APMP TCAUV Workshop

The application of acoustics, vibration and ultrasound metrology in transportation industry

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

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Date : 2016.05.31

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 opportunity.
- Improve 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 passengers per day.**
- **Electrification AC 25 kV/60 Hz catenary.**

Civil Works of THSR

viaduct

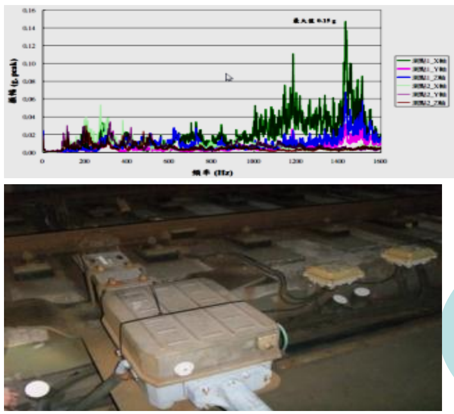
- Most of the line is carried on superstructures.
- About 251 km or 73% of the line runs on viaducts.
- About 61 km or 18% of the line is in tunnels.
- About 30 km or 9 % of lines is embankment.

tunnel

embankmen

Service Projects for THSR

Earthquake monitoring on post and bridge



Clarify relation between electric switch and vibration

Ground, Post and Bridge Dynamic Behavior

Viaduct and Pole Vibration Evaluation

Bridge and Train Vibration

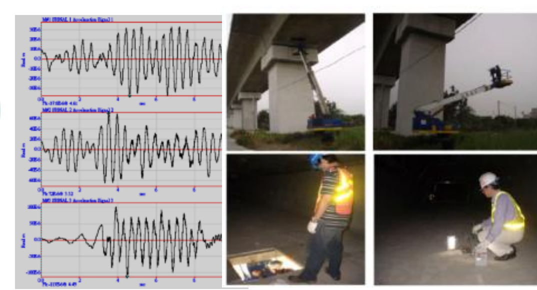
Steel Bridge and Turnout Vibration

Electric Switch Vibration

Dynamic signal evaluation for Transportation Safety

Verify the resonance of viaduct and pole

Clarify dynamical signal between steel structure and turnout



Clarify relation between bridge structure and train vibration

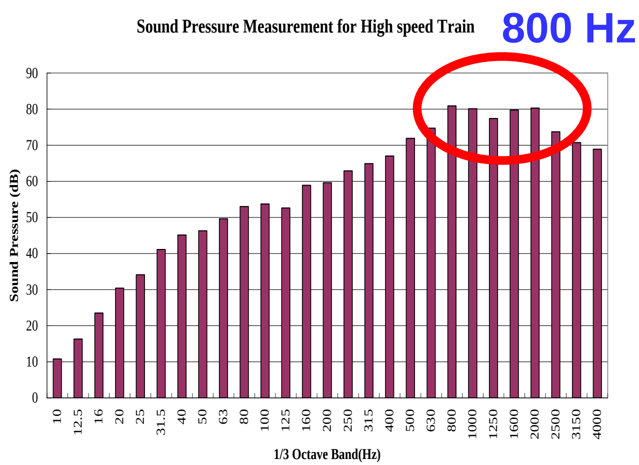
Overhead Catenary System Wire Vibration

bow collection

on site survey

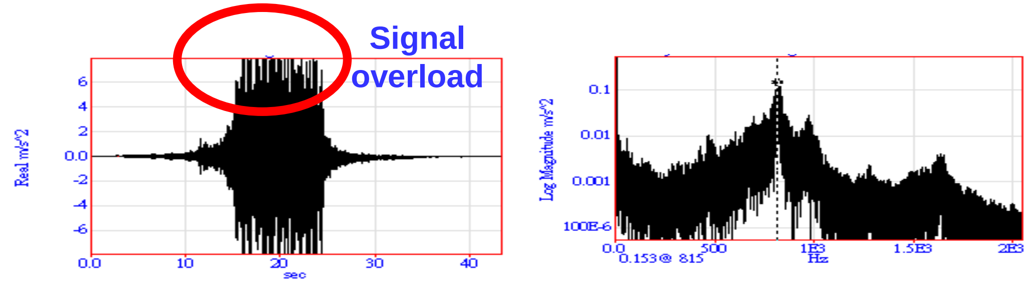
- During speed-up testing the vibration in the OCS were observed in the area of C 295 near Zuoying station.
- Curved Section with radius of 1317 m in C295.
- Long-term safety or function concern.

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 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

- **Sensitivity: (± 5%) 1 V/g**
- **Frequency Range: (± 5%) 0.5 Hz to 2000 Hz**
- **Resonance frequency 7000 Hz**

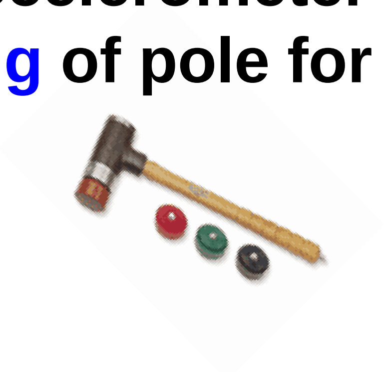
- **Sensitivity: (± 5%) 10 V/g**
- **Frequency Range: (± 5%) 0.5 Hz to 450 Hz**
- **Resonance frequency 750 Hz**

Viaduct and Pole Dynamic Evaluation

- 10 accelerometers mounted on different locations of viaducts and poles to measure vibration induced by high speed train which with three different speeds of 70 km/h, 120 km/h and 170 km/h.

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

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



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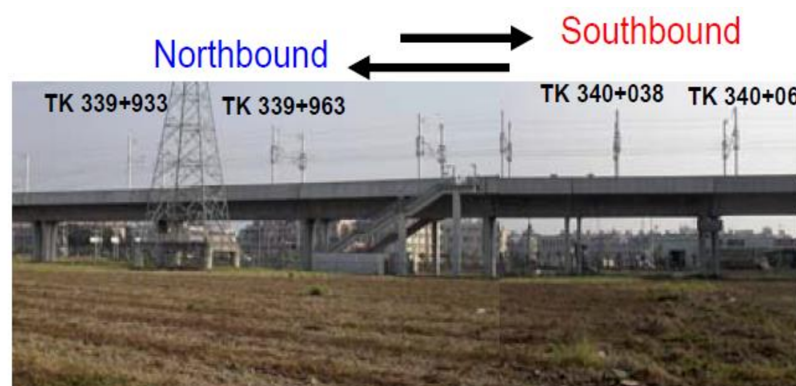
Vibration Measurement for Viaduct and Pole

◆ Measurement locations

Locations include 4 eastern poles and viaducts which are located at TK 339+933, TK339+963, TK340+038 andTK340+063.

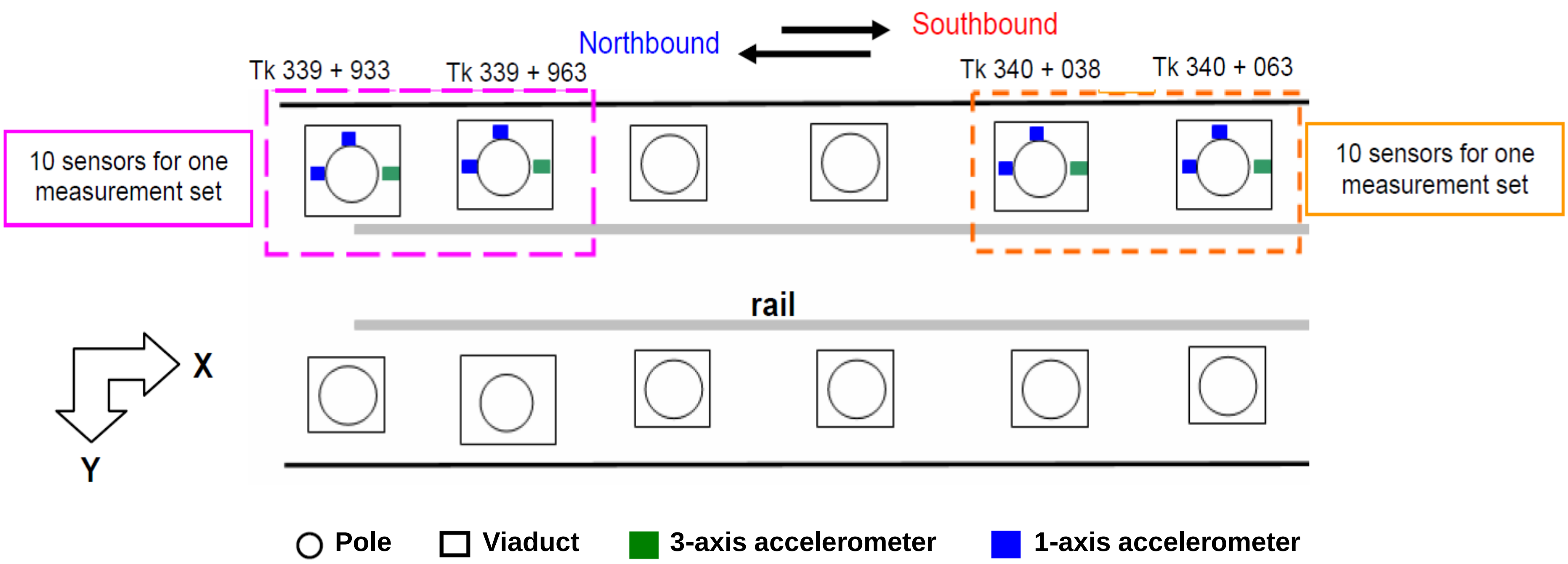
TK340 curved section



Measurement locations

Vibration Measurement for Viaduct and Pole

◆ Measurement directions and sensors arrangement



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

Mounting sensor on Pole

Cable connecting

Final check

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

Sensors mounting (2 sets, 6 3-dir vibr. sensors) on the floor /Cable connection to system

Sensors fastened (2 sets, 4 X/Y-dir vibr. sensors) on poles /Cable connection to system

→ System connection with B&K Pulse frequency analyzer

→ Power on vibration measurement system

→ Parameters setup: sampling rate: 1600

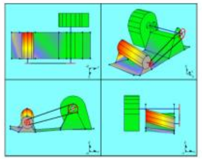
→ In-site signal verification test: vibration calibrator at 6.3 Hz

→ Start "Record" function on B&K analyzer for a long time record

→ Data storage

→ Analysis on Me'scope software

ME'scopeVES™



Vibration Measurement for Viaduct and Pole

◆ **Sensor calibration**

Low frequency calibration system

Frequency range : 0.8 Hz to 100 Hz

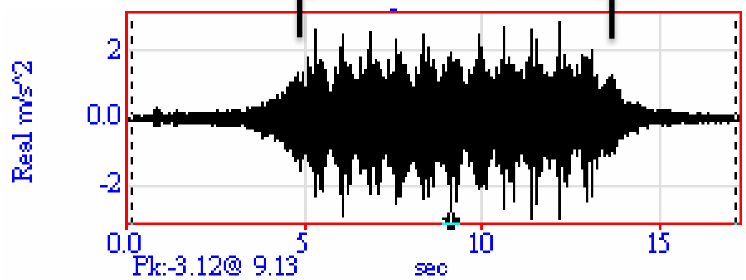
In-site signal verification test with a low frequency vibrator

Exciting level	: **97 dB** (0 dB = 10^{-5} m/s^2)
Accuracy	: ± 0.5dB
Frequency	: **6.3 Hz ± 3%**
Exciting table	: 130 mm
Maximum load	: 2.6 kg
Distortion	: < 5%(1 Hz-100 Hz)

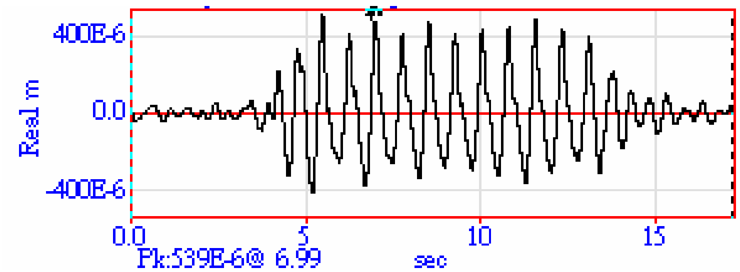
Vibration Measurement for Viaduct and Pole

◆ Measurement and Analysis Methods

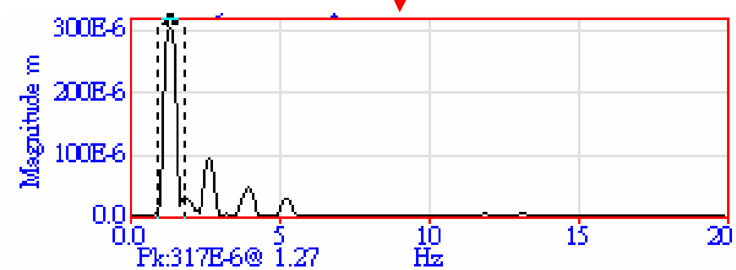
before passing by | **train passing by** | after passing by



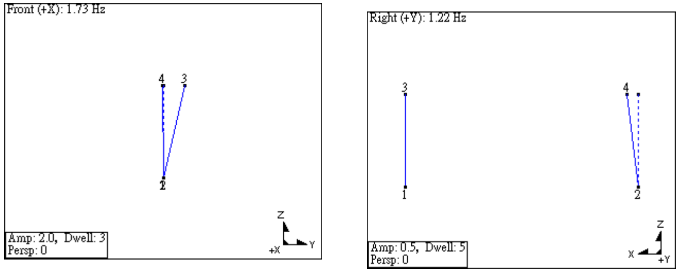
Acceleration time history signal



Displacement time history signal



Frequency domain signal



Animation between poles

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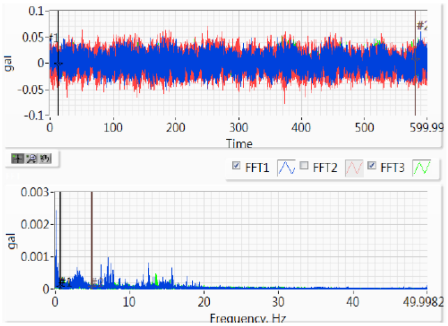
Natural Frequency test for Viaduct and Pole

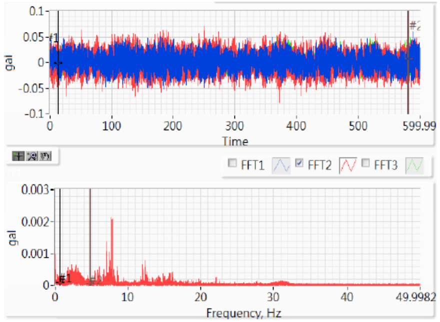
Sensor mounting position for natural frequency measurement

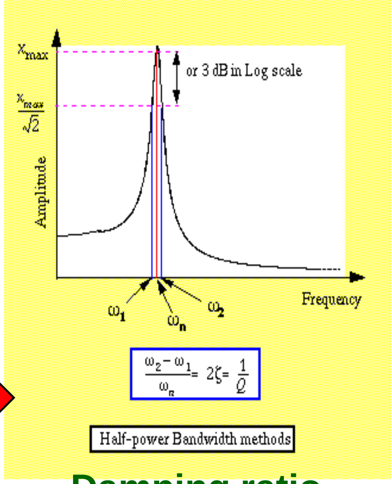
- **Exciter or hammer** is a good exciting source
- These two exciting sources are not suitable for measuring natural frequencies of viaducts and poles.
- **Background vibration** at night is used as exciting force to minimize noises from traffic.
- Background vibration is **wide band vibration** signals and can excite the characteristics of structures
- 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







Damping ratio

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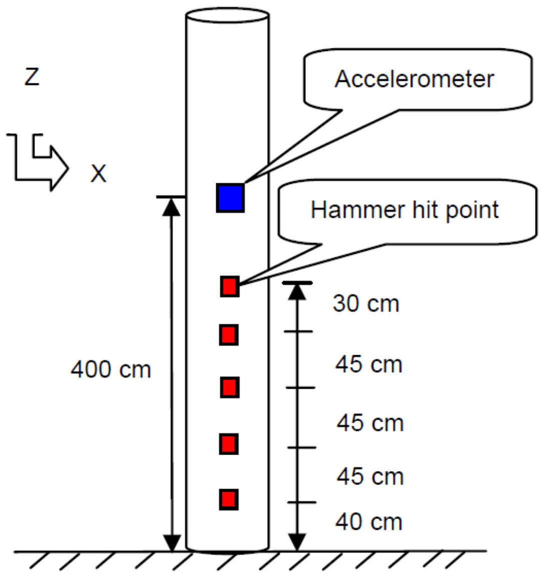
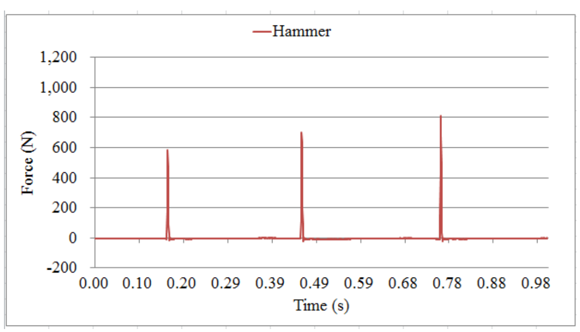
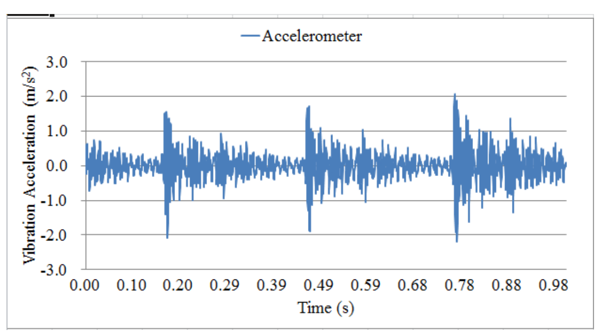
Modal Analysis for Pole's Vibration



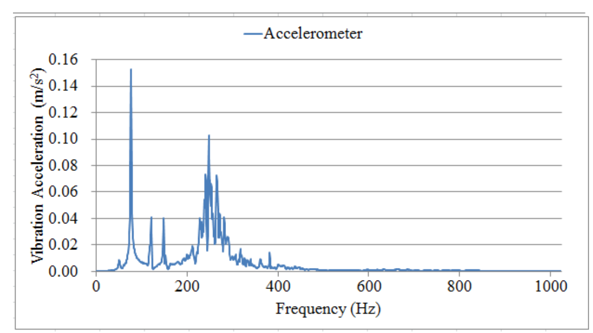
- Understanding natural frequencies in Y direction and vibration modes.
- A hammer is used to hit 5 different positions on the pole.
- An accelerometer is mounted on 400 cm height from viaduct to measure their response signals.
- Signals are input to Me'scope analysis software to calculate poles' natural frequencies and modes.



Force time signal



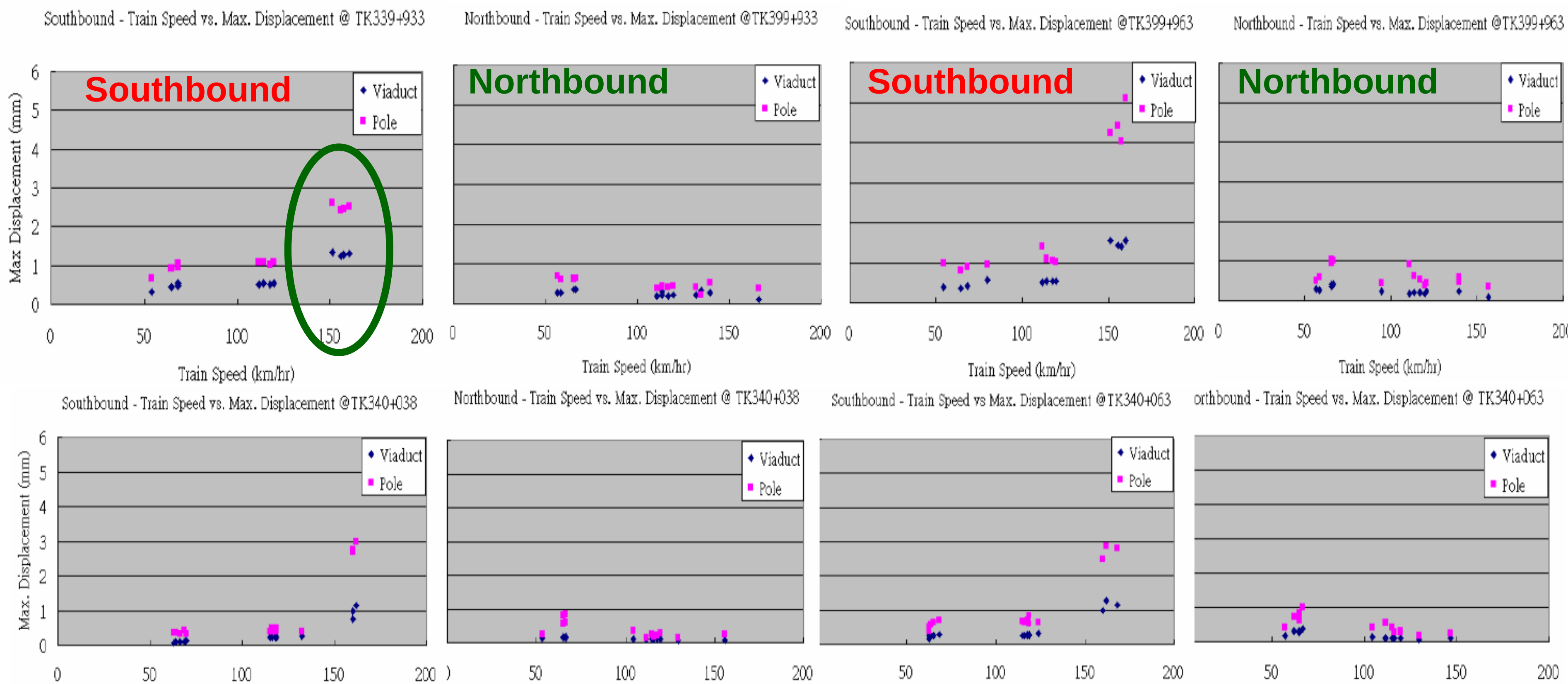
Accelerometer time signal



Accelerometer frequency signal

Measurement Results

➢ Vibration measurement results for trains passing with different speeds

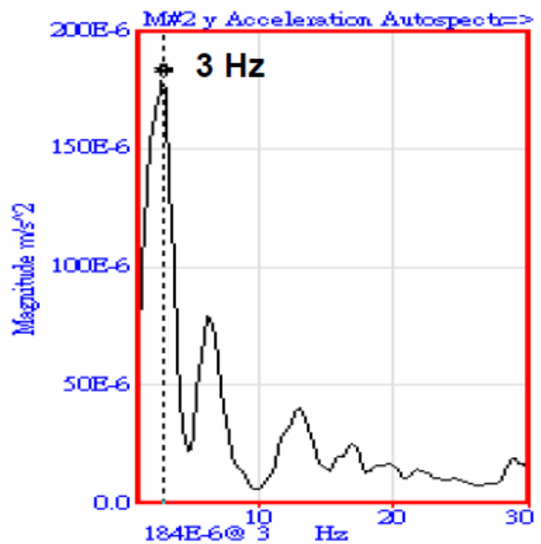


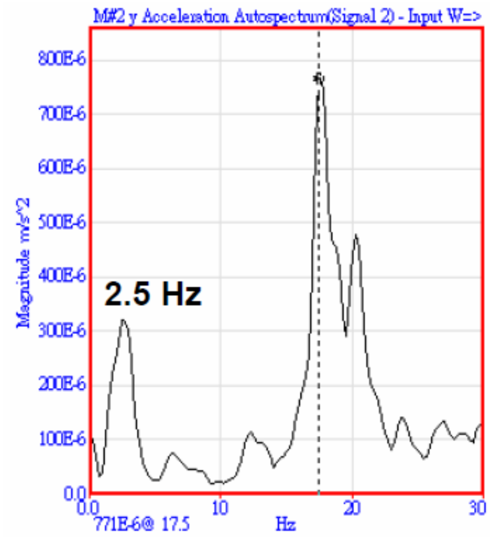
Vibration displacement for viaduct and pole of train running southbound or northbound with different speeds at different location

- 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

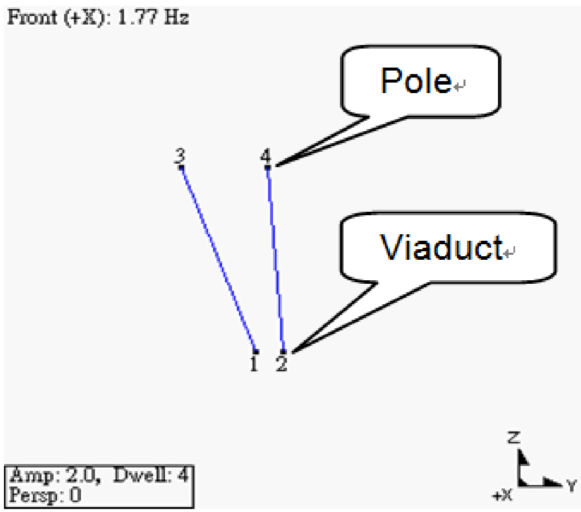




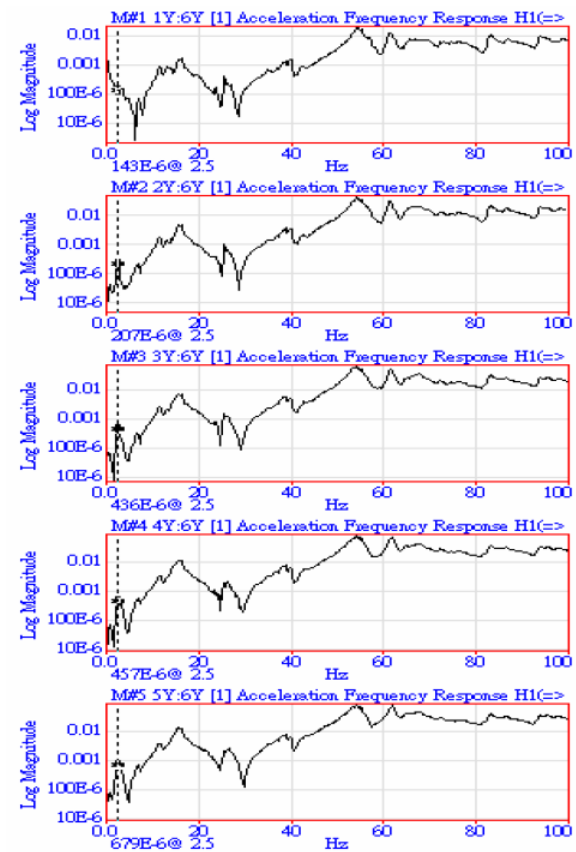
Location / Position / direction	TK339+933		TK339+963		TK340+038		TK340+063	
	viaduct	pole	viaduct	pole	viaduct	pole	viaduct	pole
Y	3	2.5	2.25	2.25	2	2.5	2.75	2.25

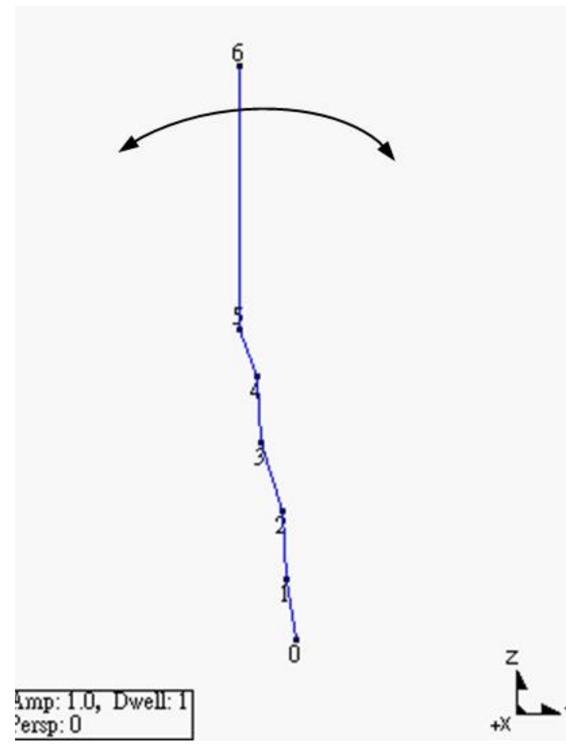
Measurement Results

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



The motion animation of viaduct and pole

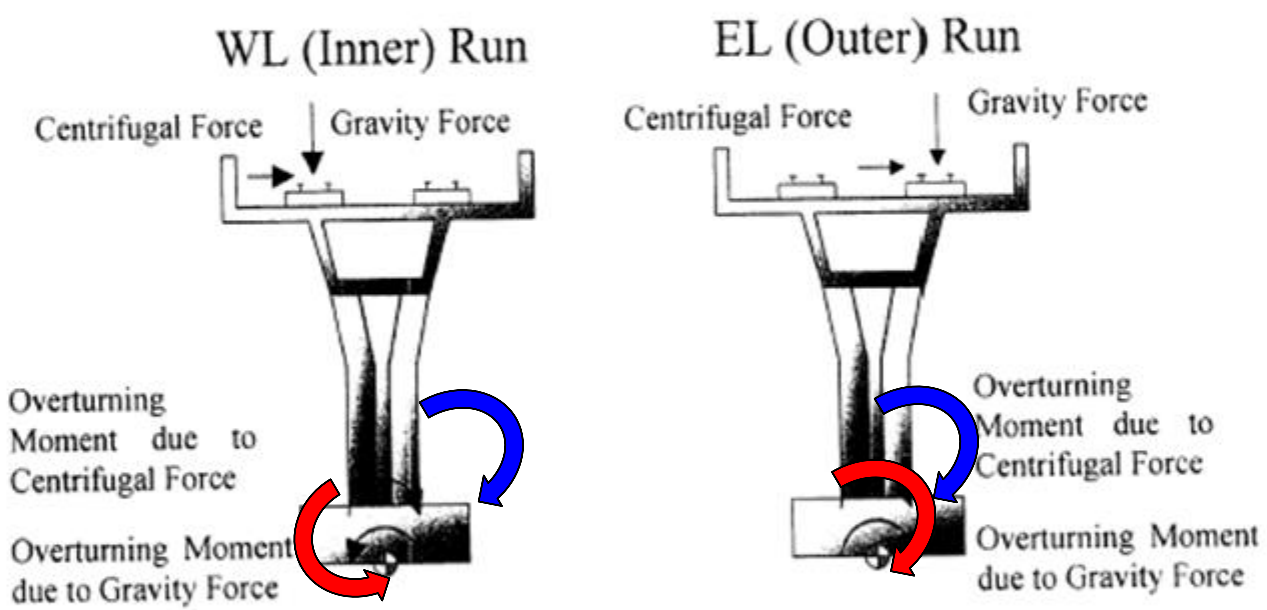




- Hitting on **5 different points** to get acceleration frequency response function.
- Using Me'scope software to sketch the whole pole structure.
- The first simulated natural frequency is **at 2.5 Hz.**

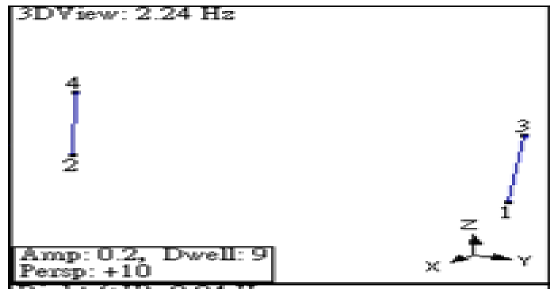
Conclusions

- From the measured data, 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

- Through Me'scope simulation software, it found that the motions of two poles, and between viaduct and pole, are in the same direction synchronously.



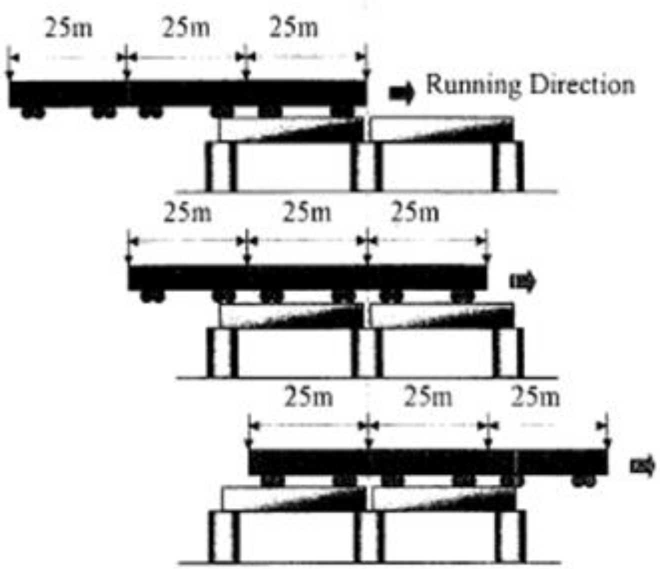
- Results of vibration testing from structural micro-vibration measurement performed at night with low-frequency, high-sensitivity accelerometers, it shows the natural frequency of viaduct is around at 2 Hz to 3 Hz and poles' around at 2.25 Hz to 2.5 Hz.

- Results of modal testing from a hammer hitting shows that poles' first natural frequency is 2.5 Hz, which is close to the results from background vibration measurement.

Conclusions

- The major reason is a resonance occurred because the frequency, 1.9 Hz, generated by trains passing, is close to the natural frequency of the viaduct.

Fundamental(Lowest frequency is based on car length(25 m)
Additional frequencies are multiples of the fundamental



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.

- Therefore, trains decelerating could reduce the vibration and electric wire swinging.

Thanks for attention

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