"Current and Future Bridge Health Monitoring Systems in Hong Kong"

by

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The Government of the Hong Kong Special Administrative Region

Why Bridge Health Monitoring System is needed?

- **Monitoring Structural Performance and Applied Loads**
- **Facilitating the Planning of Inspection and Maintenance**
- **Validating Design Assumptions and Parameters**
- **Updating and Revising Design Manuals and Standards**

WASHMS

1. **WASHMS refers to *Wind And Structural Health Monitoring System*.**

2. **Application: *"wind sensitivity structures"*, i.e. frequency lower than 1 Hz.**

3. **Existing Bridges with WASHMS:**
   - **(i) Tsing Ma & Kap Shui Mun Bridges - *LFC-WASHMS*.**
   - **(ii) Ting Kau Bridge - *TKB-WASHMS*.**

4. **Future Bridges with WASHMS:**
   - **(i) The Cable-Stayed Bridge (Hong Kong Side) in Shenzhen Western Corridor - *SWC-WASHMS*.**
   - **(ii) Stonecutters Bridge - *SCB-WASHMS*.**


HIGHWAYS AREA DIVISION
DEPARTMENT
TSING MA CONTROL BRIDGE HEALTH SECTION
Shenzhen
Shekou
Shenzhen Western Corridor
Yuen Long
New Territories
Ting Kau Bridge
Tuen Mun
北
Sha Tin
Tsing Ma Bridge
Tsing Yi
Kap Shui Mun Bridge
Kowloon
Stonecutters Bridge
Hong Kong International Airport
Lantau Island
Hong Kong Island


Tsing Ma Bridge

Kap Shui Mun Bridge

Ting Kau Bridge

View of the 3 bridges from Southwest Corner of TMCA

The two cable-stayed bridges in Shenzhen Western Corridor

Stonecutters Bridge

Part 2

System Architecture and Operation of WASHMS

System Architecture of WASHMS

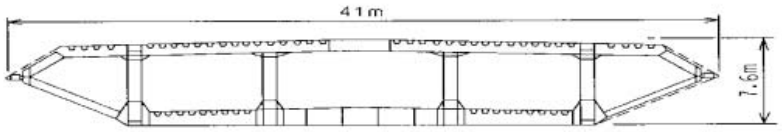
The four WASHMSs, i.e. LFC-WASHMS, TKB-WASHMS, SWC-WASHMS and SCB-WASHMS, are all configured into six integrating modules:

- **Sensory System (SS)**
- **Data Acquisition and Transmission System (DATS)**
- **Portable Data Acquisition System (PDAS)**
- **Data Processing and Control System (DPCS)**
- **Structural Health Evaluation System (SHES)**
- **Portable Inspection and Maintenance System (PIMS)**

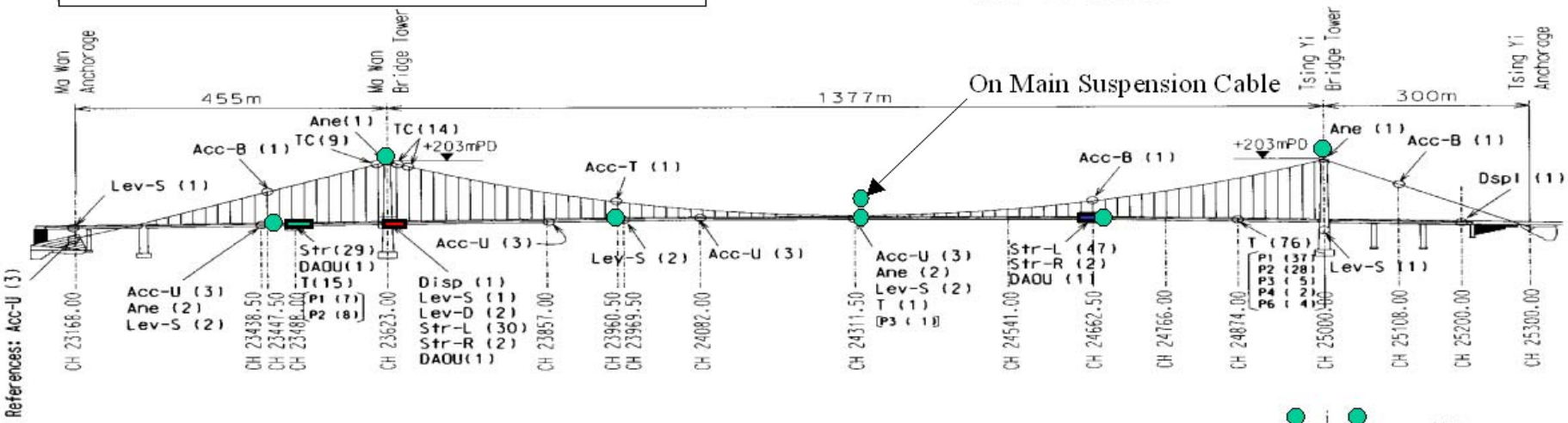
Part 3
Current WASHMS

Layout of Sensory System (SS)

KEY		
Acc-U	Uniaxial Accelerometer	(15)
Acc-B	Biaxial Accelerometer	(3)
Acc-T	Triaxial Accelerometer	(1)
Ane	Anemometer	(6)
Dspl	Displacement Transducer	(2)
Lev-S	Level Sensing Station	(9)
Lev-D	Level Sensing Datum Station	(2)
Str-L	Linear Strain Gauge	(106)
Str-R	Rosette Strain Gauge	(4)
T	Temperature Sensor	(115)
DAOU	Data Acquisition Outstation Unit	(3)
GPS	GPS Rover Station	(14)



Typical Tsing Ma Bridge-Deck Section
(not to scale)

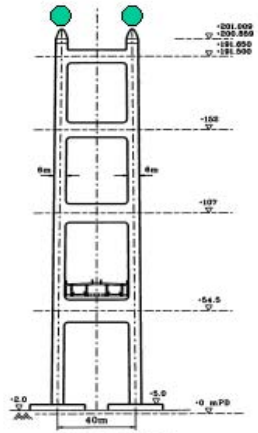


Data Acquisition Outstation OSTDS-01 (64 No. Channel)

Data Acquisition Outstation OSTEN-01 (64 No. Channel)

Data Acquisition Outstation OSTLS-01 (128 No. Channel)

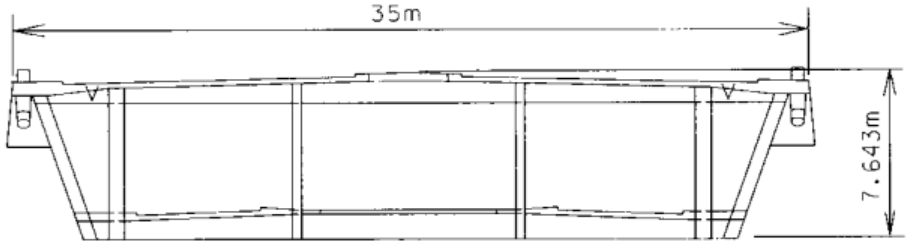
GPS Rover Stations (North and South)



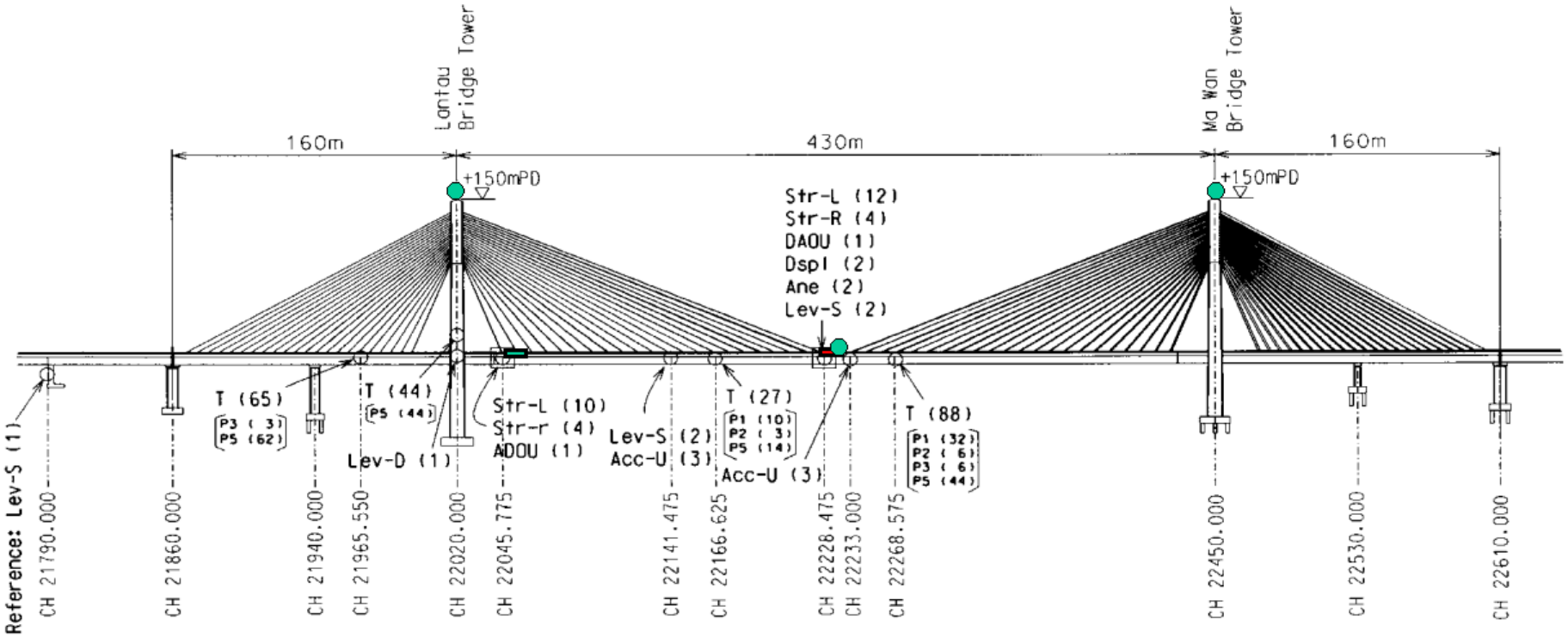
TSING MA BRIDGE
FRONT ELEVATION - TOWER

Layout of SS and DAS in LFC-WASHMS (TMB Part)

KEY		
Acc-U	Uniaxial Accelerometer	(6)
Ane	Anemometer	(2)
Dspl	Displacement Transducer	(2)
Lev-S	Level Sensing Station	(5)
Lev-D	Level Sensing Datum Station	(1)
Str-L	Linear Strain Gauge	(22)
Str-R	Rosette Strain Gauge	(8)
T	Temperature Sensor	(224)
DAOU	Data Acquisition Outstation Unit	(2)
GPS	GPS Rover Station	(6)



Typical Kap Shui Mun Bridge-Deck Section
(not to scale)

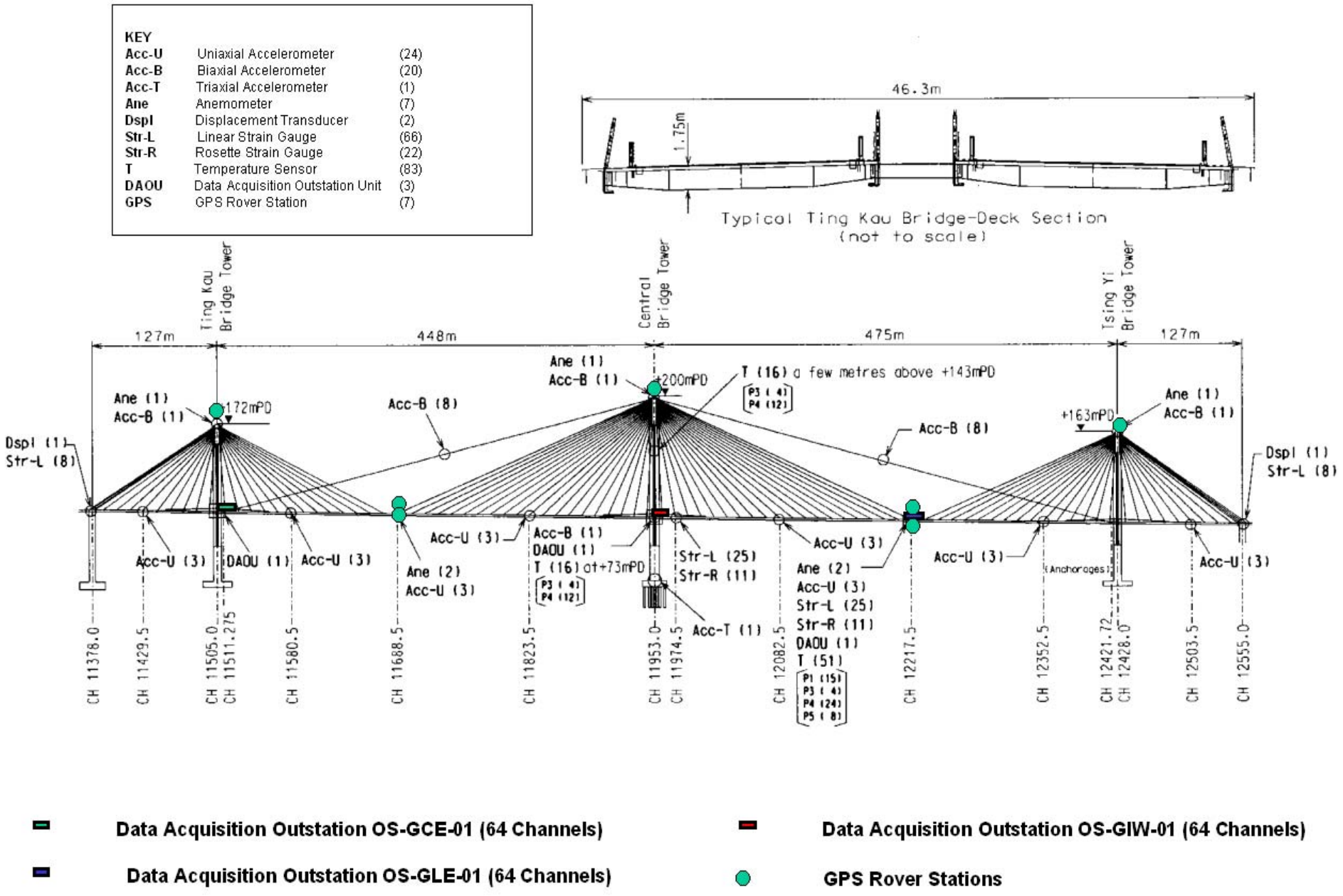


Data Acquisition Outstation OS-KDN-01 (64 Channels)

Data Acquisition Outstation OS-KHS-01 (64 Channels)

GPS Rover Stations (North and South)

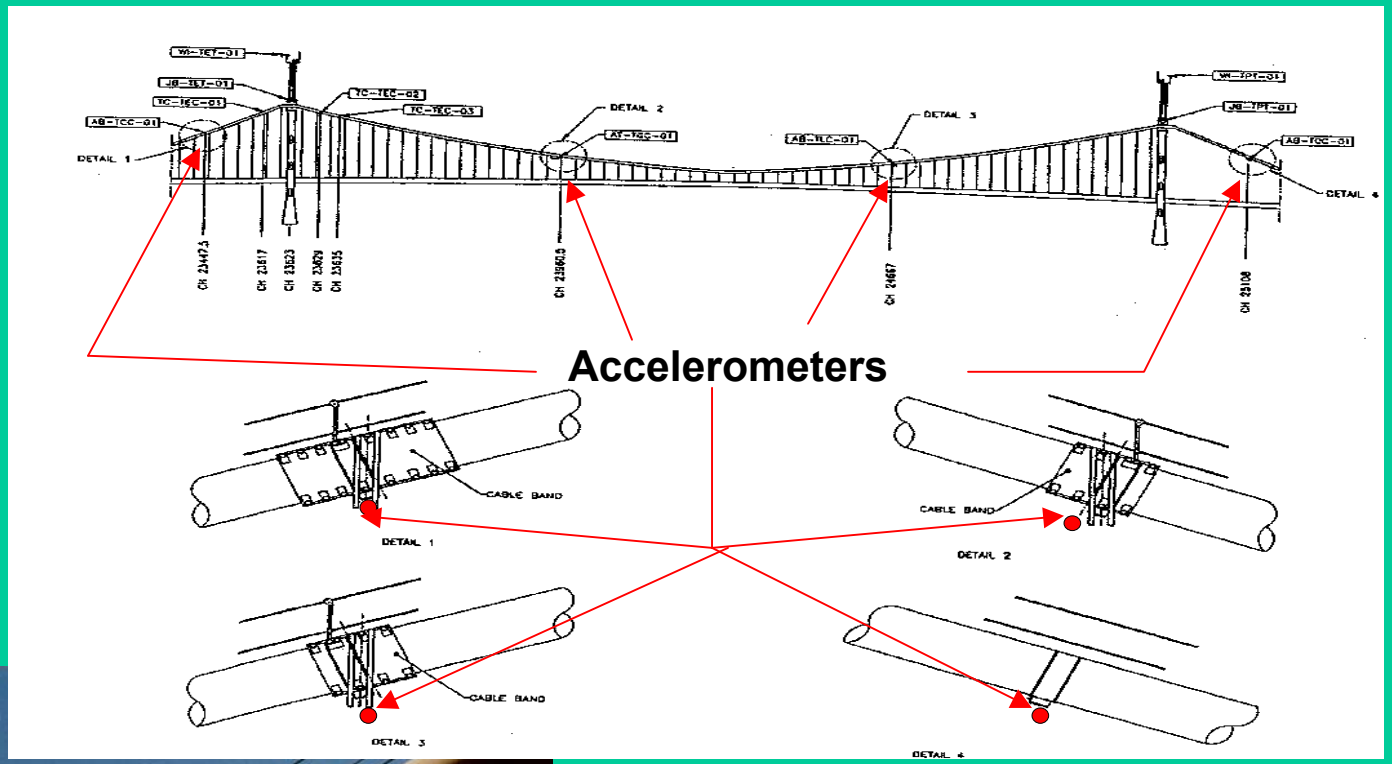
Layout of SS and DAS in LFC-WASHMS (KSMB Part)

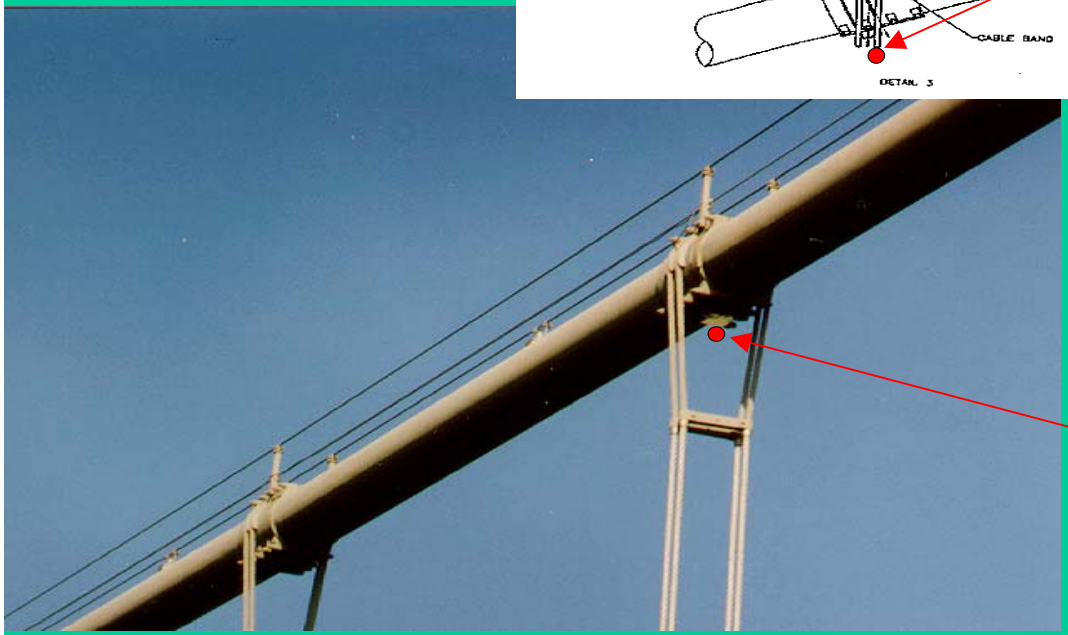


Layout of SS and DAS in TKB-WASHMS

Details of Different Types of Sensory System

Detail of Accelerometers



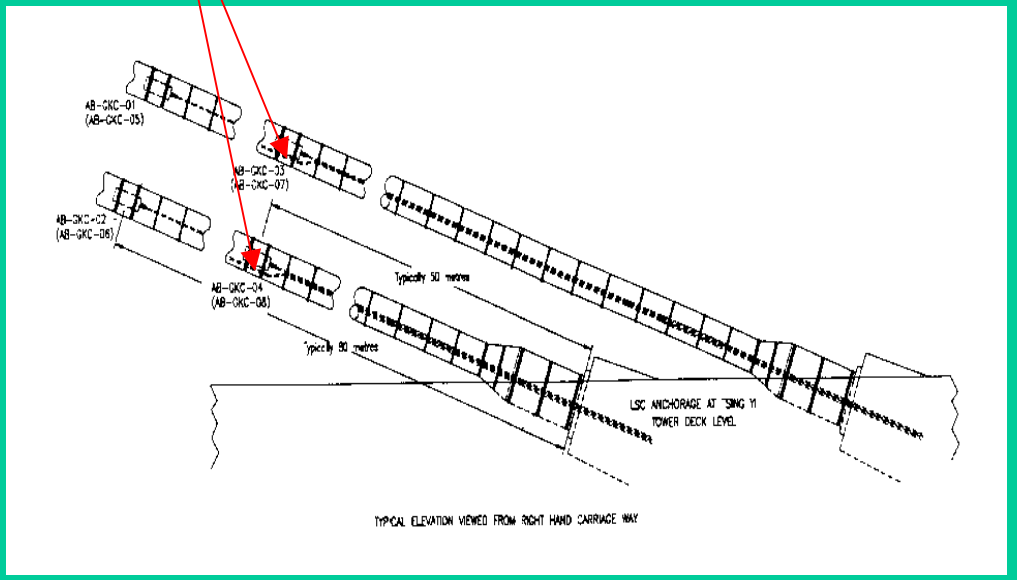


Accelerometers on Main Cable

Accelerometers on Main Cable of Tsing Ma Bridge

Accelerometers

Accelerometers Mounted on Longitudinal Stabilizing Cable

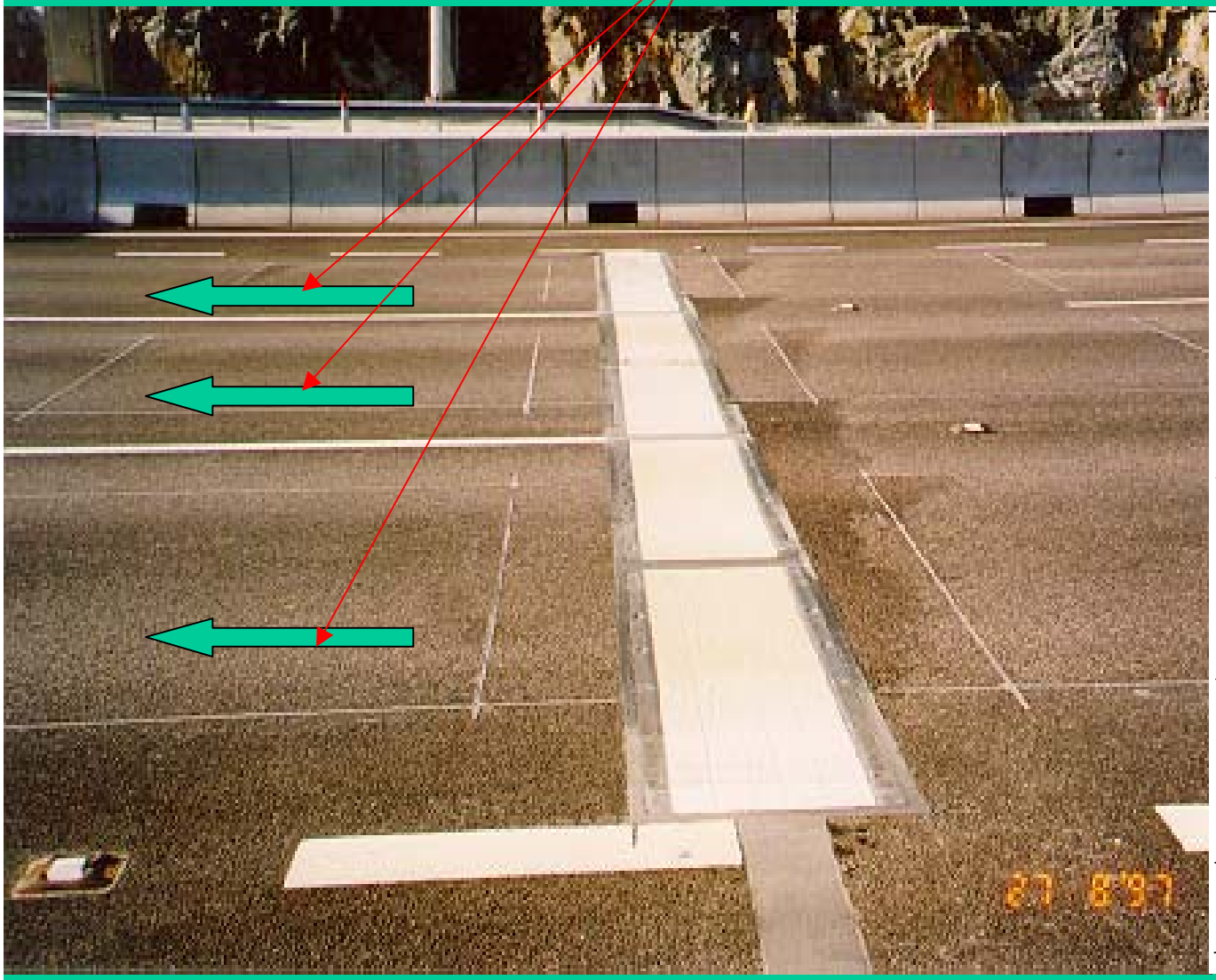


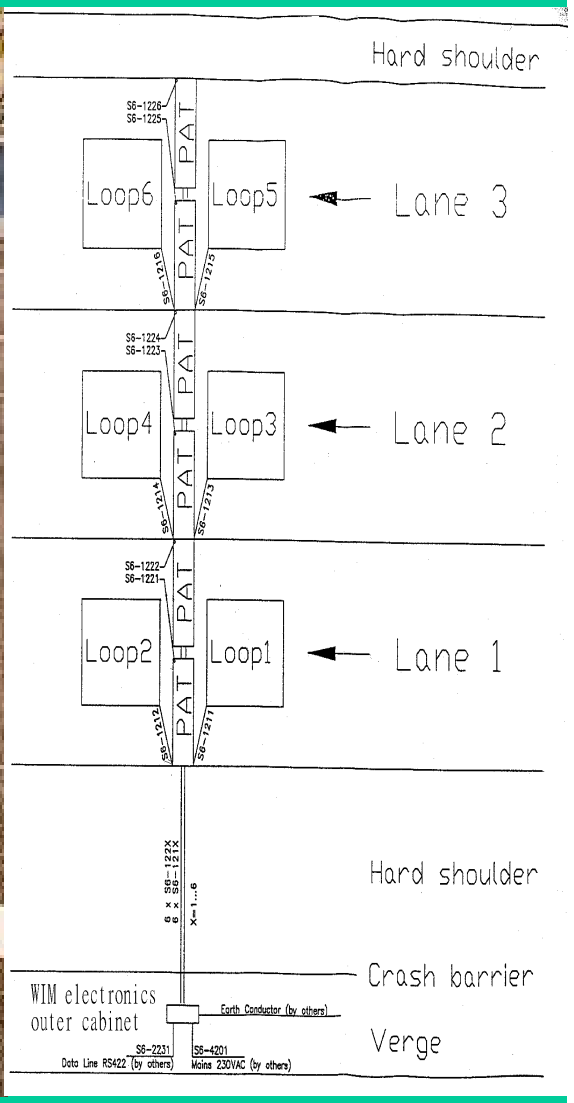
Detail of Accelerometers on Longitudinal Stabilizing Cable

Bi-axial Accelerometers on Longitudinal Stabilizing Cable of Ting Kau Bridge

Dynamic Weigh-in-Motion Sensors

Traffic Direction

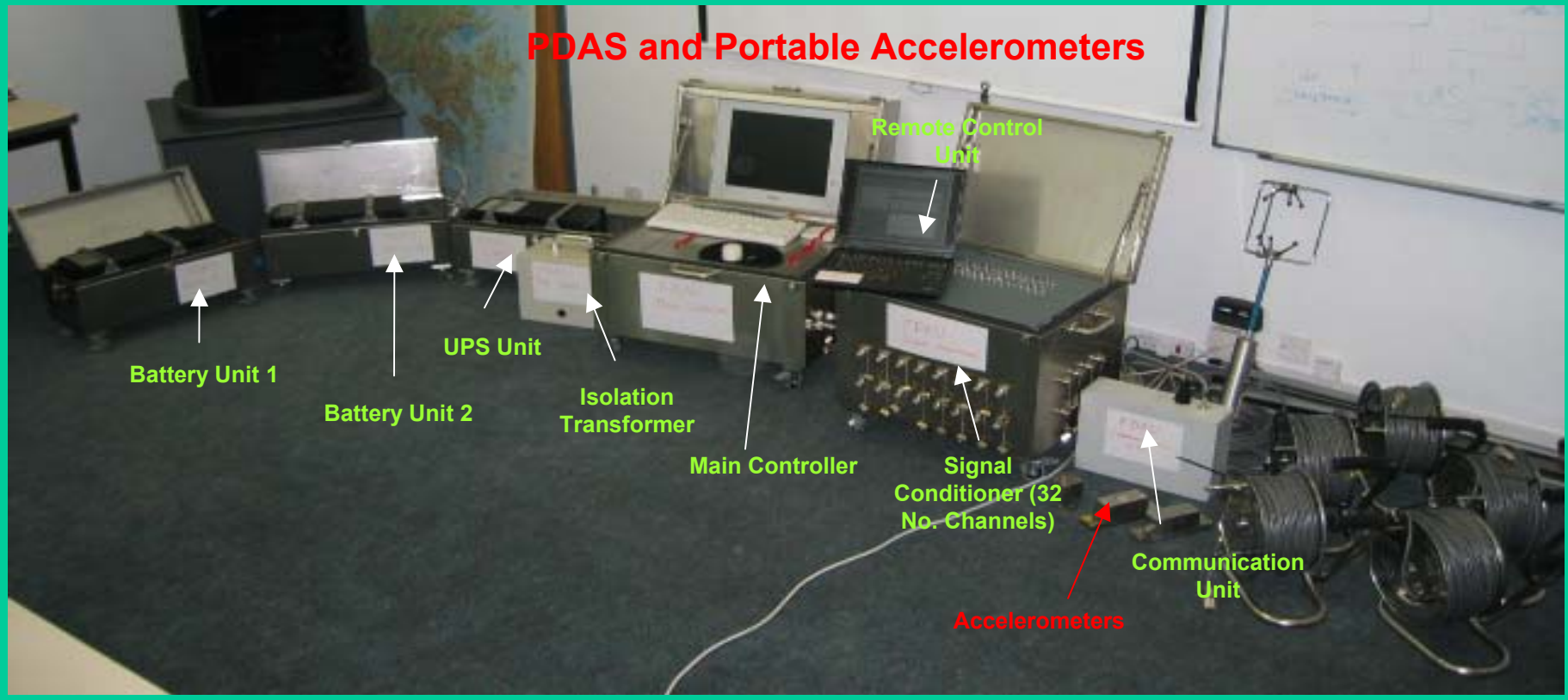




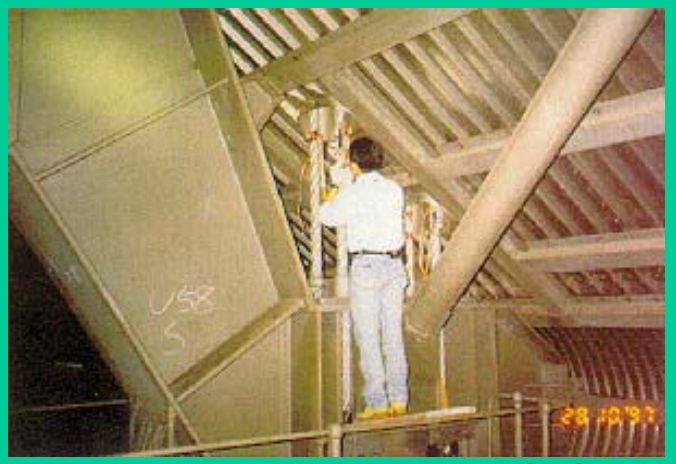
Dynamic Weigh-in-Motion Sensors for Lantau Fixed Crossing

Portable Data Acquisition System (PDAS)

PDAS and Portable Accelerometers



Field Measurement Works on Tsing Ma Bridge



Mounting Portable Accelerometers for Suspenders

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TSING MA CONTROL AREA DIVISION
BRIDGE HEALTH SECTION

Portable Data Acquisition System for Field Vibration Measurement Works

Data Processing and Control System (DPCS)

The DPCS in LFC-WASHMS & TKB-WASHMS

- One UNIX-Based 64-bit Alpha Server equipped with SPIDAR (Modified), Customized MATLAB Software and MATLAB Data Analysis Suite for overall control of SS and DAs in LFC-WASHMS
- One UNIX-Based 64-bit Alpha Server equipped with SPIDAR (Modified), Customized MATLAB Software and MATLAB Data Analysis Suite for overall control of Ss and DAS in TKB-WASHMS
- Two 32-bit SGI Intel-Based (Quad-CPU) Visual Workstations equipped GPS Monitoring Software and MATLAB Data Analysis Suite for overall control of GPS including processing, analysis, display, archiving and storage of GPS data and Video Signals from CCTV Cameras

Structural Health Evaluation System (SHES)

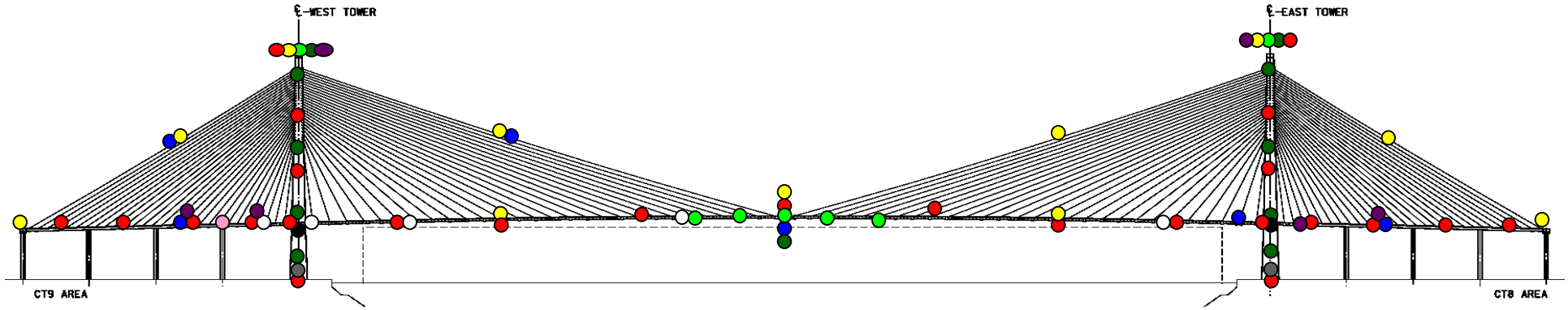
The SHES for LFC-WASHMS & TKB-WASHMS

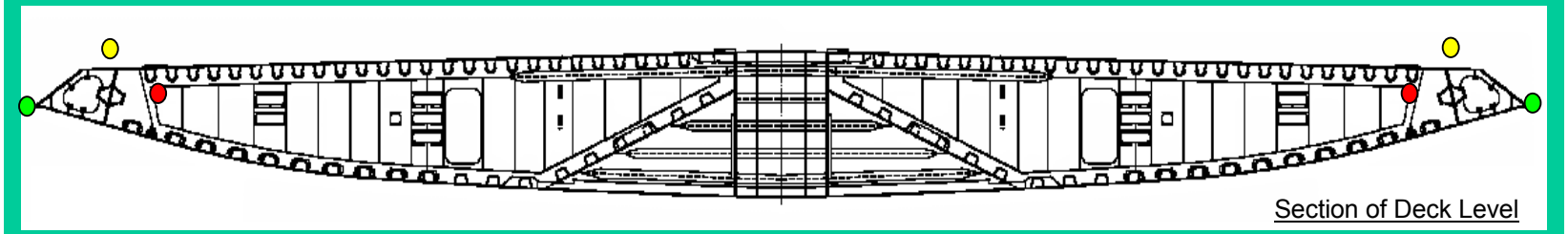
- **One 64-bit UNIX-Based (Quad-CPU) Alpha Server equipped with MSC/NASTRAN, ANSYS/Multiphysics, ANSYS/LS-DYNA, ANSYS/FE-SAFE, Structural Dynamic-Tools and MSC/PATRAN**
- **One 64-bit UNIX-Based (Dual-CPU) Alpha Server equipped with Customized SPIDAR and MATLAB Data Processing Software**
- **One 64-bit UNIX-Based Alpha Workstation equipped with MSC/PATRAN**

Part 4
Limitations of Current WASHMS

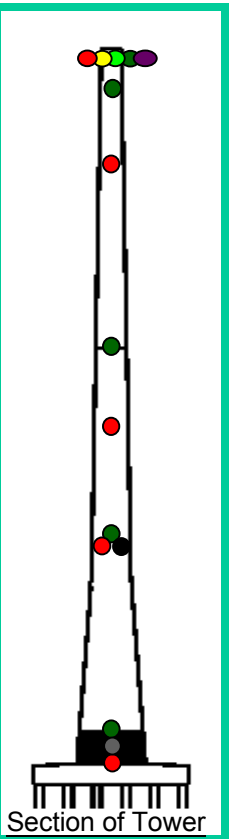
Limitations of Current WASHMS

- **No Corrosion Monitoring**
- **Insufficient Software Facilities for Automatic Data Processing and Analysis**
- **No Automatic Facilities for Correlation between Measured Results and Performance Criteria given in Bridge Rating System***
- **Insufficient Screens for Instant Display of Monitoring Results**





Section of Deck Level



Section of Tower

Accelerometer & Seismometer	48	Displacement Sensor	34
Anemometer	40	Strain Gauge	515
Temperature Sensor	388	Weigh-In-Motion Sensor	12
Temperature & Relative Humidity	28	Digital Video Cameras	16
GPS Sensor	20	Corrosion Cells	30

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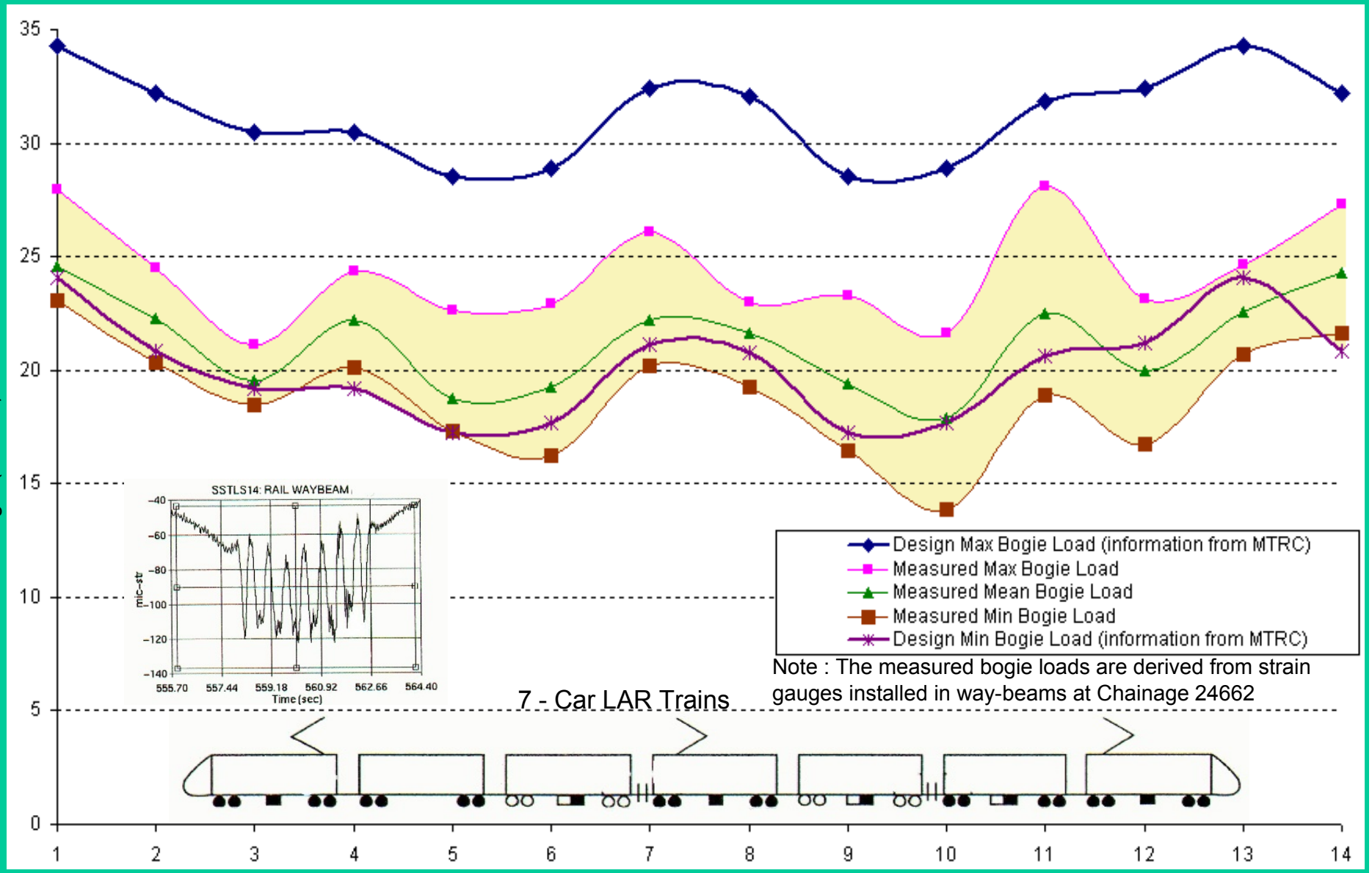
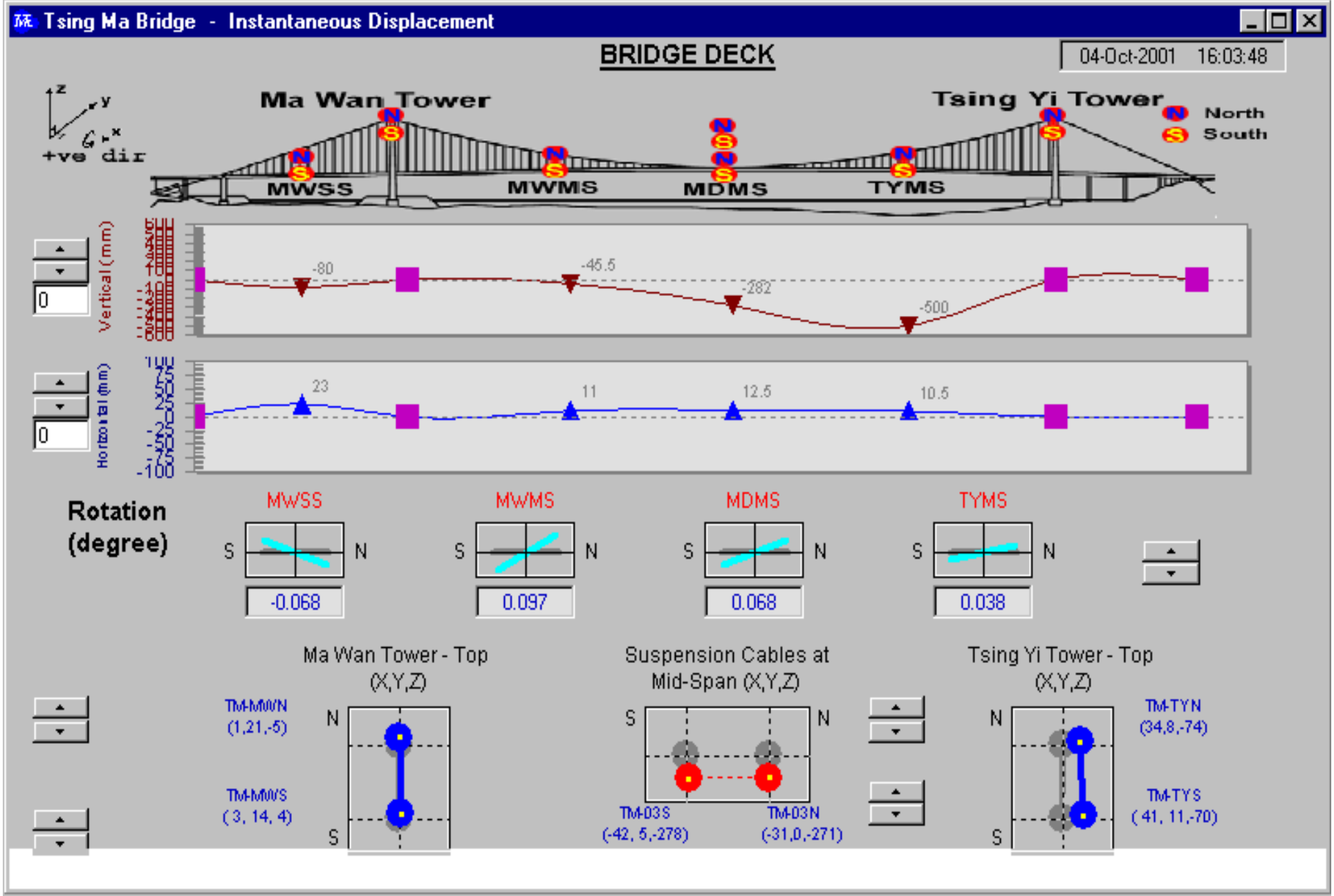
Stonecutters Bridge - Locations of Sensors



Tsing Ma Bridge – Comparison between Measured and Design Bogie Loads



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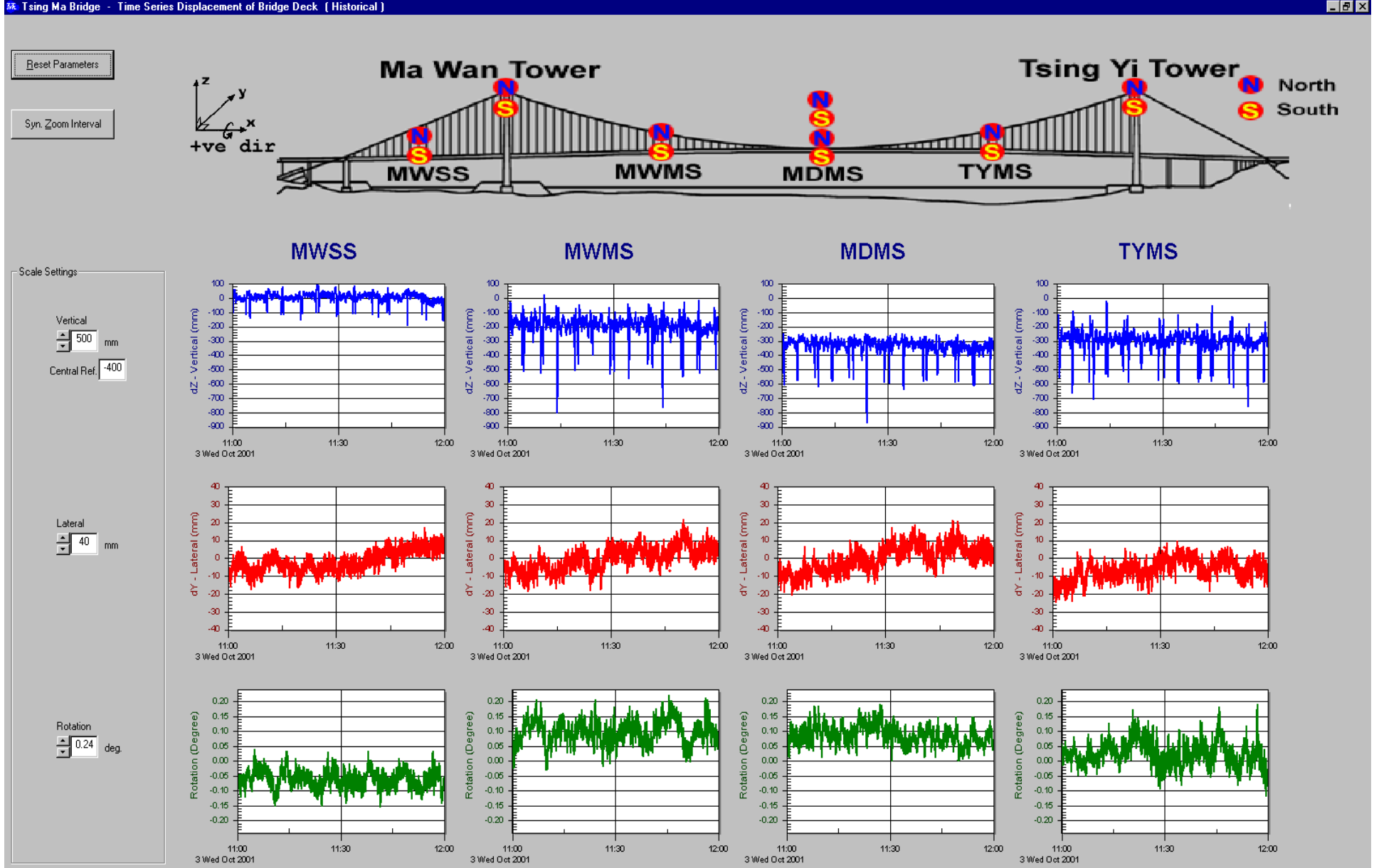
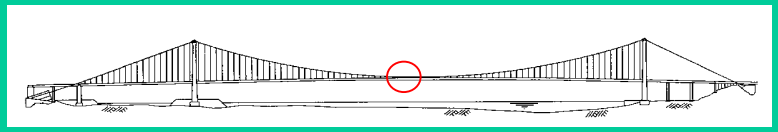
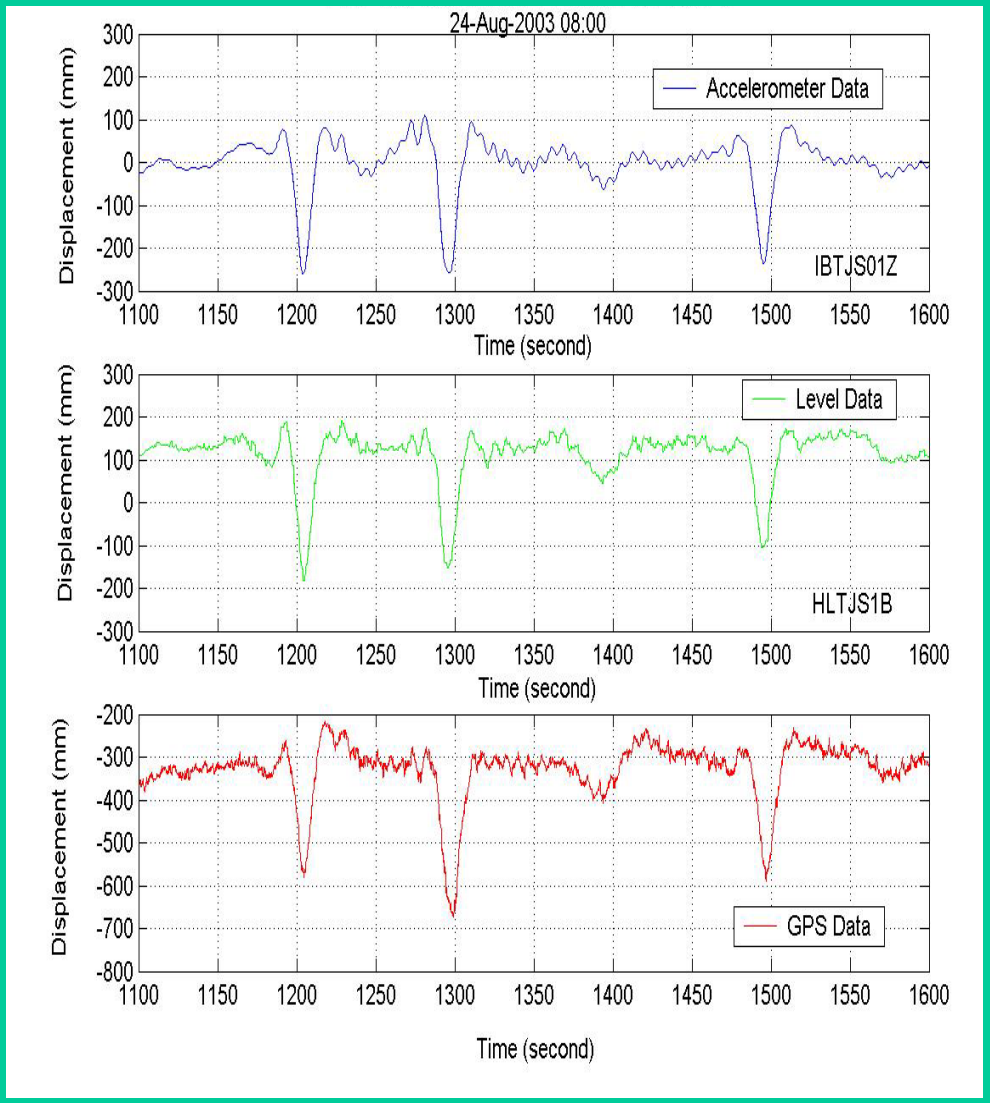
Screen Display of Instantaneous Displacement of Tsing Ma Bridge: Bridge-Deck, Suspension Cables and Tower-Tops



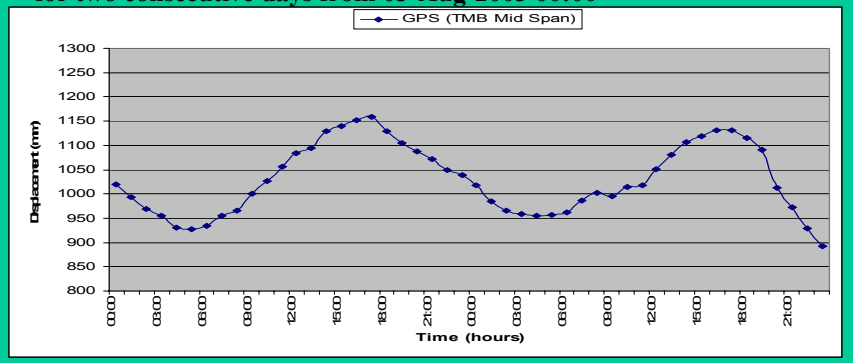
Screen Display of Time Series Displacement of Tsing Ma Bridge : Bridge-Deck

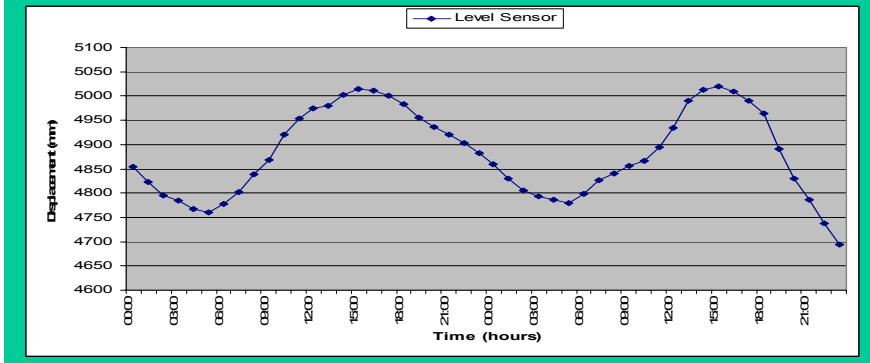


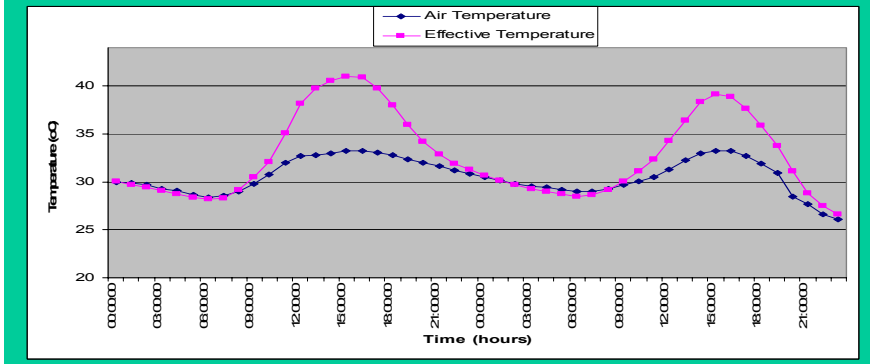
Comparison of Vertical Deck Displacement at TMB Mid-Span by GPS, Accelerometers and Level Sensor Measurement

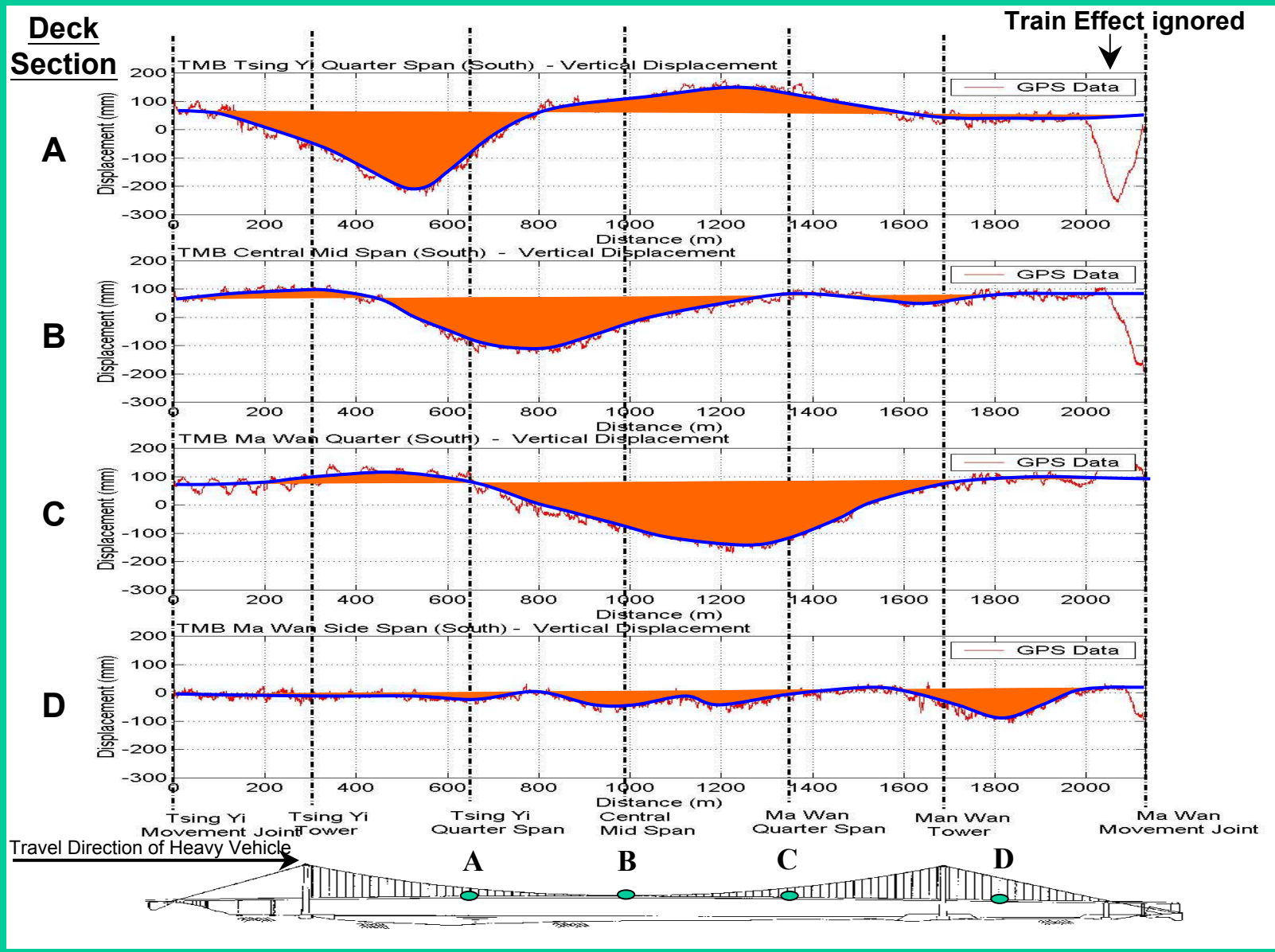


Comparison of Vertical Deck Displacement at TMB Mid-Span by GPS and Level Sensor Measurement with Temperature Variation for two consecutive days from 03-Aug-2003 00:00









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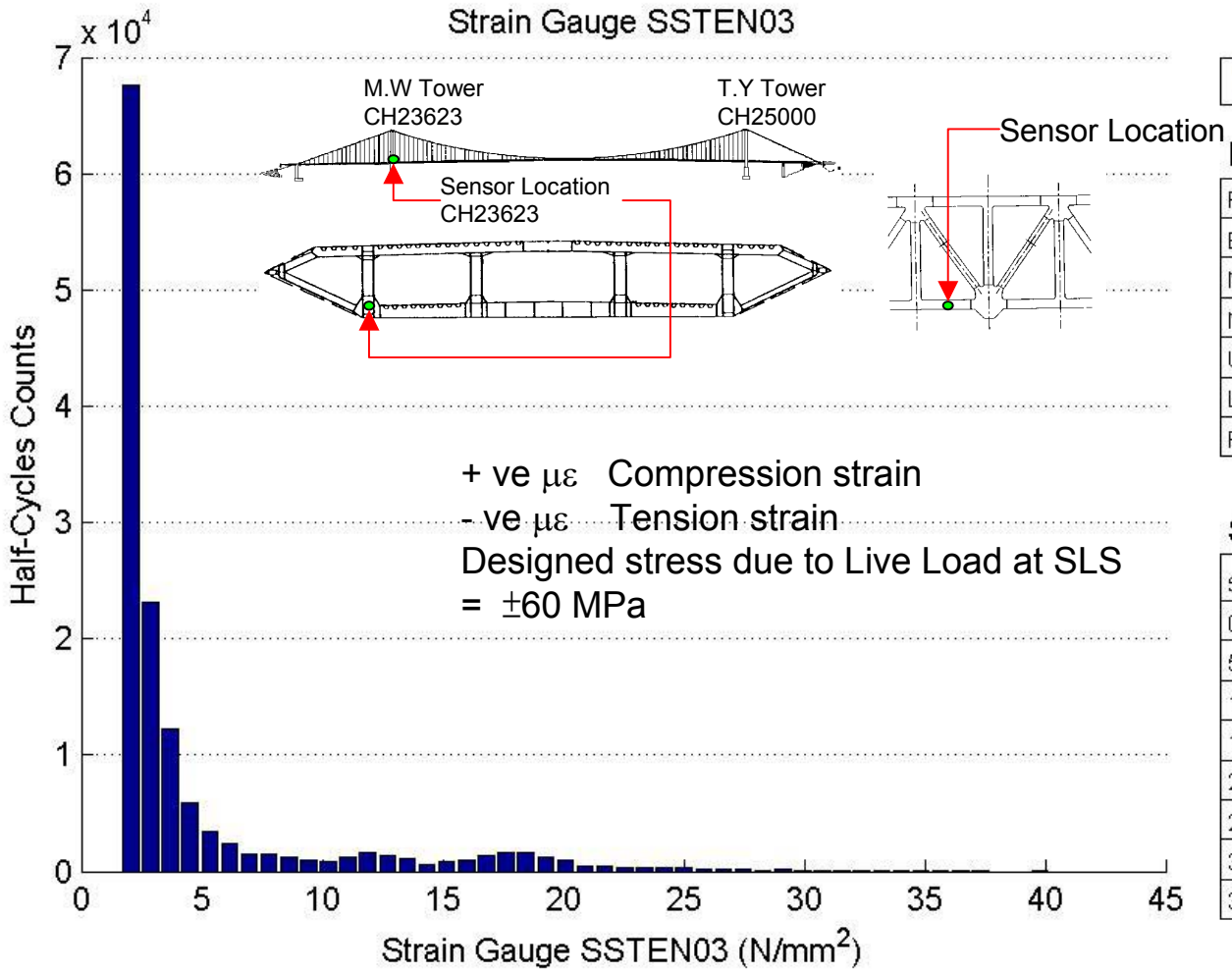
Tsing Ma Bridge - Deck Displacement Influence Lines by GPS

Histogram of Strain Half-Cycles

Results from: 01-Feb-2003 00:00 to 28-Feb-2003 23:00

Cycles from histogram data from SSTEN03.



Strain Gauge SSTEN03

Fatigue Damage Statistics

Fatigue Damage	30	micro-damage
Est Fatigue Life	2128	years
No. of Half-Cycles	138875	
No. of Hours	558	hours
Upper Valid Limit	500	micro-strain
Lower Valid Limit	10	micro-strain
Fatigue Class	F	

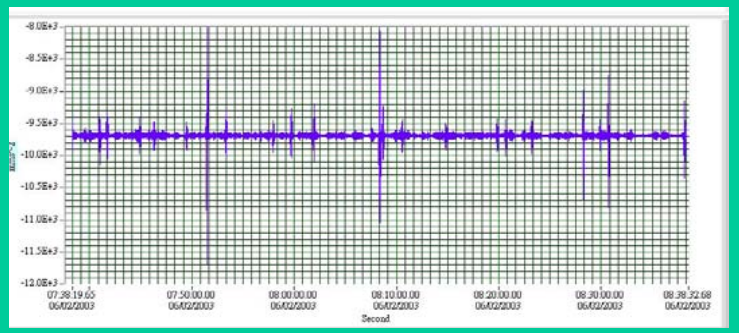
Stress Range Summary

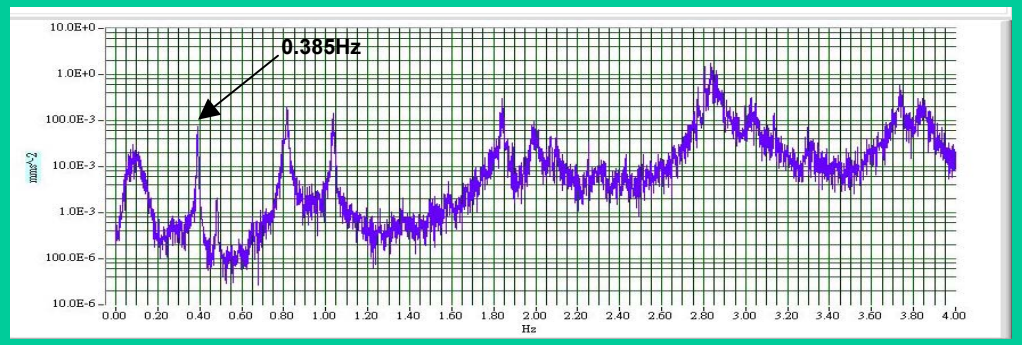
Stress Range (N/mm^2)	No. of Half-Cycles
0 to 5	109016
5 to 10	11056
10 to 15	6720
15 to 20	7681
20 to 25	2819
25 to 30	1230
30 to 35	326
35 to 40	27

Time-series acceleration data for points A1 and A2

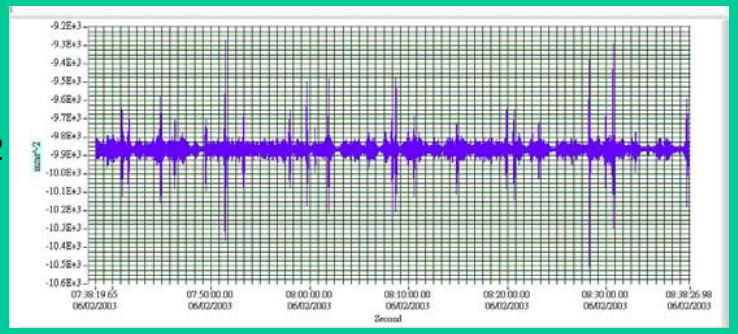
Auto power spectrum for points A1 and A2

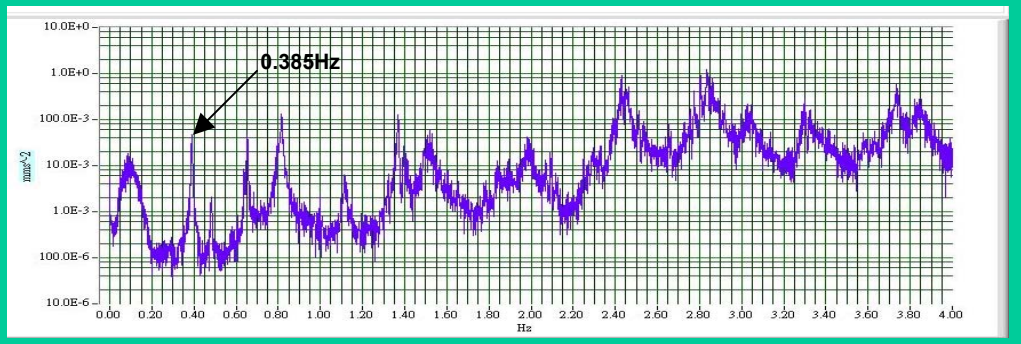
A1

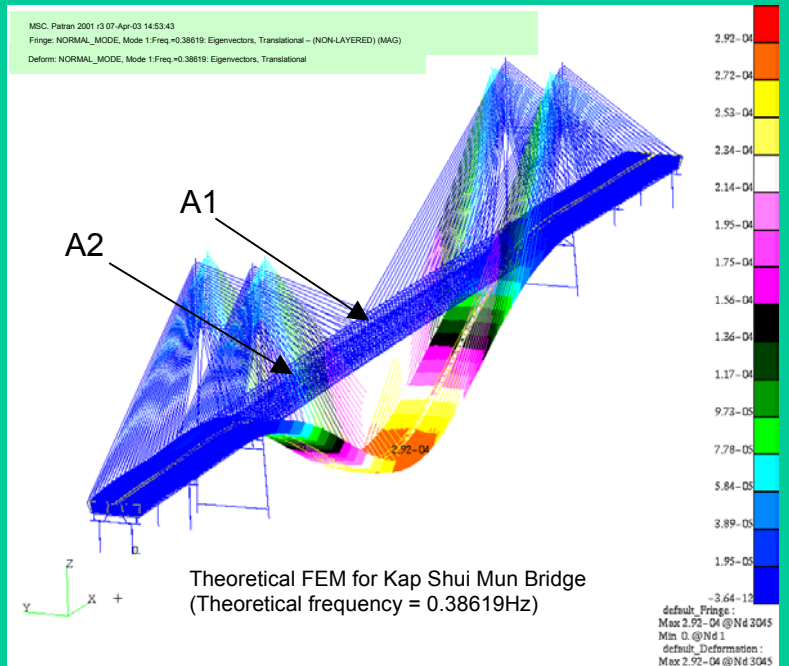




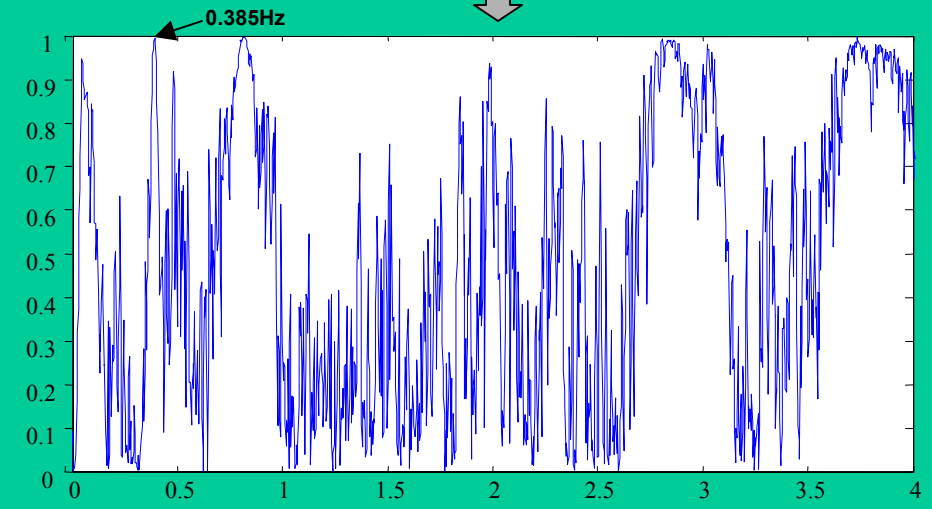
A2







Theoretical FEM for Kap Shui Mun Bridge
(Theoretical frequency = 0.38619Hz)



Coherence for points A1 and A2

Total No. of Grids = 10,914

Total No. of CBAR/ CBEAM = 24,234

Total No. of CQUAD4 = 42,906

Total No. of RBAR = 2,854

Modulus

$E_{cable} = 1.95 \times 10^{11}\ N/m^2$

$E_{steel} = 2.05 \times 10^{11}\ N/m^2$

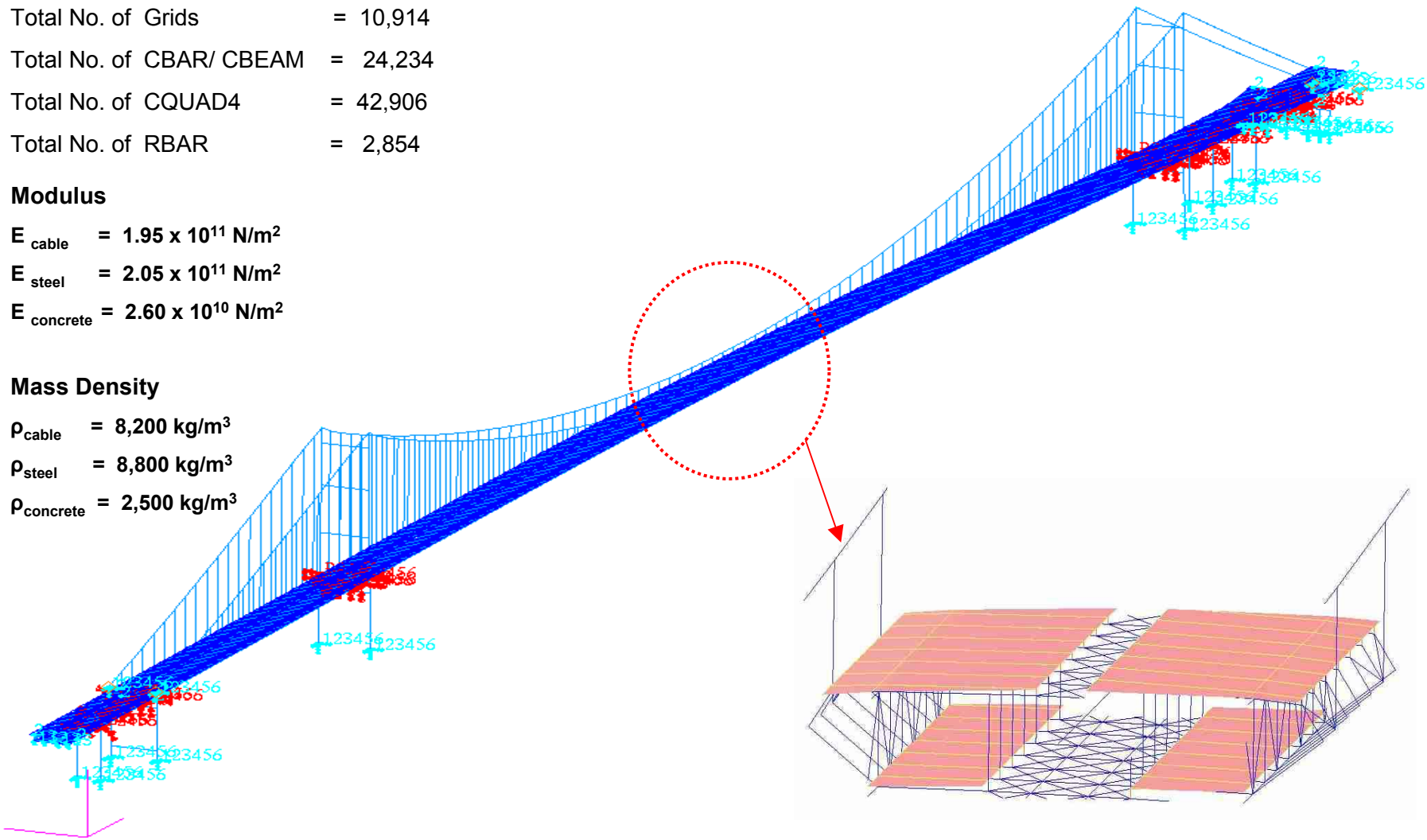
$E_{concrete} = 2.60 \times 10^{10}\ N/m^2$

Mass Density

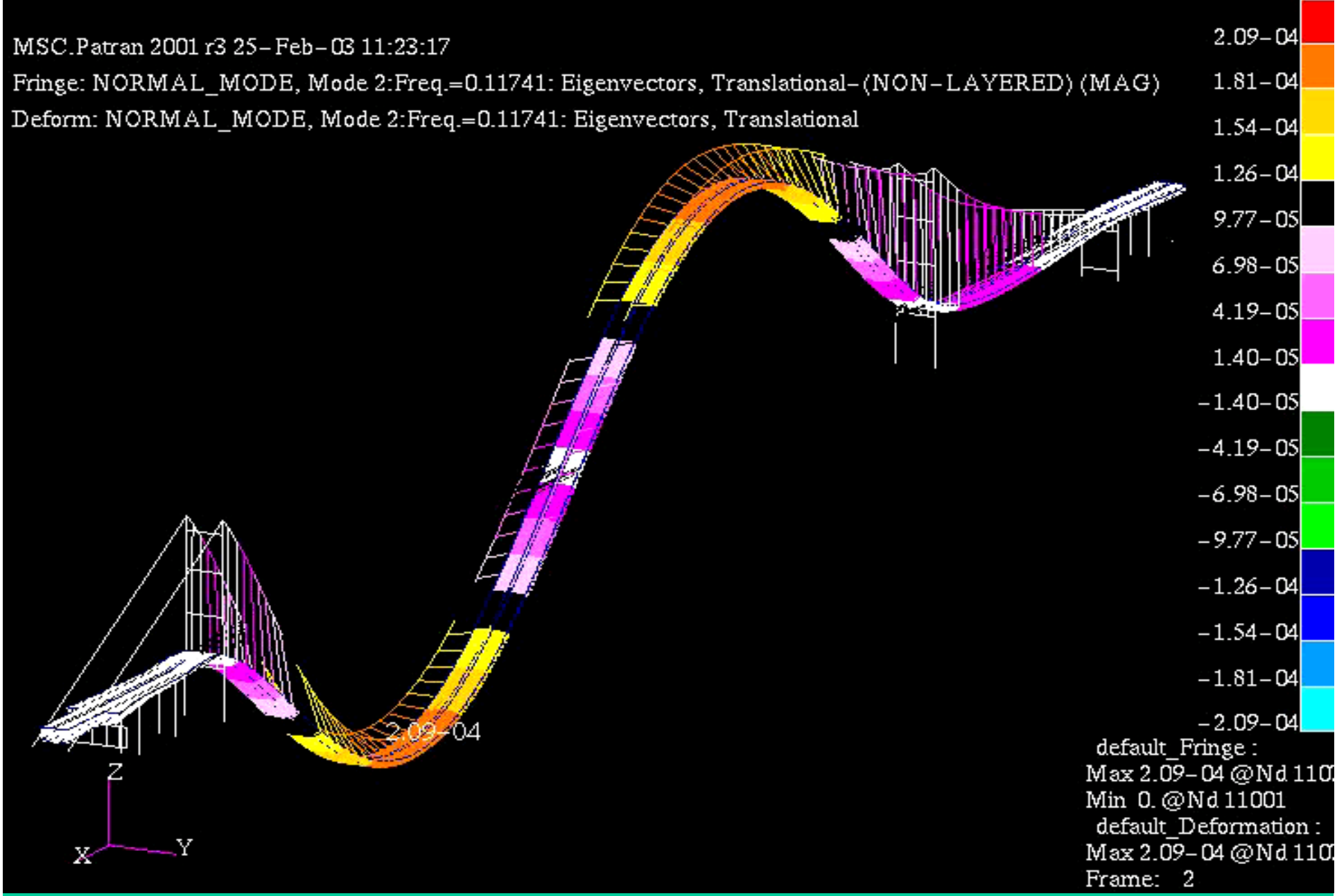
$\rho_{cable} = 8{,}200\ kg/m^3$

$\rho_{steel} = 8{,}800\ kg/m^3$

$\rho_{concrete} = 2{,}500\ kg/m^3$

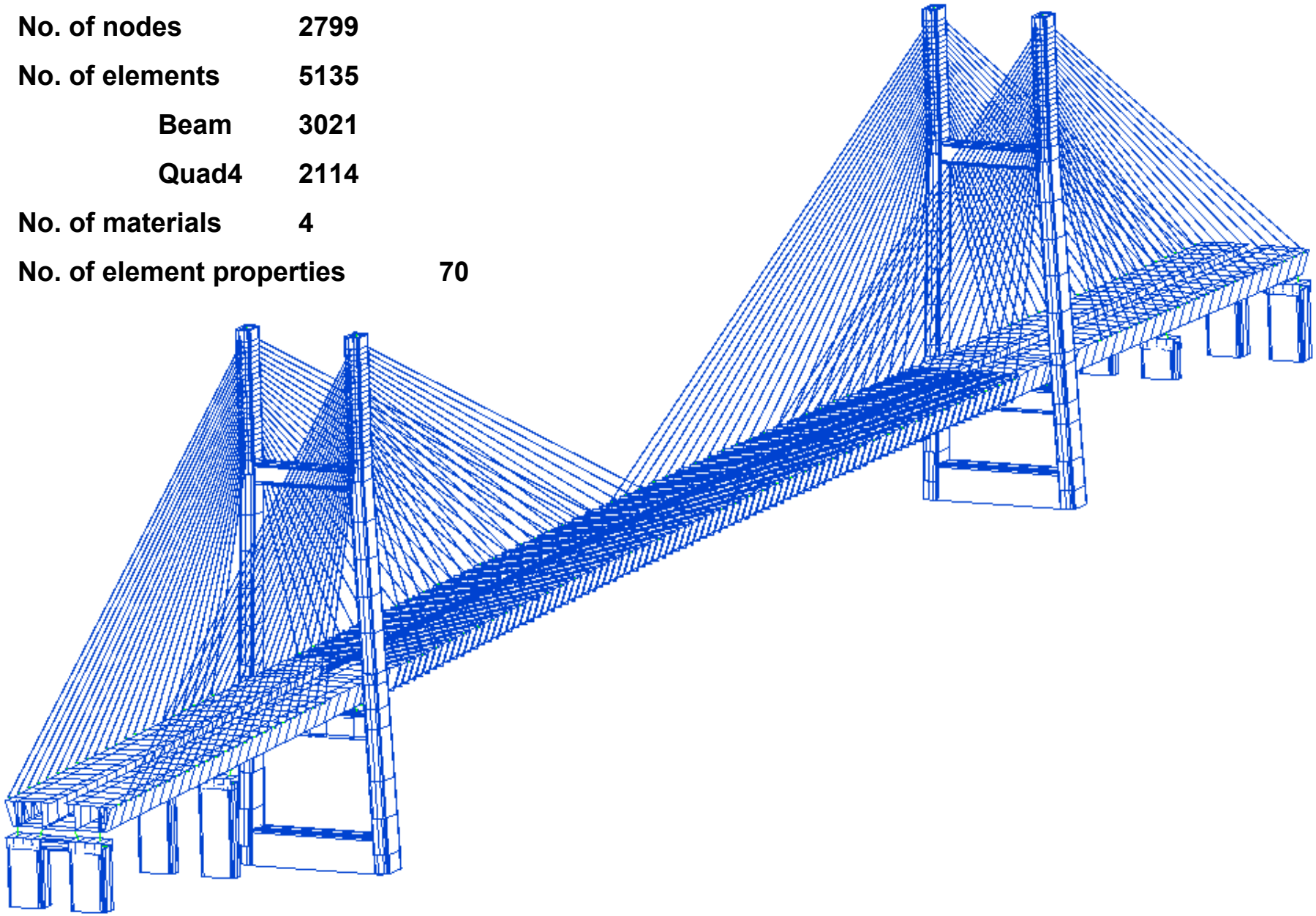


The Finite Element Model of Tsing Ma Bridge and List of Modelling Information



1st Vertical Flexural Deck and 1st Vertical Cable Mode
(Mode No. 2, Frequency = 0.11741 Hz)

No. of nodes	2799	
No. of elements	5135	
Beam	3021	
Quad4	2114	
No. of materials	4	
No. of element properties		70



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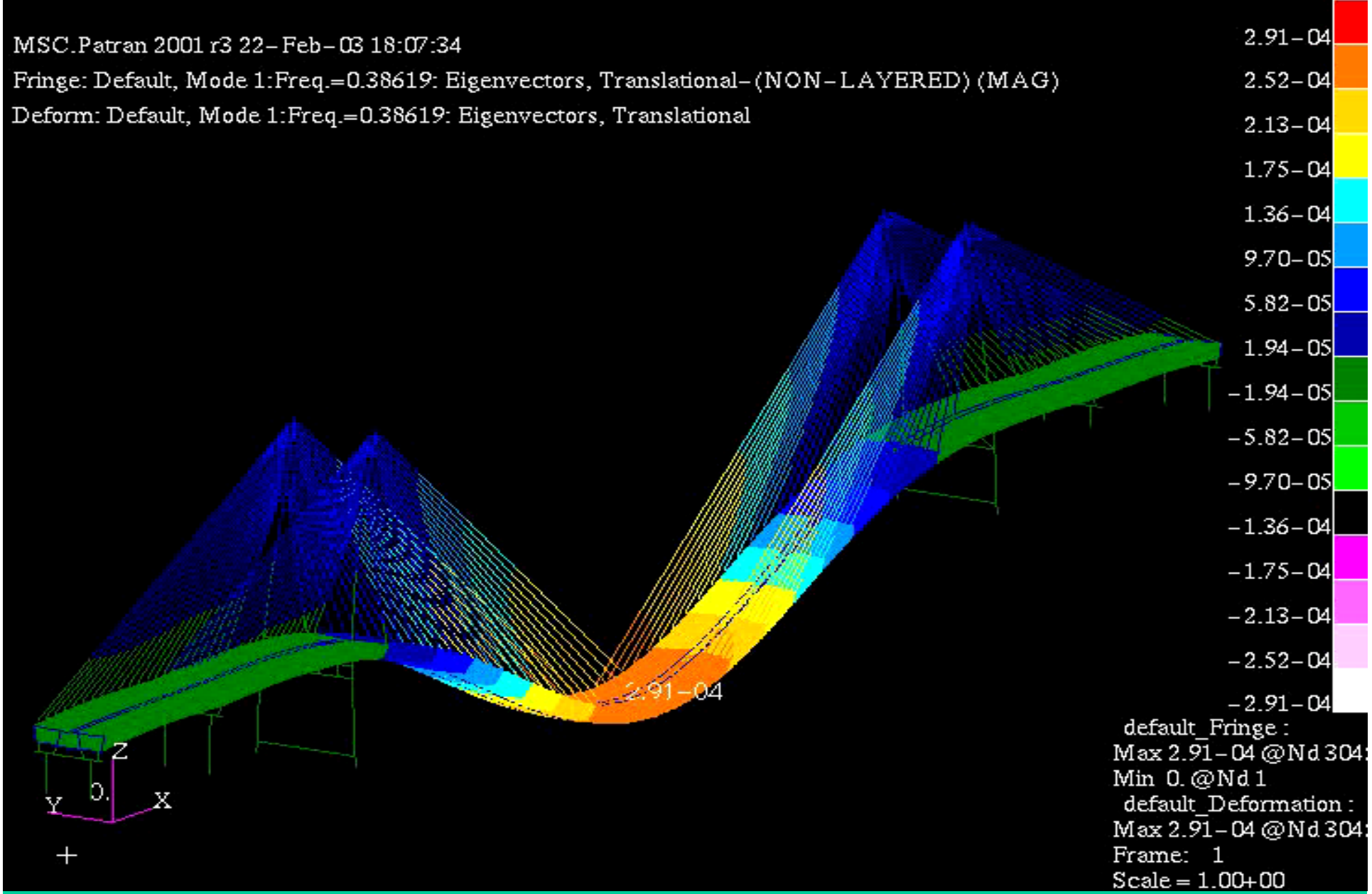
BRIDGE HEALTH SECTION

Finite Element Model of Kap Shui Mun Bridge



1st Vertical Flexural Deck
(Mode No. 1, Frequency = 0.38619 Hz)

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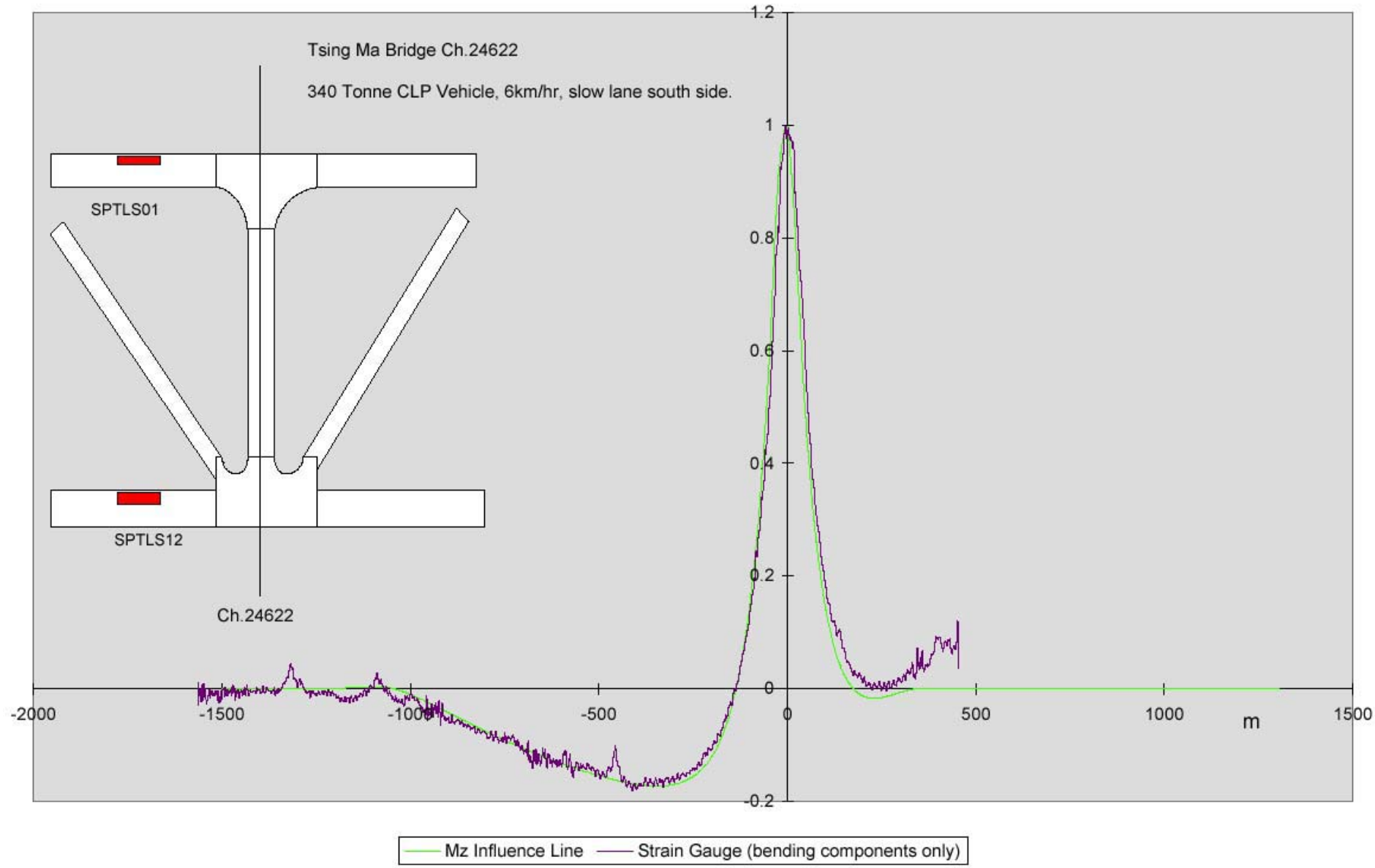
BRIDGE HEALTH SECTION


Tsing Ma Bridge Ch.24622
340 Tonne CLP Vehicle, 6km/hr, slow lane south side.
SPTLS01
SPTLS12
Ch.24622
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-2000
-1500
-1000
-500
0
500
1000
1500
m
Mz Influence Line
Strain Gauge (bending components only)

CONCLUSIONS

The WASHMS provides an effective and reliable means of bridge health evaluation which plays a key role in bridge maintenance and rehabilitation.