



APMP Mid-Year Meeting Technical Workshop_Automotive

The Analysis of Pole and Viaduct Structural Vibration Induced by High Speed Train

Transportation Safety with AV Metrology

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Center for Measurement Standards(CMS) / ITRI



工業技術研究院
Industrial Technology
Research Institute

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A BETTER FUTURE



Measurements in a Dynamic world

計量 動態世界的量測



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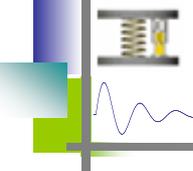
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Outline

- ◆ **Taiwan High Speed Rail**
- ◆ **Service Projects for Taiwan High Speed Rail**
- ◆ **Overhead Catenary System Wire Vibration**
- ◆ **Accelerometer Selection for Measurement**
- ◆ **Viaduct and Pole Dynamic Evaluation**
 - **Vibration measurement**
 - **Natural Frequency**
 - **Modal Analysis**
- ◆ **Measurement Results**
- ◆ **Conclusions**

Taiwan High Speed Rail (THSR)

- **Resolve the traffic jam problem.**
- **Shorten travel journey time.**
- **Breakthrough the economic bottleneck and increase investment.**
- **Offer job opportunities.**
- **Improvement of related industry output.**
- **Enhance transportation safety.**
- **.....**



Taiwan High Speed Rail (THSR)



Map of Taiwan High Speed Rail Line.

- ❑ The line opened for service on **5 January 2007**.
- ❑ THSR is a high-speed rail line that runs approximately **345 km** along the west coast of Taiwan.
- ❑ Trains running at a **top speed of 300 km/h**.
- ❑ There are **11** operational Stations now.
- ❑ About **120,000** ridership per day.
- ❑ Electrification **AC 25 kV/60 Hz catenary**.

Civil Works of THSR



viaduct

- Most of the line is carried on superstructures.
- About **251 km or 73 %** of the line runs on **viaducts**.
- About 61 km or 18 % of the line is in **tunnels**.
- About 33 km or 9 % of lines is **mound**.



tunnel

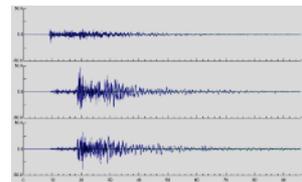


mound

Service Projects for THSR



Earthquake monitoring on post and bridge



Ground,
Post and
Bridge
Dynamic
Behavior

Electric
Switch
Vibration

Viaduct
and Pole
Vibration
Evaluation

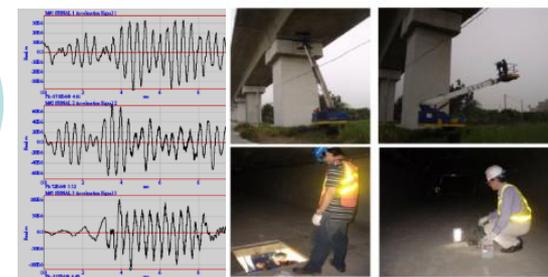


Verify the resonance
of viaduct and pole

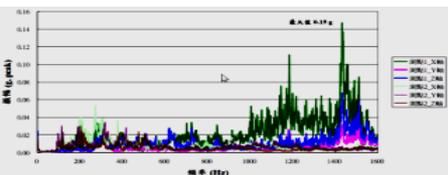
Transportation
Safety

Steel
Bridge and
Turnout
Vibration

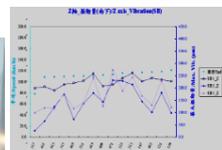
Bridge
and
Train
Vibration



Clarify relation between
bridge structure and train vibration



Clarify relation between
electric switch and vibration



Clarify dynamical signal between
steel structure and turnout



Overhead Catenary System Wire Vibration



bow collection



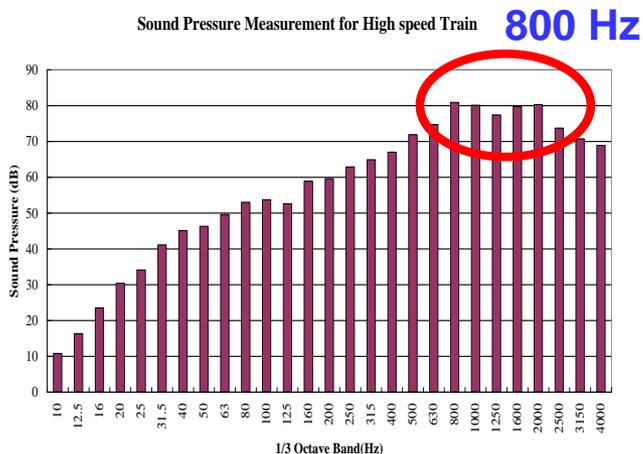
on site survey



C295

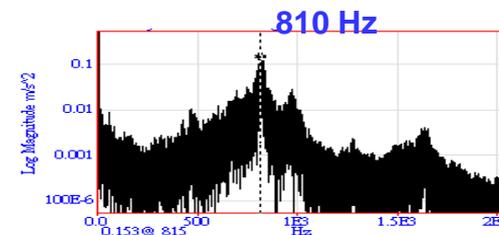
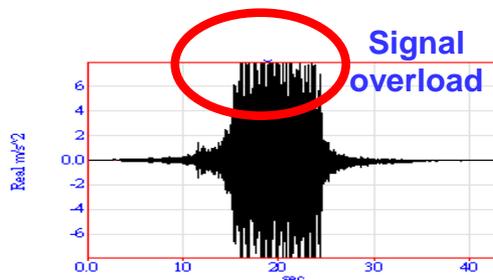
- During speed-up testing the vibration in the OCS were observed in the area of C 295 near Zuoying station.
- Curved Section with radius of 1317 m in C295.
- Long-term safety or function concern.

Accelerometer Selection for Vibration



Wheel-rail noise frequency spectrum of train passing by

- ◆ The swing vibration of an electric power wire belongs to **low frequency** vibration which **is less than 20 Hz**.
- ◆ Wheel-rail vibration induced by the high speed rail belongs to **wide and high frequency** range which is **more than 500 Hz**.



Vibration measurement result of Viaduct and Pole by WR 731A



suitable for viaduct and pole vibration measurement.

- Sensitivity: ($\pm 5\%$) 1 V/g
- Frequency Range: ($\pm 5\%$) 0.5 Hz to 2000 Hz
- Resonance frequency : 12 kHz



suitable for micro-vibration measurement.

- Sensitivity: ($\pm 5\%$) 10 V/g
- Frequency Range: ($\pm 5\%$) 0.5 Hz to 450 Hz
- Resonance frequency : 780 Hz

Viaduct and Pole Dynamic Evaluation

- **10** accelerometers mounted on different locations of viaducts and poles to measure vibration for three different speeds of **70 km/h, 120 km/h and 170 km/h.**



3-axis accelerometer

- A **high-sensitivity accelerometer** to measure environmental micro-vibration of viaducts and poles for getting the **natural frequency and damping ratio.**

Voltage Sensitivity : **10.0 V/g**, Frequency range($\pm 5\%$) : **0.1 Hz to 200 Hz**
Resolution(Broadband) : **1 μ g** (0.2 μ g)



- Applying a hammer and an accelerometer to proceed the **experimental modal testing** of pole for evaluating its motion behaviour.



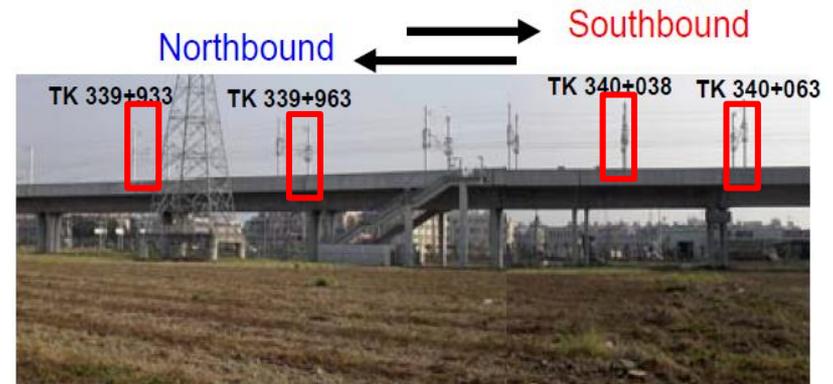
Vibration Measurement for Viaduct and Pole

◆ Measurement locations

Locations include 4 eastern poles and viaducts which are located at TK 339+933, TK339+963, TK340+038 and TK340+063.



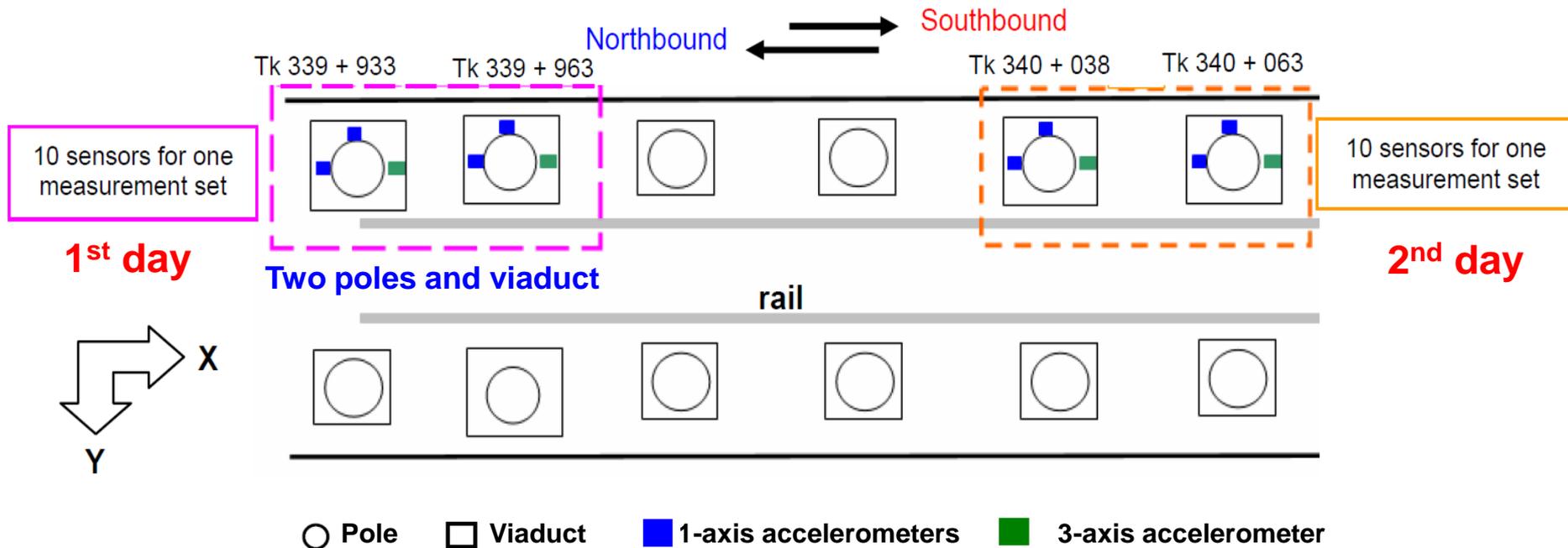
TK340 curved section



Measurement locations

Vibration Measurement for Viaduct and Pole

◆ Measurement directions and sensors arrangement



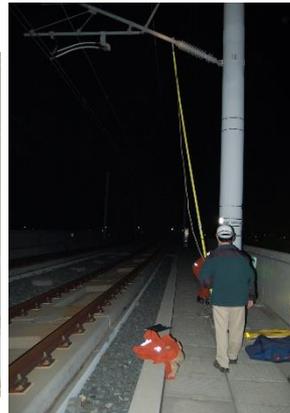
- 10 sensors for simultaneous vibration measurement of two poles and viaduct.
- X-direction of vibration measurement is parallel to the direction of rail.
- Y-direction is perpendicular to the rail.

Vibration Measurement for Viaduct and Pole

◆ Measurement preparation at night



Investigating the wire electric power



Mounting sensors on Pole



Cable connecting



Final check before running

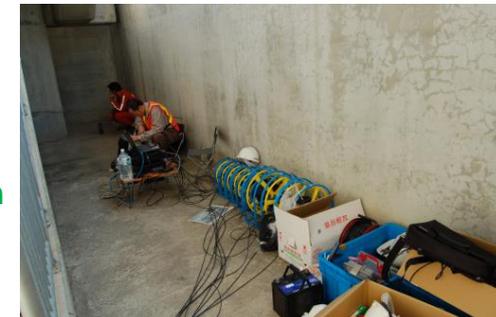


ring fixture



gypsum

Sensors on the viaduct and pole



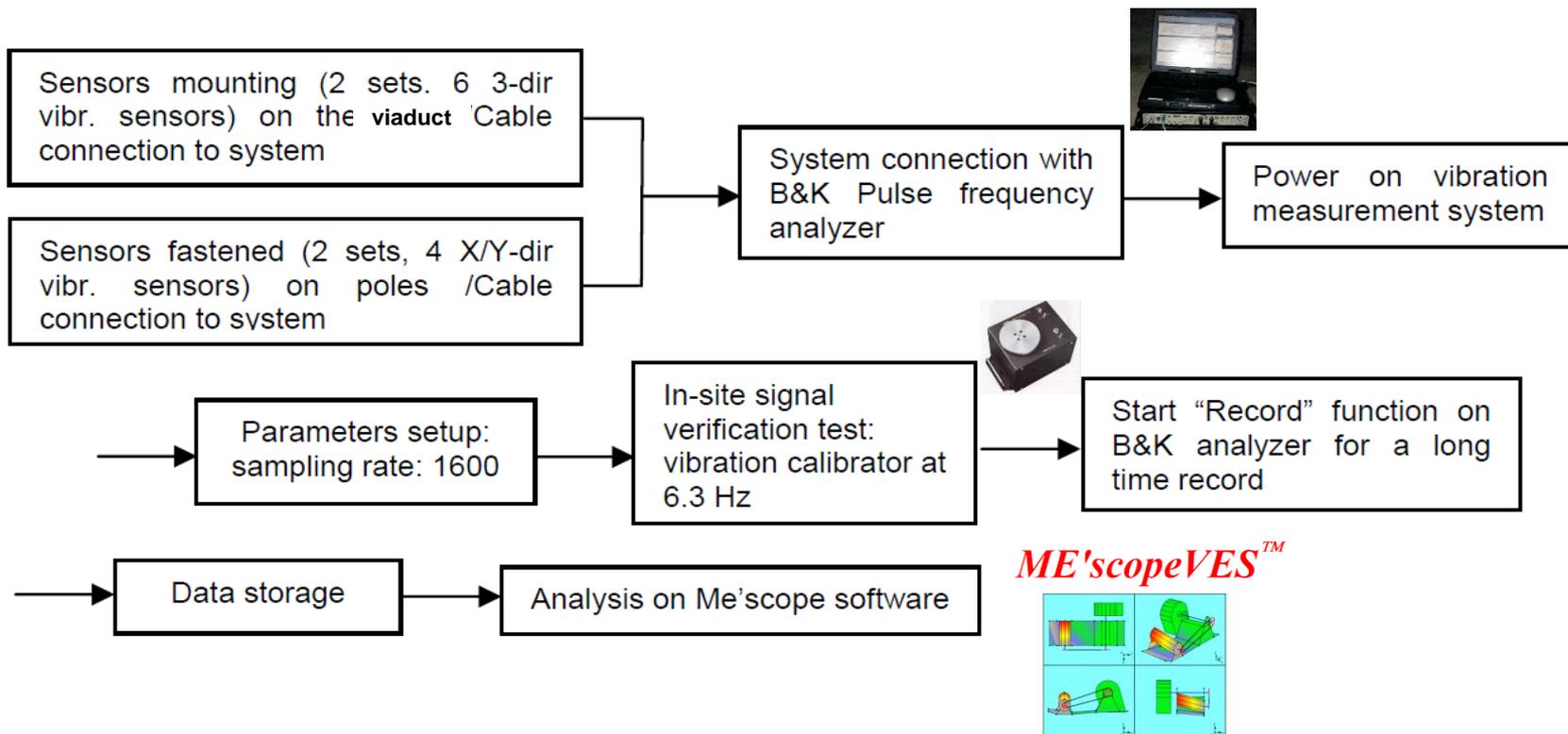
Signal recording system

Vibration Measurement for Viaduct and Pole

◆ Measurement Time

Measurement time is from 08:00 A.M. to 10:00 P.M. **19 trains** ran southbound and northbound **at 3** different speeds.

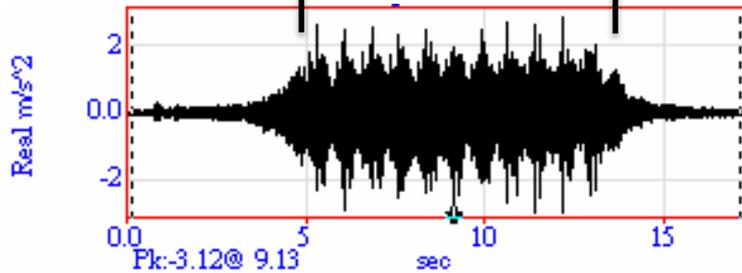
◆ Measurement procedures



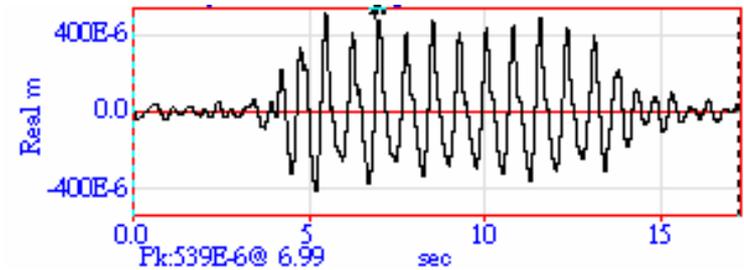
Vibration Measurement for Viaduct and Pole

◆ Measurement and Analysis Methods

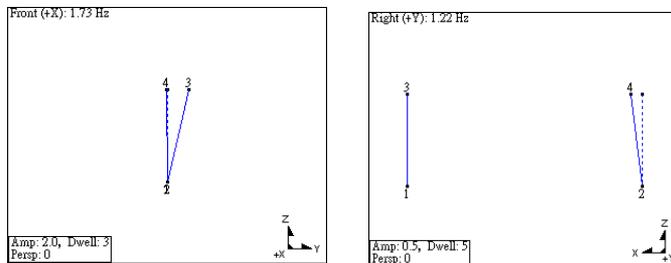
before passing by | train passing by | after passing by



Acceleration time history signal



Displacement time history signal



Animation between poles and viaduct



Frequency domain signal

- Maximum displacement of viaducts and poles is obtained from the time domain data.
- The dominant frequencies can also be obtained from the frequency domain.
- Animated vibration mode is simulated between viaducts and poles.

Natural Frequency test for Viaduct and Pole



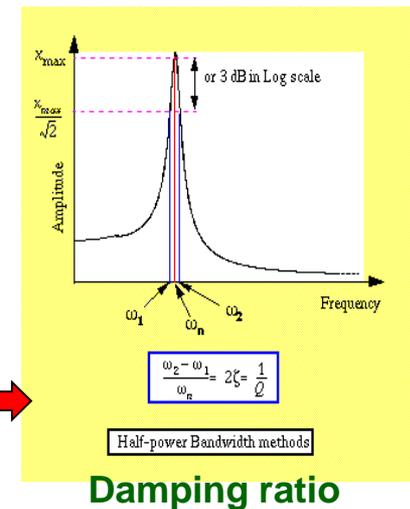
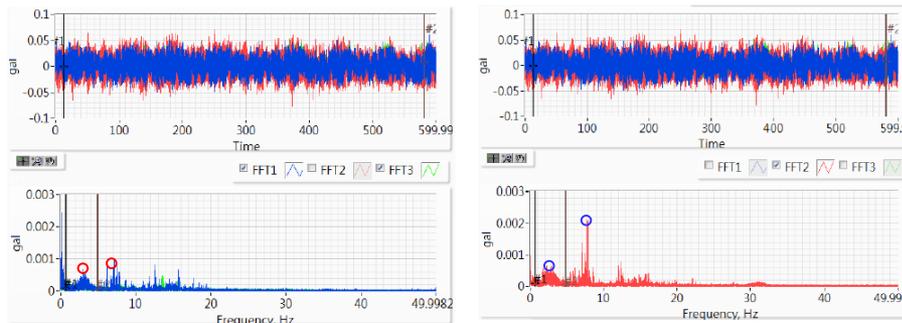
Sensors mounting position for natural frequency measurement

- Exciter or hammer is a good exciting source but not suitable for viaducts and poles.
- Background vibration is wide band vibration signals and can excite the characteristics of structures at night.
- A higher sensitivity sensors are used for measurement and natural frequencies are shown from peak vibration signals in frequency domain.

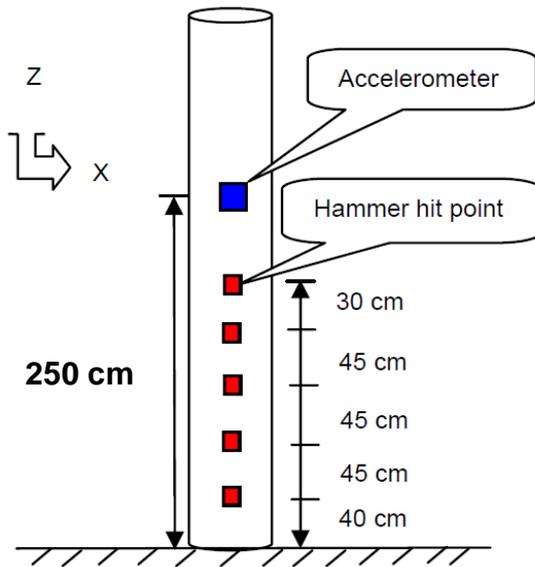
Time domain data



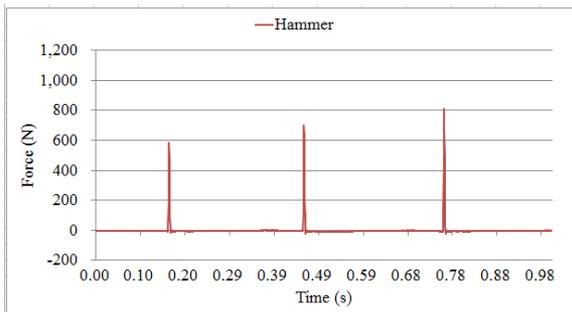
Frequency domain data



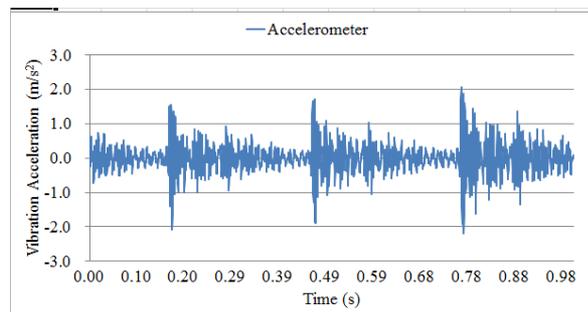
Modal Analysis for Pole's Vibration



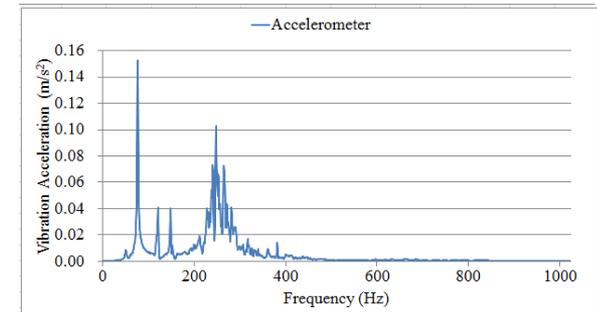
- Understanding natural frequencies in **Y direction** and vibration modes.
- A hammer is used to hit **5** different positions on the pole.
- An accelerometer is mounted on **250 cm** height from viaduct to measure their response signals.
- Signals input to **Me'scope** analysis software to calculate poles' natural frequencies and modes.



Force time signal



Accelerometer time signal



Accelerometer frequency signal

Measurement Results

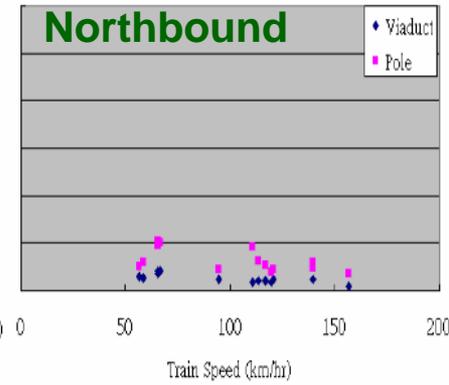
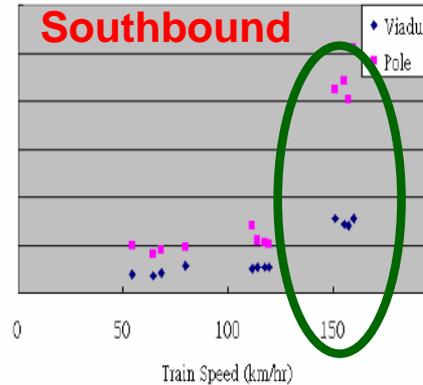
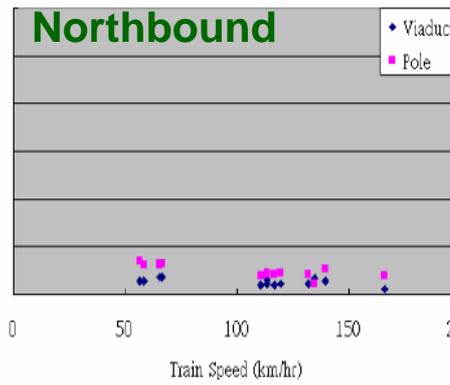
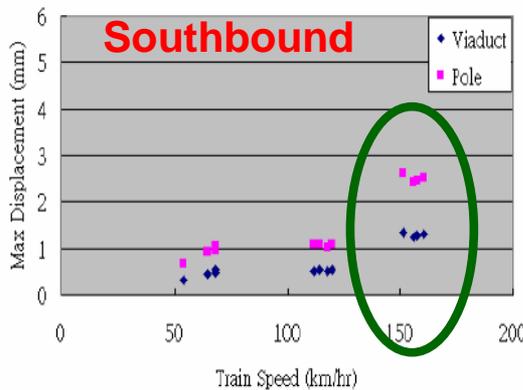
➤ Vibration measurement results for trains passing with different speeds

Southbound - Train Speed vs. Max. Displacement @ TK339+933

Northbound - Train Speed vs. Max. Displacement @TK399+933

Southbound - Train Speed vs. Max. Displacement @TK399+963

Northbound - Train Speed vs. Max. Displacement @TK399+963

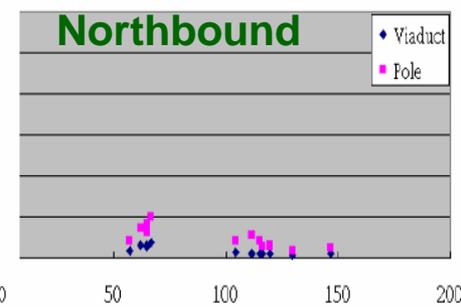
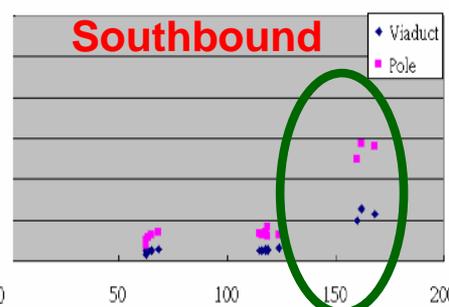
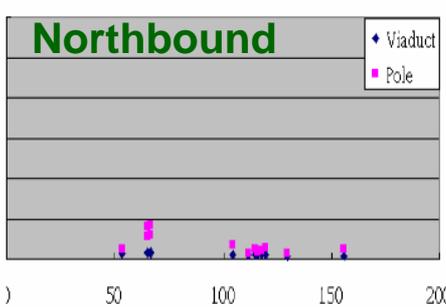
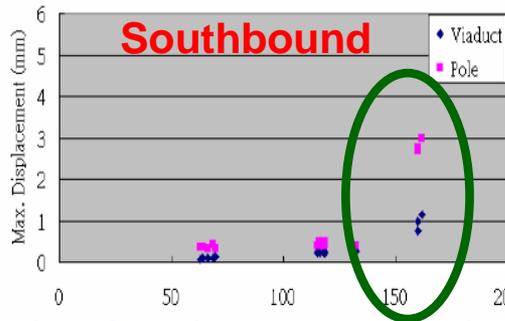


Southbound - Train Speed vs. Max. Displacement @TK340+038

Northbound - Train Speed vs. Max. Displacement @ TK340+038

Southbound - Train Speed vs Max. Displacement @TK340+063

Northbound - Train Speed vs. Max. Displacement @ TK340+063

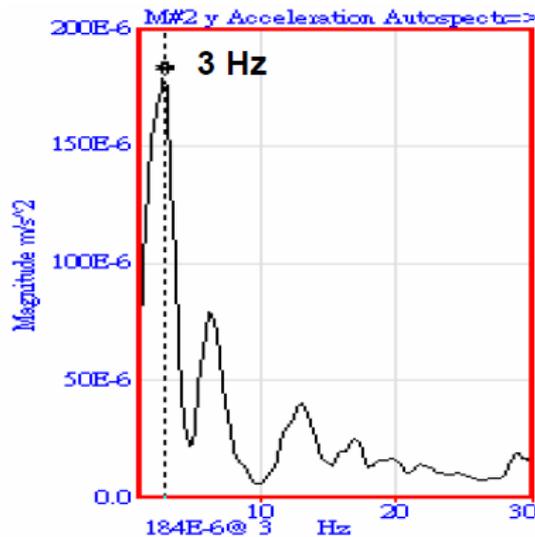


Vibration displacement for viaduct and pole of train running southbound or northbound with different speeds at different location

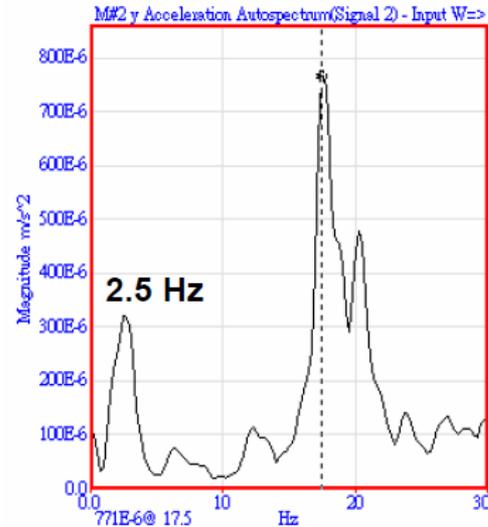
- ❑ Poles' vibration is 2 to 4 times higher than viaduct's vibration.
- ❑ Vibration of trains running **southbound is higher** running northbound especially at speed of **150 km/hr to 170 km/hr.**

Measurement Results

- Natural frequency measurement for viaducts and poles at night



TK 339+933 Viaduct

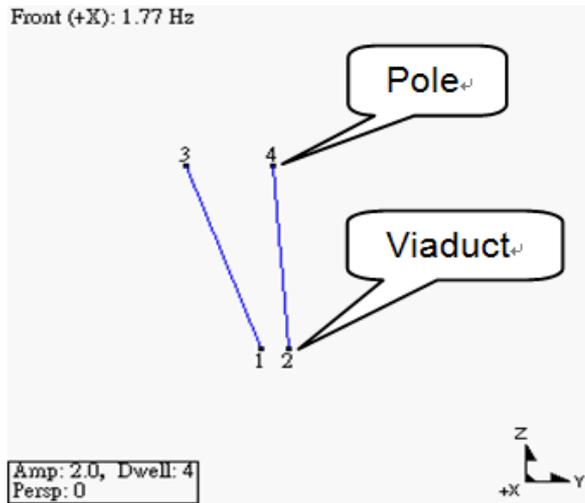


TK 339+933 Pole

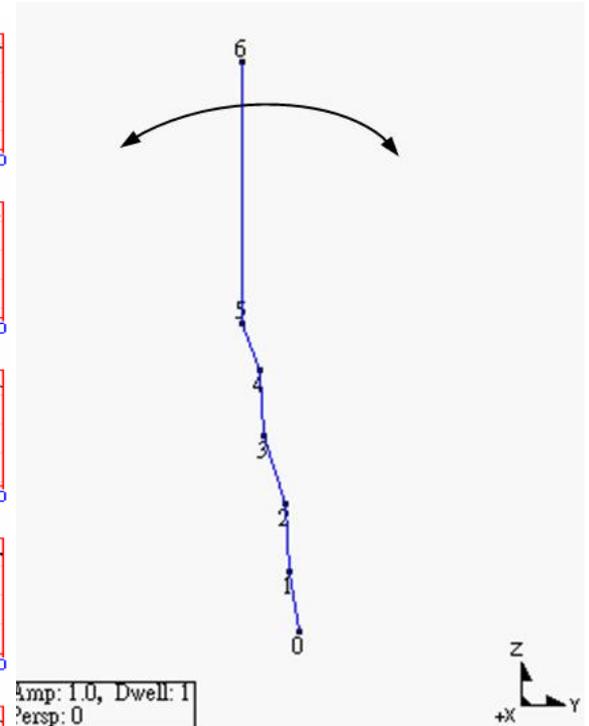
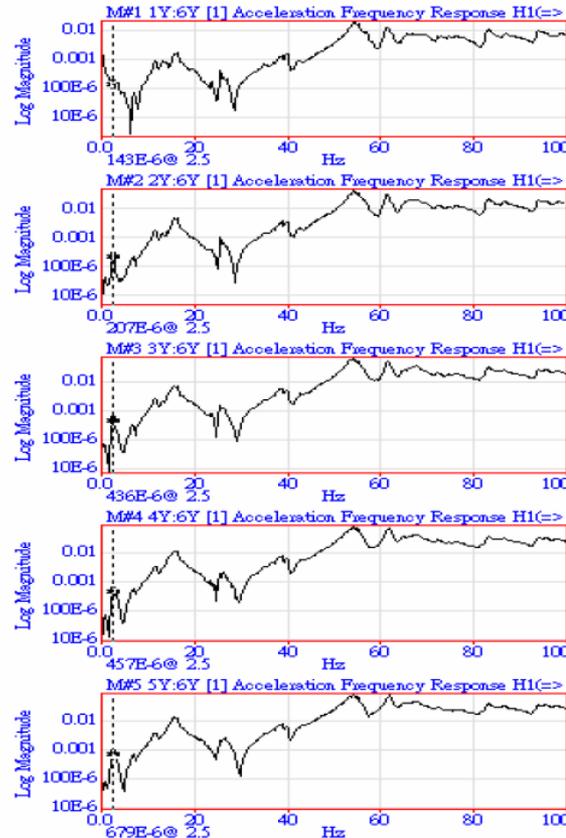
Location Position	TK339+933		TK339+963		TK340+038		TK340+063	
	viaduct	pole	viaduct	pole	viaduct	pole	viaduct	pole
direction Y	3	2.5	2.25	2.25	2	2.5	2.75	2.25

Measurement Results

➤ Measurement results of TK340+038 pole for its simulation analysis



The motion animation of viaduct and pole

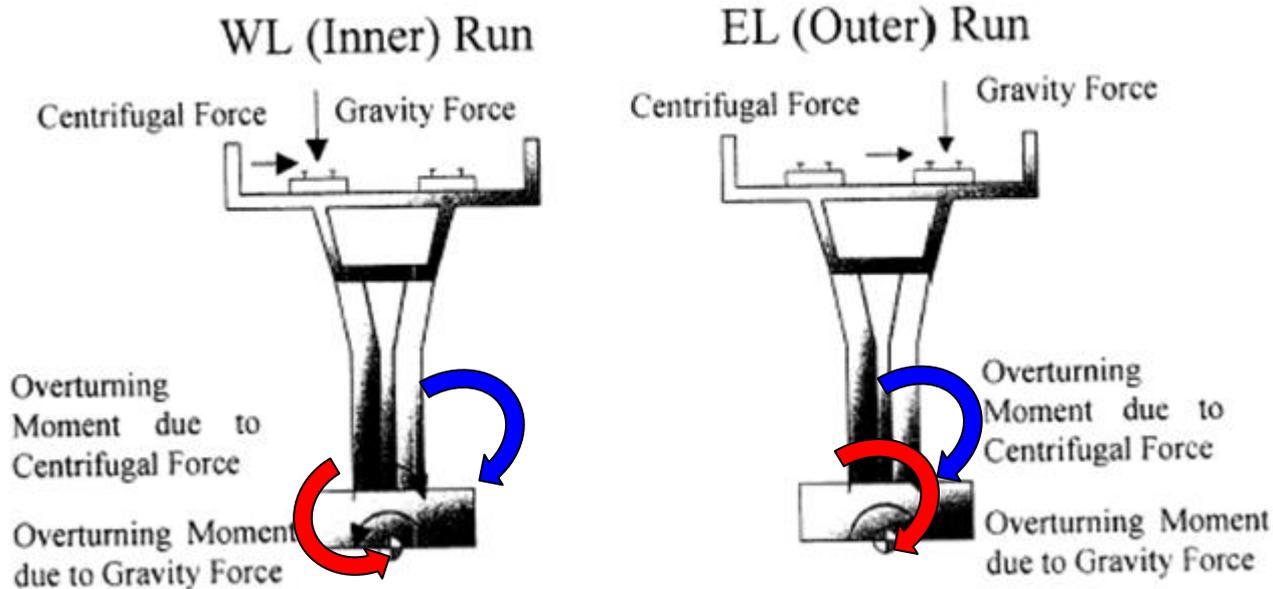


Pole's vibration behaviour

- Hitting on **5 different points** to get acceleration frequency response function.
- Using Me'scope software to sketch the whole pole structure.
- The first simulated natural frequency is **at 2.5 Hz** close to **background measurement**.

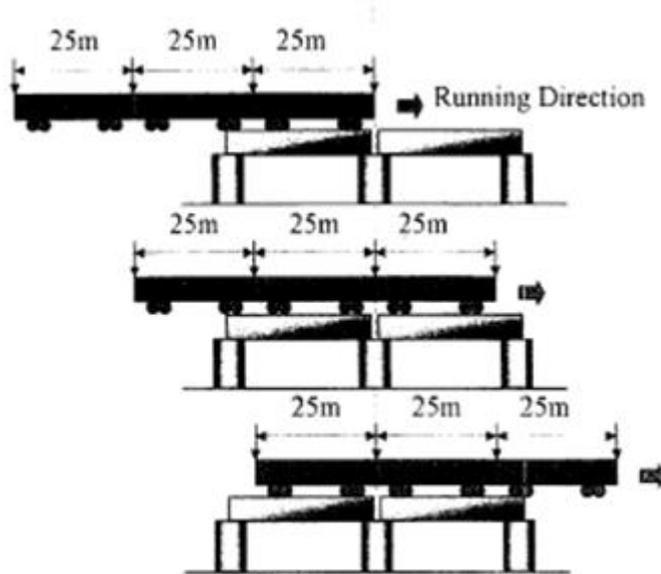
Conclusions

- ❑ Vibration from **southbound trains is higher than northbound.**
- TK340 is a curved section, a moment and higher vibration are generated on the viaduct by the **weight of the train and its centrifugal force.**



Conclusions

- The major reason for wire vibration is a resonance occurred because the frequency 1.9 Hz, generated by trains passing, is close to the natural frequency of the viaduct.
- Fundamental running train lowest frequency is based on car length(25 m).



Item	Value
Velocity (m/s)	$v = 170\text{km/h} = \frac{170 \times 1000}{60 \times 60} = 47.2\text{m/s}$
Time to run 25m	$t = \frac{25\text{m}}{47.2\text{m/s}} = 0.53\text{s}$
Frequency (Hz)	$f = \frac{1}{0.53\text{sec}} = 1.89\text{Hz}$

Conclusions

- Vibration induced by trains **at 150 km/hr to 170 km/hr** is much higher than at other speeds.
- Trains **decelerating** could reduce the vibration and electric wire swinging.



Thanks for Attention

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