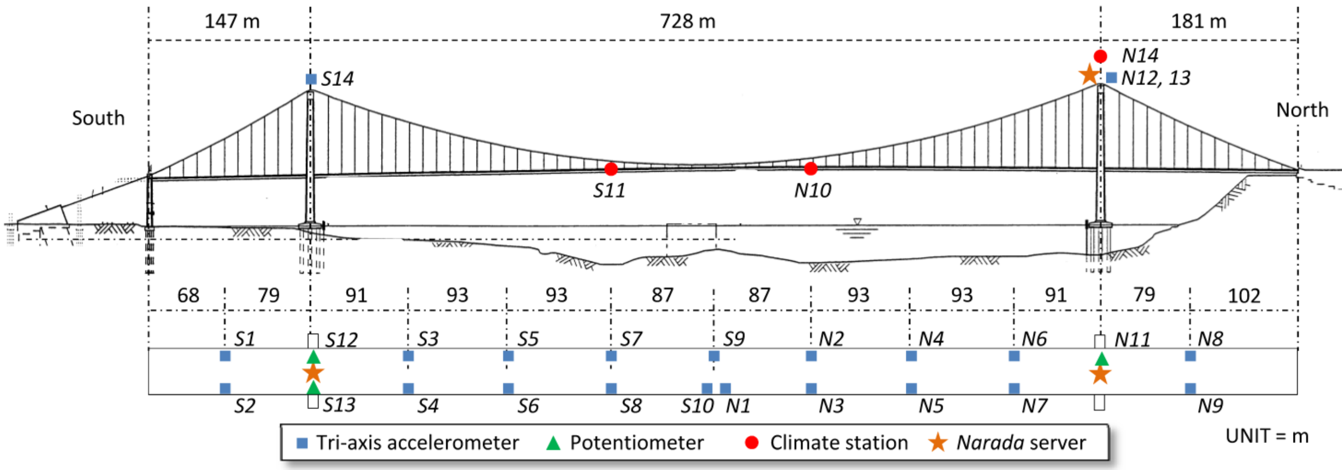


Western Bridge Engineers' Seminar
September 9-11, 2015
Peppermill Hotel | Reno, Nevada

Measured and Computed Frequencies – Model Calibration

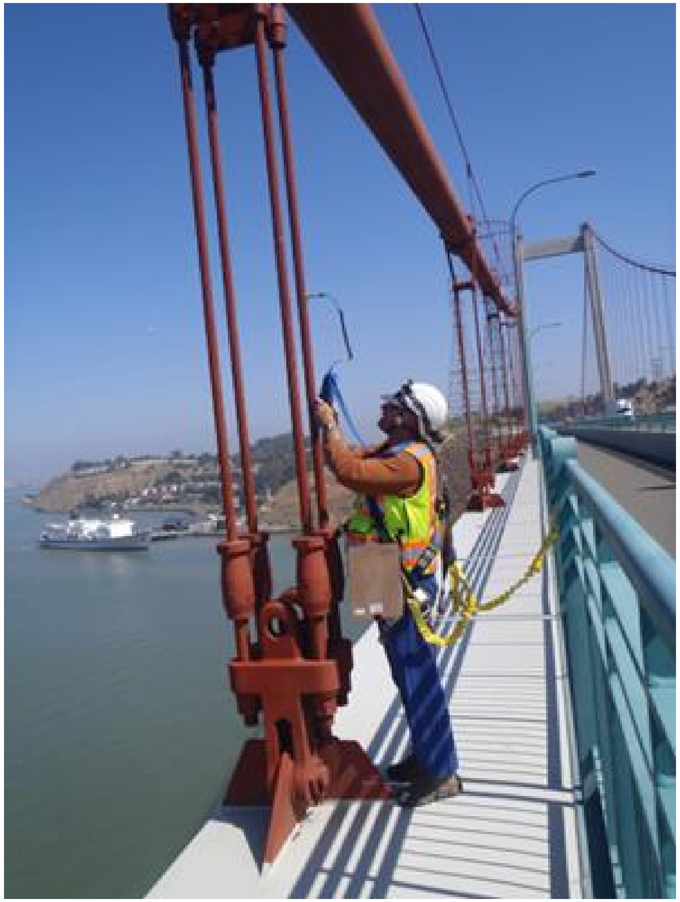
- Excellent agreement between measured and un-calibrated frequencies
- No significant improvement after FE model calibration

Mode number	1	2	3	4	5
Measured Frequencies	0.194	0.260	0.351	0.413	0.487
FE Frequencies (uncalibrated)	0.195	0.256	0.347	0.394	0.459
FE Frequencies (calibrated)	0.195	0.262	0.348	0.399	0.461
% difference (measured and uncalibrated)	-0.57	1.31	0.94	4.65	5.73
% difference (measured and calibrated)	-0.57	-0.82	0.86	3.63	5.49



22 Accelerometers and 4 Strain gauges were installed on the bridge

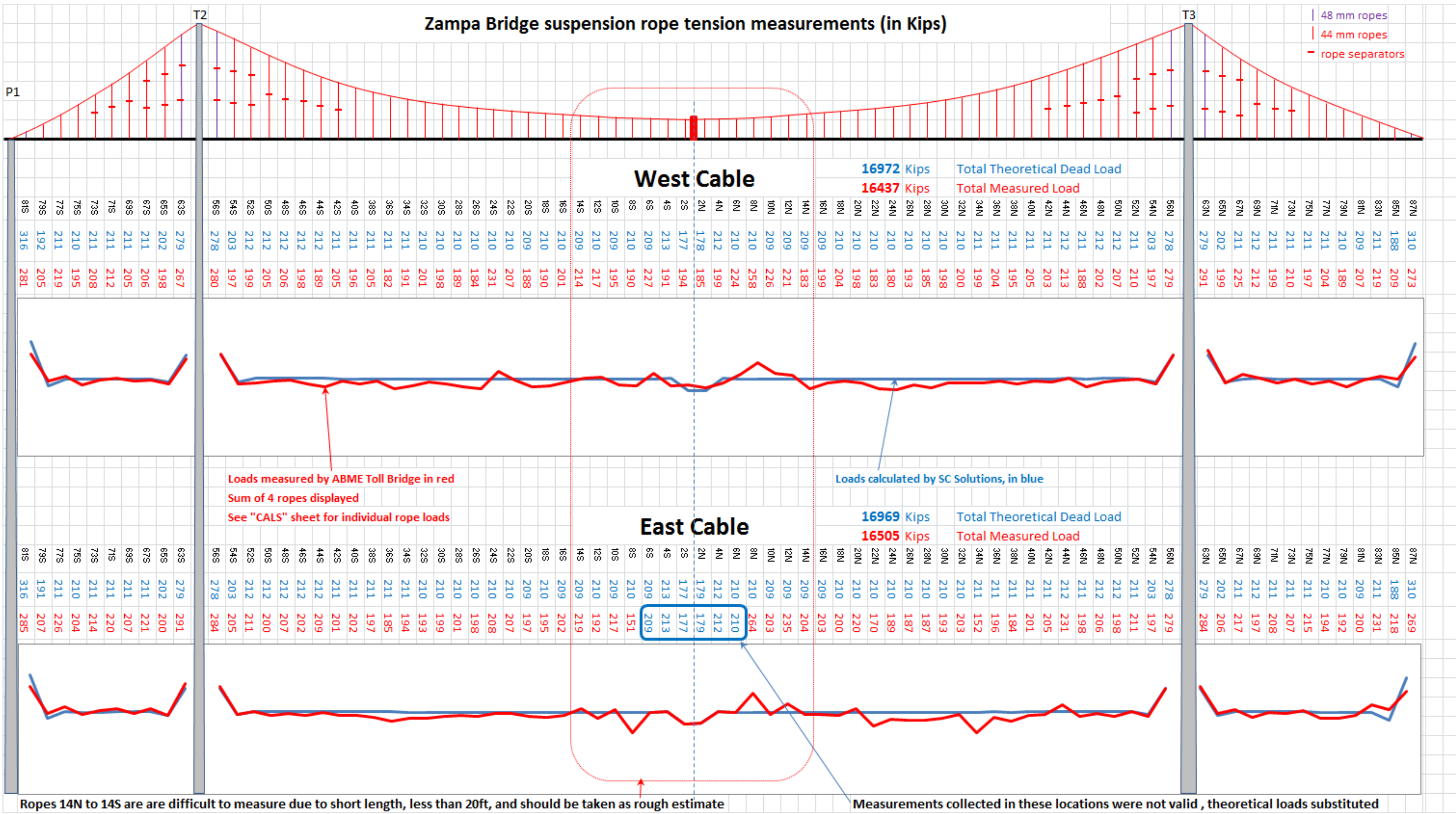
Installation of Temporary Sensor on Suspenders of the New Carquinez Bridge by Caltrans Maintenance Crew



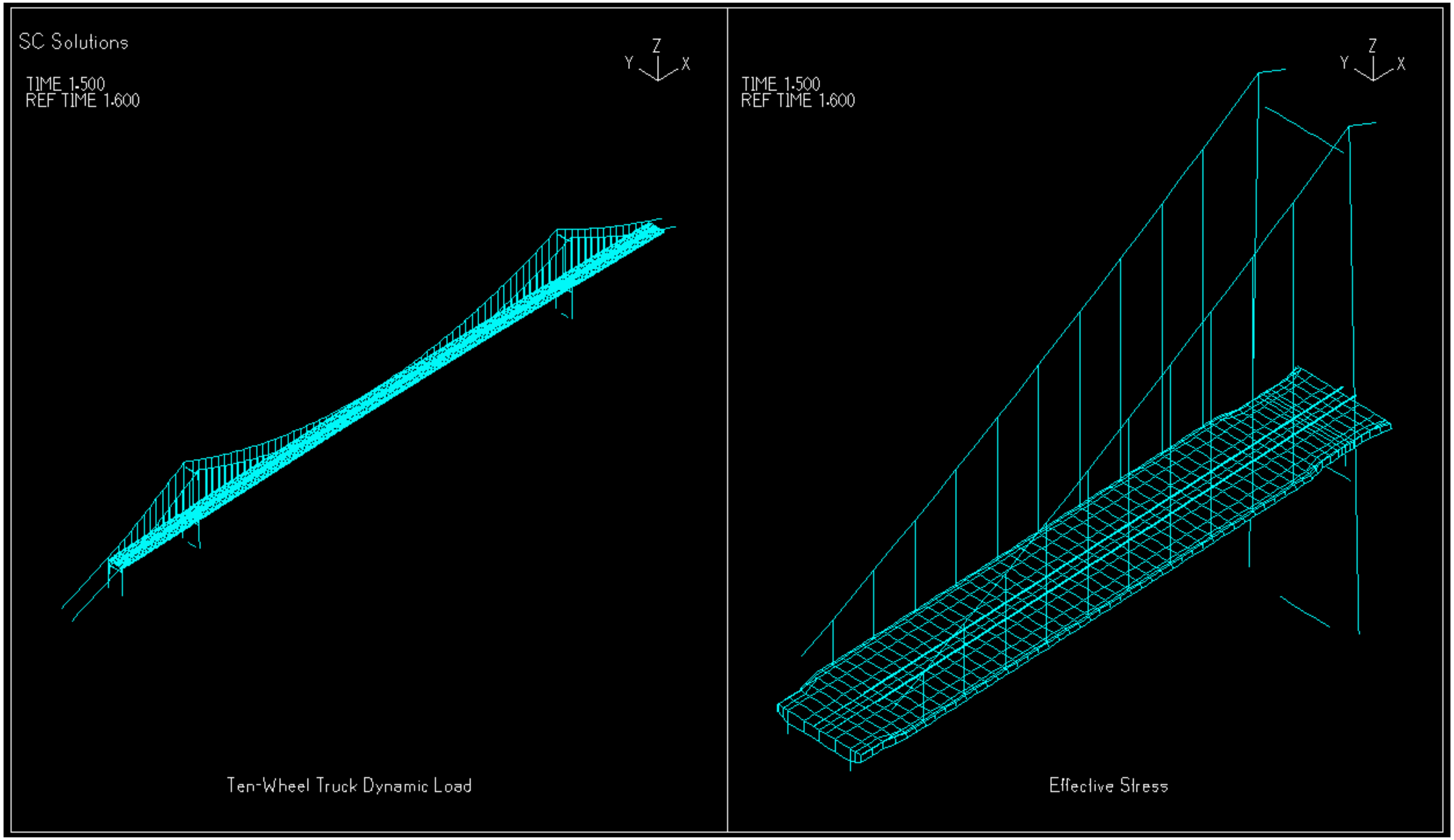
Validation of the FE Model

Forces in the hangers: Measured and computed

Error on total measured load = 3%



Step 2 : Develop Flexibility Analysis



Implementation

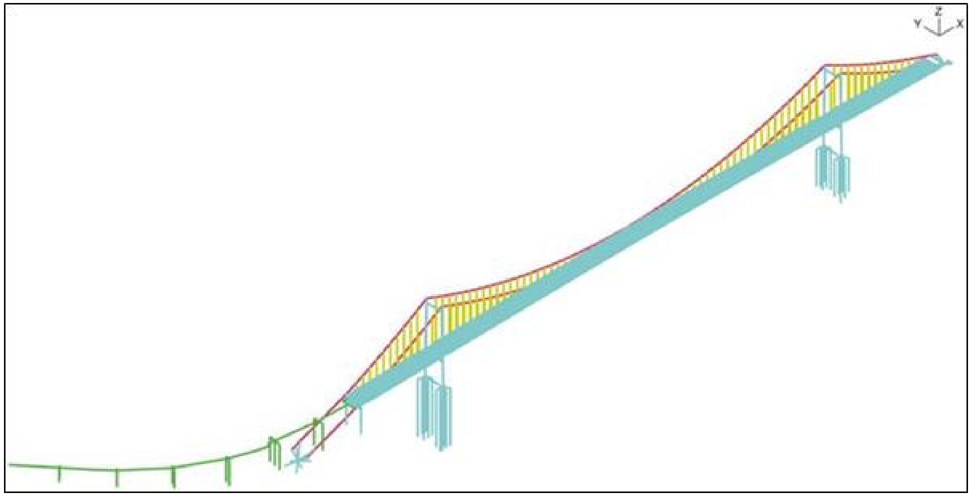
Steps 1 and 2:
Finite Element Analysis
Flexibility Analysis
This is a one-time effort

Step 3:
Measure displacement of bridge using wireless accelerometers
Measurement in real-time

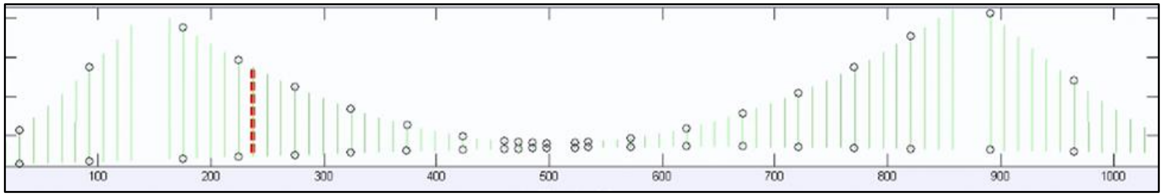
Step 4:
Estimate the response of the bridge in real-time (without performing finite element analysis)

Step 5:
Calculate the C/D ratio of the estimated response for any desired bridge component
Or
Compare with Baseline Condition

- Bridge displacements are measured through forces in the hangers
- Install sensors to selected number of hangers



- Location of sensors on the hangers



Implementation

Steps 1 and 2:
Finite Element Analysis
Flexibility Analysis
This is a one-time effort

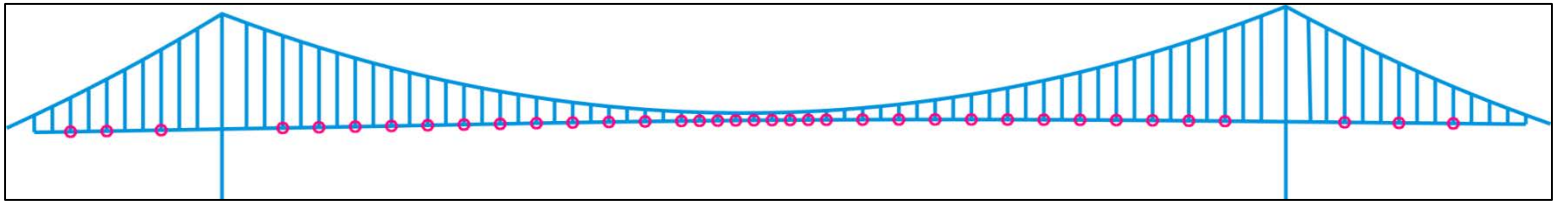
Step 3:
Measure displacement of bridge using wireless accelerometers
Measurement in real-time

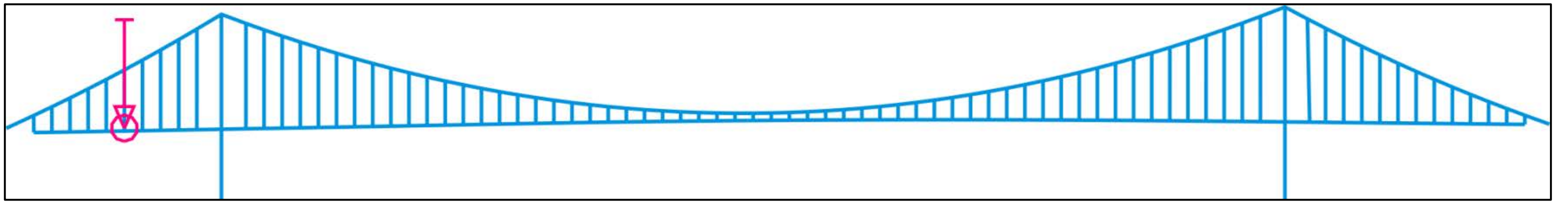
Step 4:
Estimate the response of the bridge in real-time (without performing finite element analysis)

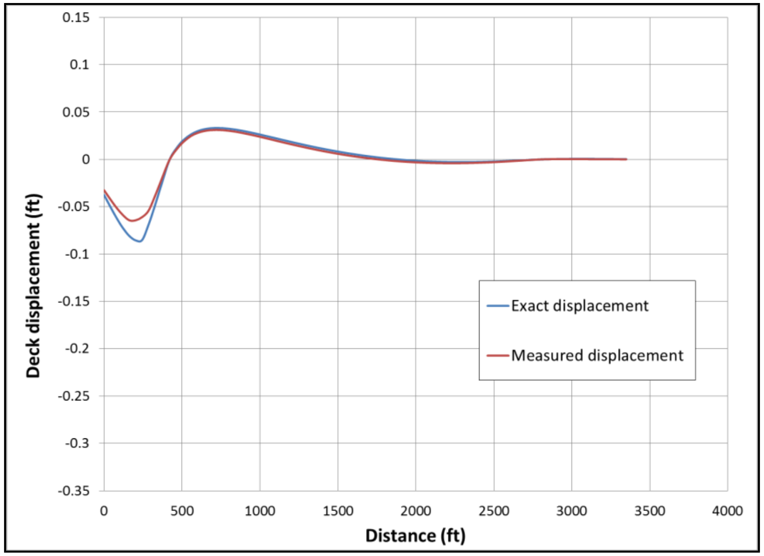
Step 5:
Calculate the C/D ratio of the estimated response for any desired bridge component
Or
Compare with Baseline Condition

Step 4: Estimate Response in Real-Time

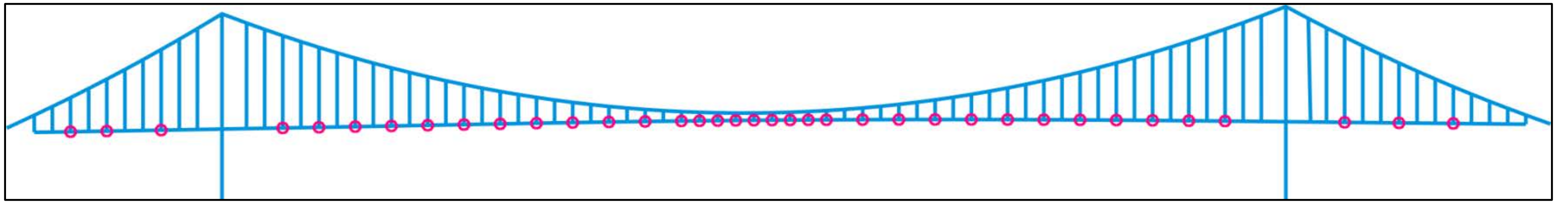
Results (Load at approach span)

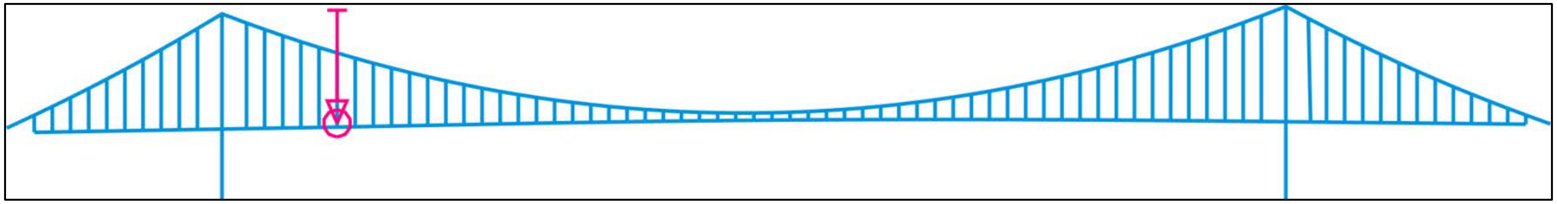


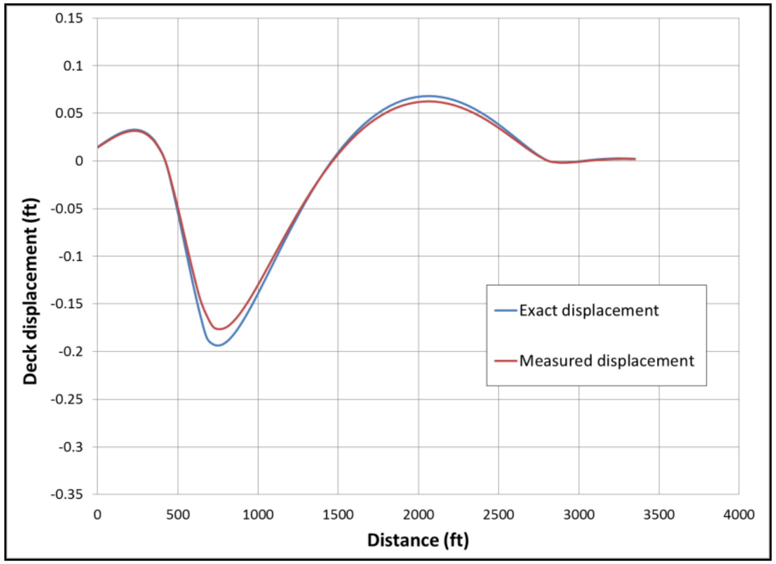




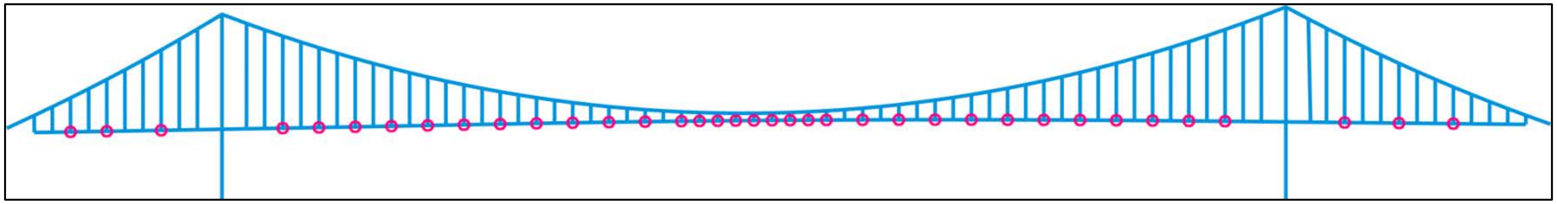
Results (Load at main span)

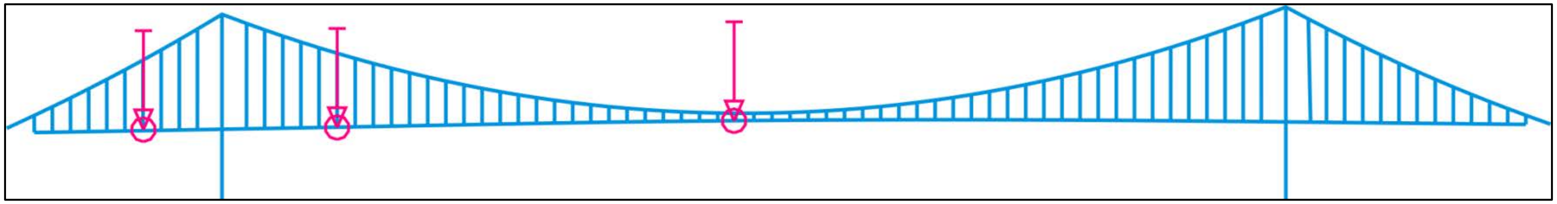


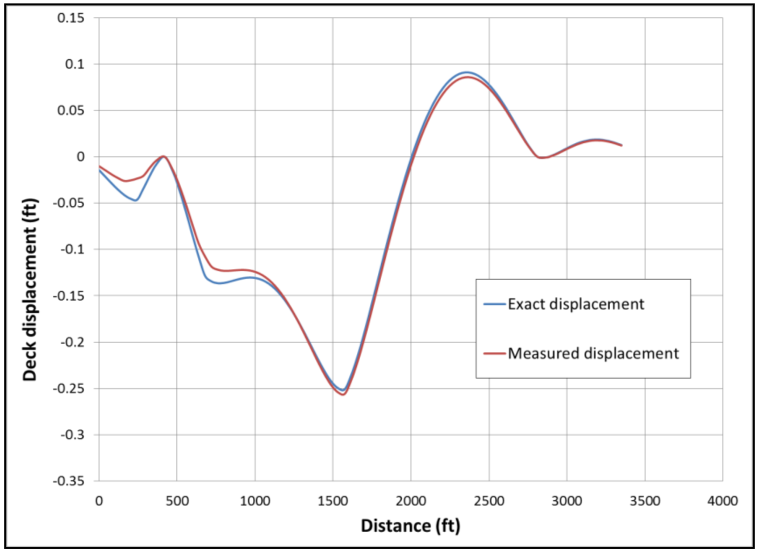




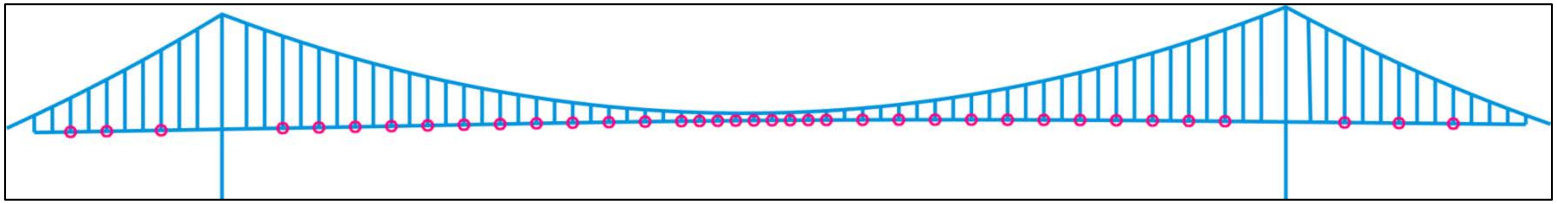
Results (Load at three locations)

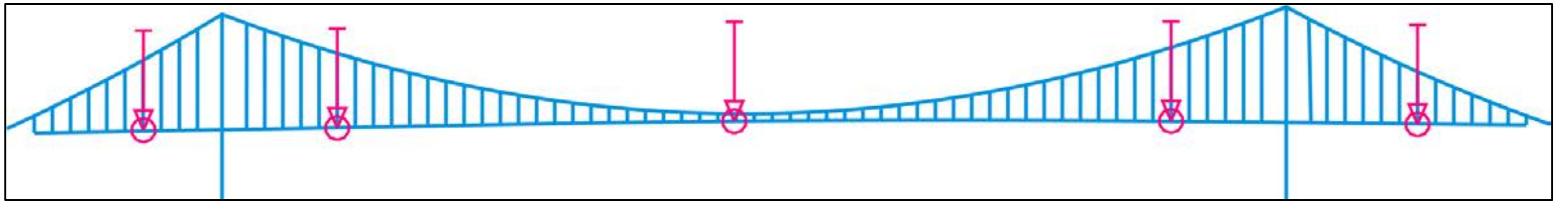


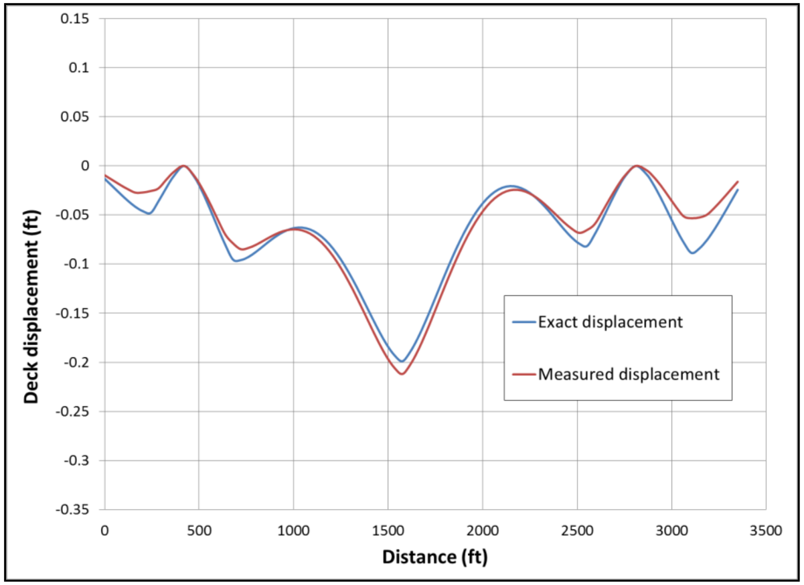




Results (Load at five locations)

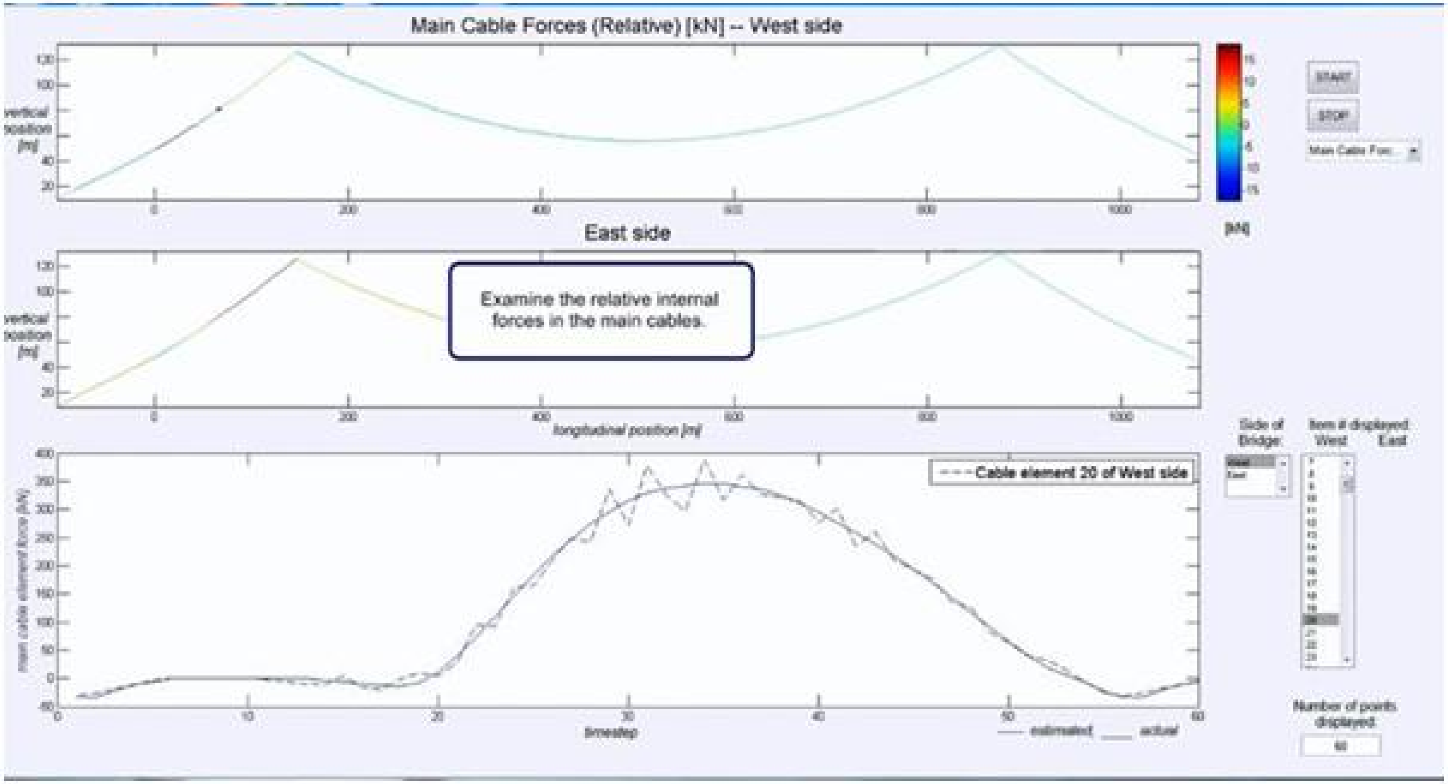






Step 4: Estimate Response in Real-Time

Cable forces due to traffic load - estimated versus actual



Step 5: Load Rating

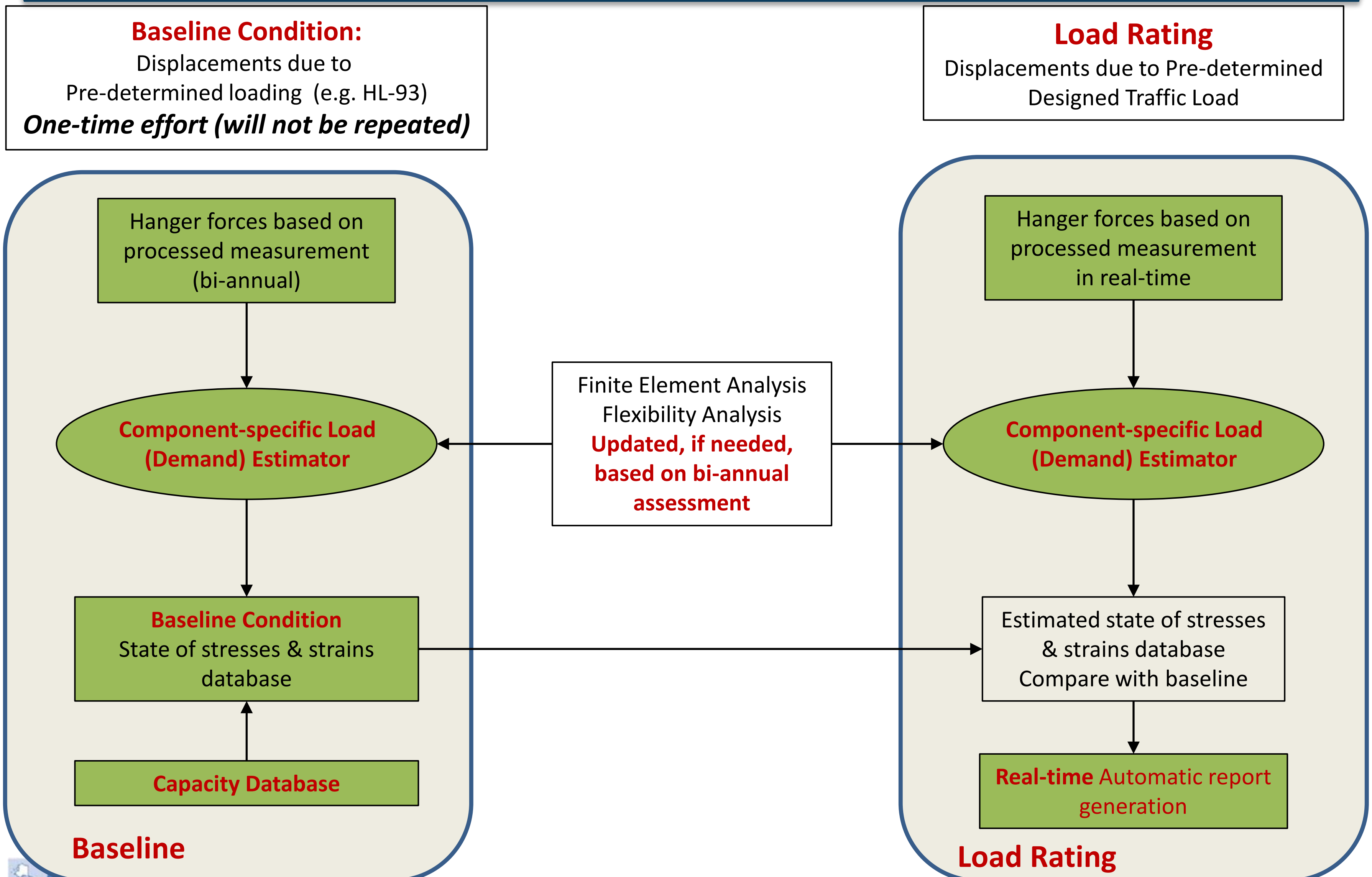
Steps 1 and 2:
Finite Element Analysis
Flexibility Analysis
This is a one-time effort

Step 3:
Measure displacement of bridge using wireless accelerometers
Measurement in real-time

Step 4:
Estimate the response of the bridge in real-time
(without performing finite element analysis)

Step 5:
Calculate the C/D ratio of the estimated response for any desired bridge component
Or
Compare with Baseline Condition

Step 5: Load Rating



Conclusions

- The proposed procedure estimates demands in real-time without performing FE analysis

- Demands (forces and displacements) can be estimated with very good accuracy for:
  - Dead Load & Live Load
  - Defined Vehicle Loads (known load)
  - Traffic Loads (unknown load)
  - Unknown Overweight Vehicles
  - Increase in Traffic Volume
  - Speed of Vehicles
  - Temperature Effect

Conclusions

- Distribution Factor and Impact Factor are automatically included in demand calculations
- Construction deficiencies are automatically included in demand calculations
- Capacity updates
- This technique can be used for load rating of complex bridges

Thank You