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Application of Multi-Monitoring Information for Bridge Safety Evaluation

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Abstract. Due to large flexibility in cable-stayed bridges, vibrations induced by seismic, traffic and wind loads are more significant than those in other types of bridges. These vibrations may cause structural damage, such as fatigue in stay cables, large deflection in main girder, etc. The objective of this paper is to investigate long-term dynamic characteristics of the Kao Ping Hsi cable-stayed bridge subjected to different external force conditions by using a bridge health monitoring system (BHMS). The bridge has been bearing the loads of traffic for more than a decade. To ensure the safety of the Bridge, the Bureau has developed a BHMS for the long-term monitoring of the overall structural safety over the entire operation stage in terms of seismic response, wind resisting response and cable vibration, as well as travel comfort. The BHMS will provide multi-alarm information for the study of bridge safety management and maintenance in relation to seismic activities, wind vibration and traffic.

Introduction

Cable-stayed bridge features a degree of aesthetics and the economic benefit of ultra-long spans. The design of cable-stayed bridge became fashionable thanks to the advancing of engineering technology [1]. With the completion of Kao Ping Hsi cable-stayed bridge on Freeway 3 and the advancing bridge technology in Taiwan, there are an increasing number of cable-stayed bridges designed for river crossing. These are the examples showing the improvement of bridge engineering in Taiwan and the footsteps to catch up with the rest of the world. However, with the fast development of cable-stayed bridges, there are still several concerns, such as the safety maintenance strategies after they are commissioned for wind[2], earthquake[2] and traffic[3], whether there is a system for damage assessment, and whether bridge engineers are up for the upcoming challenge that we may neglect some problems that will result in failure of these engineering marvels under the pressure of not wanting to be left behind in this international engineering ranking of cable-stayed bridge. This work contains two major parts; the first is the introduction of a complete in-situ BHMS. The second is the assessment of bridge safety by using multi-monitoring data from vibration response of bridge.

BHMS description for the bridge

The Kao Ping Hsi cable-stayed bridge was open to traffic on December 30, 1999 in southern Taiwan. As shown in Fig. 1, the bridge is an asymmetric cable-stayed bridge with a deck of 34.5 m width, a steel-based main span of 330 m and a concrete-based side span of 180 m. An inverted Y-shaped reinforced concrete pylon was adopted to increase the torsional rigidity of the bridge. A total of 30 sets of stay cables arranged on two planes were used to connect the girder to the pylon. The development of monitoring items and the functions for the cable-stayed bridge monitoring system requires the analysis and investigation of the bridge's characteristics and current status as it is. The monitoring instruments are placed at spots where are sensitive to damage. By studying the changes in characteristic parameters after the bridge is loaded, it is possible to determine the damage to the bridge. Thus, the monitoring and analysis demands are:

1. Vibration test and system identification: to establish a reasonable finite element analysis model for seismic and wind loading analysis.
2. Cable tensioning measurement and analysis: to establish the clear picture of the tensioning on all cables for the behavioral analysis of the wind and rain vibrations of the Bridge.
3. Aerodynamic stability analysis: to carry out the aerodynamic stability analysis of the entire Bridge.
4. Influence of traffic effects on bridge vibrations.

The monitoring of the entire system is designed to cover earthquakes, winds and traffic as the 3 major axes. An alarm capability focusing on "multiple safety monitoring" is established centering on dynamic monitoring aided with static monitoring. Also for future expandability, serviceability and cost down, the features of distributed transmission are put to good use. The overall dynamic and static monitoring system structure is shown in Fig. 1. Table 1 lists types and number of monitoring instruments.

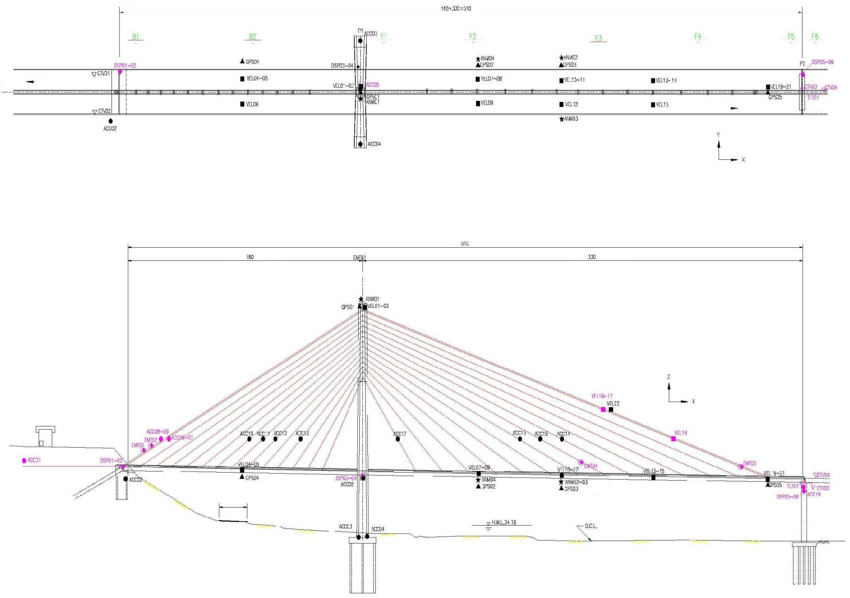


Fig. 1 BHMS for Kao Ping Hsi cable-stayed bridge

Assessment of Dynamic Characteristics

The monitoring data recorded from BHMS was processed using a random decrement technique. The natural frequencies (*f*) and modal damping ratios (ξ) of the first five modes in three main directions are listed in Tables 2. For a long span cable-stayed bridge, such as the Kao Ping Hsi bridge, the frequency range of interest lies below 2 Hz in the vertical direction. The frequencies of the first five modes are less than 2 Hz. It implies that no severe interaction can occur between the bridge and running vehicles, whose resonant frequencies lie generally in the 2-5 Hz range. From Tables 2, the ratio of the first torsional frequency to the first vertical frequency is 2.65:1. Based on the flutter analysis results, this high torsional/vertical frequency ratio indicates that the wind resistance of the bridge is generally suitable[4].

Table 1 Types and number of monitoring instruments

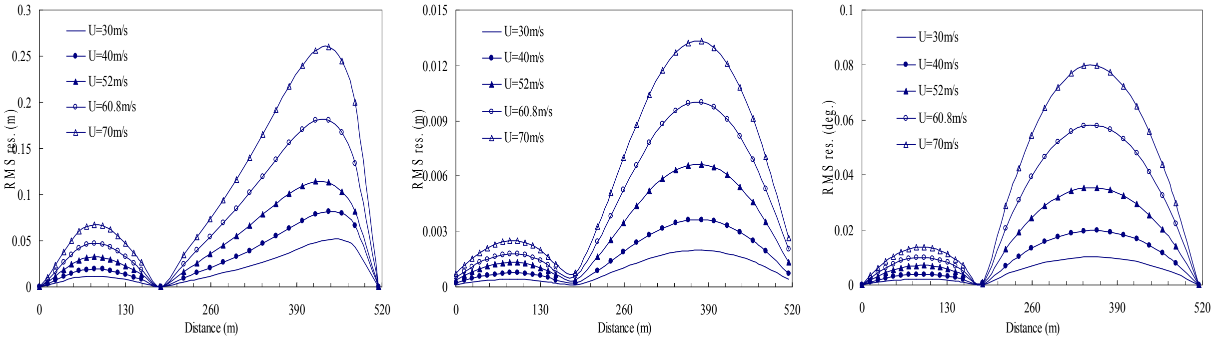
Item	Name	Code	Mark	Unit	Qty
1	3D anemometer	ANM	★	Set	4
2	Embedded seismometer for acceleration (3-axis)	ACC	●	Set	1
3	Surface-mounted seismometer for acceleration (3-axis)	ACC	●	Set	5
4	Surface-mounted seismometer for acceleration (uni-axial)	ACC	●	Set	12
5	Vibration sensor for velocity (uni-axial)	VEL	■	Set	22
6	Dynamic displacement sensor (uni-axial)	DSP	◆	Set	6
7	Dynamic displacement sensor (3-axis)	TLT	⊕	Set	1
8	Global position system	GPS	▲	Set	5
9	Video monitoring system	CTV	▽	Set	4
10	Electromagnetic tensional gauge	EMT	⊙	Set	4
11	Rain sensor	RAN	○	Set	2
Data acquisition system					
12	Dynamic data acquisition system	DRS	□	Set	1
13	Static data acquisition system	SRS	※	Set	1

Table 2 Comparison of natural frequencies and damping ratios

Mode	Vertical direction (Z)			Transverse direction (Y)			Torsional direction (T)		
	Field test		FEM	Field test		FEM	Field test		FEM
	f (Hz)	ξ (%)	*f* (Hz)	*f* (Hz)	ξ (%)	*f* (Hz)	*f* (Hz)	ξ (%)	*f* (Hz)
1	0.284	2.9	0.293	0.643	3.3	0.646	0.754	1.84	0.771
2	0.574	3.7	0.561	1.64	2.9	1.68	1.46	1.09	1.43
3	0.92	4.4	0.93	2.17	3.2	2.15	2.18	1.29	2.25
4	1.54	3.9	1.52	2.51	2.5	2.49	2.91	1.82	2.86
5	1.81	3.0	1.79	3.13	3.9	3.15	3.68	1.69	3.74

Assessment of Aerodynamic Characteristics

Based on the linear dynamic analysis, the results obtained for the root mean square (RMS) responses of the deck obtained under the different wind velocity for the three directions plotted in Fig. 2. Clearly, the RMS responses increase with wind velocity. The maximum RMS responses of the deck in the three directions under different wind velocities have been plotted in Fig. 3, which indicates that the responses increase more rapidly with the wind velocity in the vertical and torsional directions than in the transverse direction.

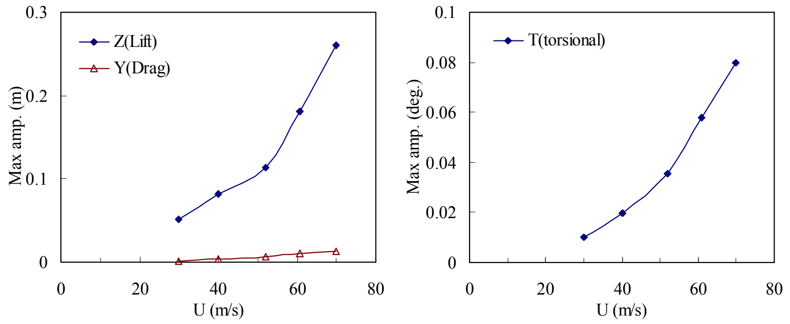


(a) (b) (c)

Fig. 2 Comparison of RMS responses: (a) vertical; (b) transverse; (c) torsional

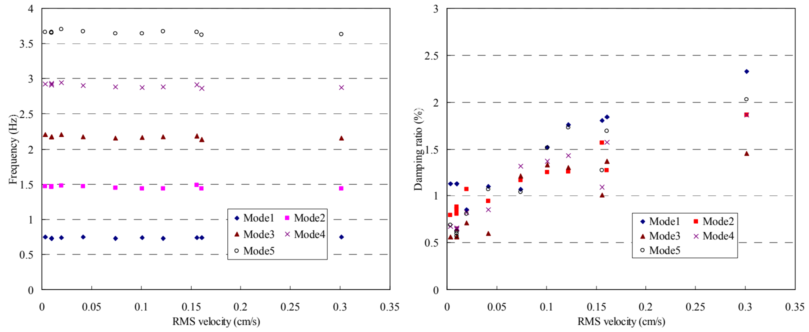
Assessment of Traffic-Iduced Vbration

To obtain the dynamic characteristics with corresponding variable traffic loading conditions, the long-term structural health monitoring system has been run for over 24 months. The all-weather measurements were carried out in normal traffic conditions by using the structural monitoring system. Fig. 4(a) shows the frequency of each mode which is related to the velocity RMS values of the deck in the torsional direction. The excellent agreement of the identified results from different traffic conditions indicates that the traffic flow would not significantly change the natural frequencies of the cable-stayed bridge. Further, the damping ratio of each mode is related to the velocity RMS values of the deck, as plotted in Fig. 4(b). It shows that the vibration intensity increases with damping ratios in the torsional direction. The possible reason is that the high capacity of energy dissipation of the cable element provided some additional contribution for the development of extra structural damping.



(a) (b)

Fig. 3 Comparison of maximum RMS responses: (a) vertical and transverse; (b) torsional



(a) (b)

Fig. 4 Variability dynamic characteristics under normal traffic: (a) frequencies; (b) damping ratios

Conclusions

In this work, the benchmarks established for the comparison of the characteristics of the bridge for long-term monitoring preparation include: (1). Vibration test and system identification: to establish a reasonable finite element analysis model for seismic and wind loading analysis; (2). Aerodynamic stability analysis: to carry out the aerodynamic stability analysis of the entire Bridge. (3). Influence of traffic effects on bridge vibrations. As a result, all the monitoring indicators must be collected and studied to reach the demand for multiple monitoring indicators and to arrive at the best judgment. It is hoped to modify the alarm indicators to best fit the maintenance management requirements with the long-term monitoring results in the future.

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References

[1] Y.B. Yang and C.H. Chen: *Structural Engineering*, Vol. 10, No. 2, (1995^{a}), p. 45.
[2] C.H. Chen and C.I. Ou: *International Journal of Structural Stability and Dynamics*, Vol. 11, No. 1, (2011), p. 1.
[3] C.H. Chen, Y.Y., Lin and S.C. Yang, *Journal of Chung Cheng Institute of Technology*, Vol. 39, No. 2, (2010), p. 47.
[4] C.H. Chen, J.C. Wu and J.H. Chen, *J. Wind Eng. Indust. Aerodyn.* Vol. 96, No. 10-11, (2008) p. 1925.

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