REAL TIME STRUCTURAL HEALTH MONITORING SYSTEM FOR A LONG SPAN CABLE STAYED BRIDGE

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Abstract

Structural Health Monitoring System ("SHMS") is to evaluate structural soundness based on correlation between excitations and responses, and additionally, is to detect structural deterioration and performance degradation analyzing tendency of the chronological transition. This paper presents an actual result of the SHMS for a long span cable stayed bridge including major purposes of the SHMS, applied sensor arrangement, total evaluation system and trigger values in conjunction with structural analysis.

Keywords: Structural Health Monitoring System, Cable-Stayed Bridge, steel, maintenance, traffic control, design verification

1. INTRODUCTION

Although semi permanent durability is generally expected to long-span bridges including cable-stayed bridges, structural performance is gradually degraded with time passage due to various continuous factors such as corrosion, cracks, abrasion, structural deterioration, fatigue and deformation. Therefore, appropriate maintenance management is necessary to be implemented uninterruptedly so that suitable services, which have been designed in the bridge design stage, are definitely provided. Accordingly, monitoring technique, which has sufficient capability to detect structural deterioration and performance degradation accurately, is essential to be applied in order to implement effective maintenance management. Currently, structural health monitoring system ("SHMS") becomes general monitoring method for long-span bridges; the main objective is to evaluate bridge soundness based upon conduct of continuous monitoring activity. SHMS is to evaluate structural soundness by utilizing various numeric data based upon correlation between excitations and responses, and additionally, is to detect structural deterioration and performance degradation by seizing tendency of the chronological transition. Accordingly, it provides informative data for planning of efficient maintenance management, and at the same time bridge administrators enable to estimate a period of that generated stresses, forces and deformations reach critical value, appropriately.

In this paper, an actual result of the SHMS designed for a long-span cable stayed bridge named Can Tho Bridge in Vietnam is introduced.

2. STRUCTURAL FEATURE OF THE BRIDGE

Can Tho Bridge ("the Bridge) shown in Figure 1 is constructed in Can Tho city in Vietnam. The main span is 550m, which is the longest cable-stayed bridge in Vietnam. The deck and girder are designed as a hybrid structure. For the main span of 550m, the center area, the length of which is 210m, is composed from steel deck box girders; the other area are constructed by PC box girders, the shape of which is designed as similar shape to steel deck of the center area.

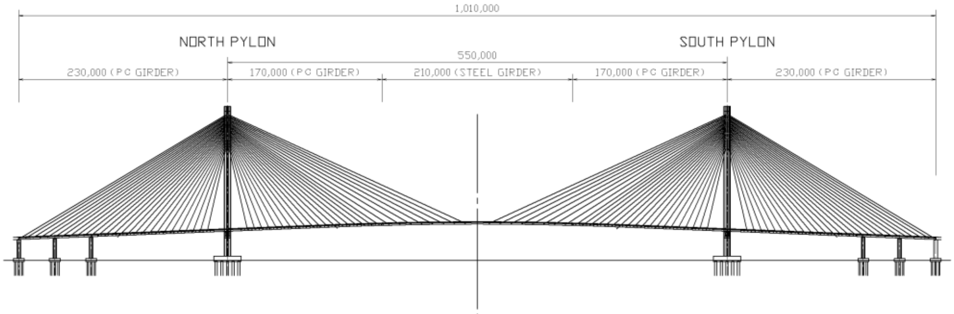


Figure 1: Side View of Can Tho bridge

3. USAGE AND ADVANTAGES OF THE SHMS

The following three general usages of various SHMS are shown as general main purposes of SHMS for long-span bridges in the world.

(1) Design verification

i) To provide data to verify the design assumption

ii) To provide data to develop appropriate analyses or methodology for other projects

(2) Structural maintenance

i) To provide data for assessment of structural deterioration and performance degradation

ii) To provide data for improvement of maintenance activities

(3) Traffic management

i) To utilize the monitoring data for traffic management or control passing on the bridge, not only during abnormal climate but also after attacked by earthquake or strong wind blows

Periodic the labor inspection executed by bridge inspectors must be a significant role in the evaluation of the structural soundness and maintenance activities; however, it would be of arduous activity physically and economically for only the labor inspection to organize vast accumulated data requisite to understand the chronological transition of the bridge structure or meteorological conditions, such as unexpected climate, unexpected occurrence to the bridge structure and the transition of structural deterioration or performance gradation progressing slowly for a long term. Therefore, the monitoring utilizing the SHMS may have efficient advantages to provide informative data for macroscopic bridge management based upon evaluation of organized vast accumulated data; however, if a lot of number of sensors were installed, it would require tremendous investment in spite of its effectiveness. Additionally, because the SHMS consists of aggregation of electrical devices, its running cost would be quite an expense due to trouble or breakdown of the electrical devices. Nevertheless, if bridge administrators utilized the SHMS without realizing the device trouble or breakdown, it would be a crucial issue for organizing the accumulated data based upon the continuous observation of transition.

Consequently, the SHMS for the Bridge should be determined based upon specific the main purposes and the measurement objects in consideration of following the concepts.

- Sensor selection in consideration of the structural property and natural environment of the Bridge
- Specific measurement objects and usage
- Economic efficiency
- Reliability of the sensors

4. DESIGN POLICY

4.1 The Main Purposes of the SHMS for the Bridge

As mentioned in previous section, if a lot of number of sensors were installed, it would require tremendous investment in spite of its effectiveness. Therefore, the sensor arrangement of the SHMS for the Bridge is to be determined based upon the main purposes and specific the measurement objects in consideration of the structural property, natural environment of the Bridge, their usage, reliability of the sensors and case study including economic efficiency. The main purposes of the SHMS for the Bridge are shown as follows.

4.1.1 Main Purposes

(1) Structural Maintenance

This purpose is to provide data for analyzing and evaluating on the structural health in the behavior of the bridge structures. It is also effective to contribute for improving necessary maintenance activities with assessment of structural deterioration.

(2) Traffic Management

It is to utilize the monitoring data for traffic management (control) for traffic safety and trafficable flow under strong wind blows.

4.1.2 Available usage

(1) Design Verification

As a field of design verification, various accumulated data utilized for foregoing the two main purposes would be available partially to provide data for verification of design assumptions such as strength and direction of wind blows, live loads and thermal effects.

4.2 Prerequisite conditions for the arrangement of the devices

The following prerequisite condition for the arrangement of the devices and sensors should be considered from technical and economical viewpoints based upon the main purposes, actual achievements on SHMS in the world and explanation on various measuring sensors.

- If a lot of number of devices or sensors were installed, it requires tremendous investment in spite of its effectiveness. Therefore, it is of important to allocate the budget in relation to the type and number of devices or sensors in consideration of its data effectiveness.

- The quality of monitoring results should be reflected to the monitoring purposes, efficiently. Therefore, it is important the appropriate requirements for their roles to obtain the satisfactory data for effective use in relation to purposes, and installation of instruments or sensors, including their durability after installation.

- Adequate reliability even in harsh climate is required.

- The measurement object that can be measured utilizing portable device in periodic labor inspection may be excluded from the sensor arrangement of the SHMS.

- The measurement object, for which vast accumulated data are not necessary to be organized in order to evaluate long-term inclination of the behaviour, may be excluded from the sensor arrangement of the SHMS.

4.3 Case study and determination of sensor arrangement of the SHMS for the Bridge

Based on the above prerequisite condition, the case study on the possible sensor arrangement is carried out shown in the table 1

Table 1: Case study and determination of sensor arrangement for the Bridge

Items	Nos.	Case-1	Case-2A	Case-2B	Case-3	Case-4
GPS	6	Set	Set	Set	Set	Set
Anemometer	2	Set	Set	Set	Set	Set
Thermometer	14	Set	Set	Set	Set	Set
Rain gauge	1	Set	Set	Set	Set	Set
Monitoring camera	4	Set	Set	Set	Set	Set
EM sensor	36	Set	---	Set	---	---
Disp. Gauge	2	Set	---	---	Set	Set
Peak sensor	4	Set	---	---	Set	Set
Scour sensor	1	Set	---	---	Set	Set
Velocity gauge	4	Set	---	---	---	Set
Seismometer	1	Set	---	---	---	Set
Installation Cost Ratio		2.03	1.00	1.39	1.30	1.64

From the following reason, the Case-2A is recommendable for application of the SHMS for the Bridge. The specific locations of the sensors and the supports are shown in the figure 2.

- The sensor arrangement should meet the prioritization of the measurement objects, which is GPS and anemometers for monitoring bridge structure deformation due to strong wind blows, also includes thermal effect.

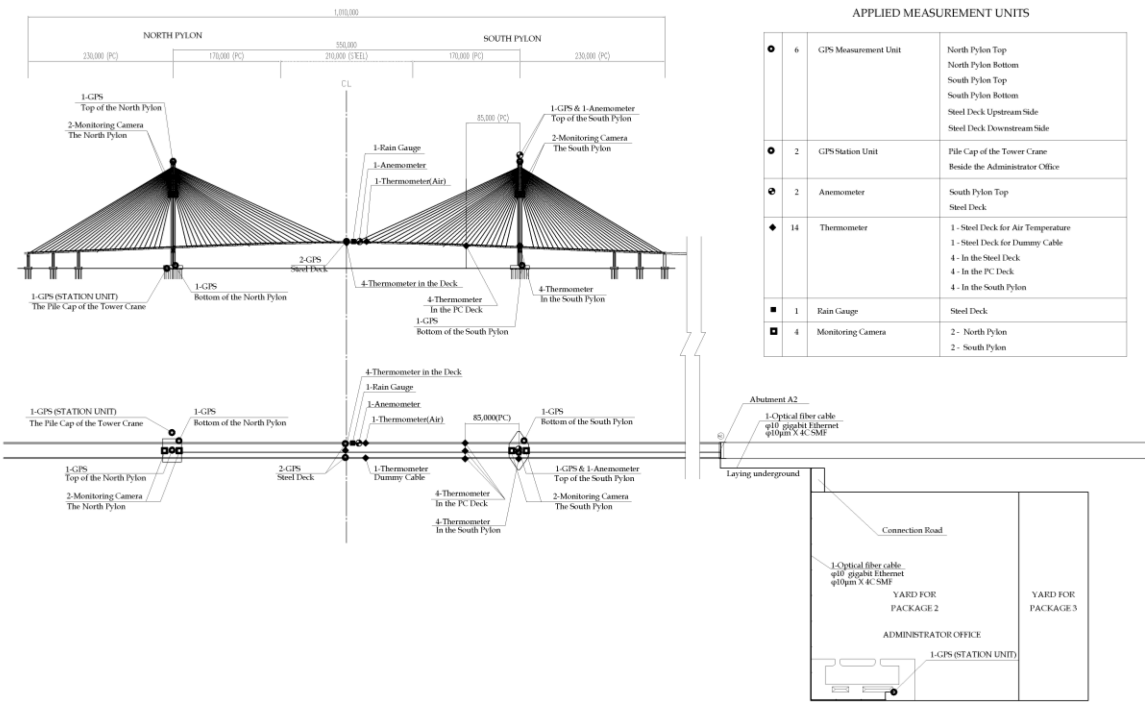
- For traffic management purpose, anemometer and rain gauges are necessary.

- Accelerometers, EM sensors, peak sensors and scour sensors are rather low priority consideration because bridge inspectors can measure directly, and in terms of the relations of proper number of installation and data analysis.

- Installation of seismometer should be considered occurring earthquake for the project area.

- The maintenance efficiency and reliability are appropriate based upon the number of the installed sensors and actual achievement.

- The CASE-2A is an appropriate the SHMS for the Bridge, which will perform adequate continuous monitoring with the minimum installation costs, in conjunction with periodic labour inspections.



APPLIED MEASUREMENT UNITS

○	6	GPS Measurement Unit	North Pylon Top North Pylon Bottom South Pylon Top South Pylon Bottom Steel Deck Upstream Side Steel Deck Downstream Side
○	2	GPS Station Unit	Pile Cap of the Tower Crane Beside the Administrator Office
◒	2	Anemometer	South Pylon Top Steel Deck
◆	14	Thermometer	1 - Steel Deck for Air Temperature 1 - Steel Deck for Dummy Cable 4 - In the Steel Deck 4 - In the PC Deck 4 - In the South Pylon
■	1	Rain Gauge	Steel Deck
◘	4	Monitoring Camera	2 - North Pylon 2 - South Pylon

Figure 2 Sensor Arrangements for the Bridge

5. THE TOTAL EVALUATION SYSTEM UTILIZING VISUAL MONITORING SYSTEM

5.1 Introduction of the Total Evaluation System of the Bridge

Primitively, the SHMS must enable to evaluate the bridge soundness diagnosing the structural initial damages, chronological transition of behaviors subjected to various excitations and environmental conditions. Therefore, establishing appropriate the SHMS functionally and economically effects informative advantages in the maintenance activities and the traffic controlling; however, the collected data for some of the bridges in the world transmitted from applied the sensors are not appropriately incorporated into maintenance or evaluation systems; efficient evaluation of the bridge soundness is not performed in such the bridges. The Total Evaluation System utilizing visual monitoring system that is originally designed only for the Can Tho bridge is to be introduced in this chapter, and will become one of the unprecedented system that will enable to evaluate the bridge soundness visually and quantitatively by the administrators in the monitoring room.

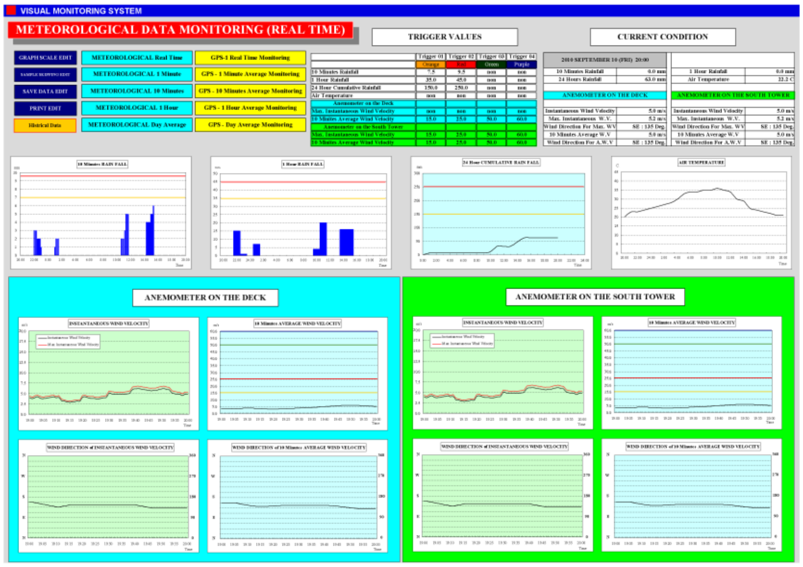


Figure 3 Conceptual Image of the Software of the Total Evaluation System

5.2 Advantageous Aspect of the Total Evaluation System

One of the major purposes of the SHMS utilizing the Total Evaluation System is firstly evaluating the bridge soundness visually and quantitatively based upon chronological transition of the relationship between the structural behaviors and the specific excitations that consist of not only the real time monitoring data but also statistical processing data.

Additionally, another major purpose is providing meteorological data for accurate traffic management, and is to notify the administrators of the significance of the meteorological or structural conditions based upon various the trigger values incorporated into the system.

The software applied to the Total Evaluation System should have enough capability that the administrator can seize accurately current the bridge condition based upon the real time monitoring data, and should provide the statistical processing data efficiently in order to the transition of the behaviors for a long duration is available to be evaluated quantitatively. The deterioration progressing gradually for a long duration should be evaluated in accordance with the relationship between the bridge behaviors and excitations on the same time axis. Therefore, appropriate the sensitivity analysis should be performed frequently in consideration of not only the performance requirement expected in the bridge design stage but also the expected excitations caused to the bridge in order to determine or designate various kinds of the trigger values to be incorporated into the software. Of course, the trigger values should be alterable to be designated optionally by the administrators without any suggestion of the bridge engineers; also, when new sensors are required to be installed into the system, the software including the hardware should have enough expandability. We define the comprehensive system including foregoing considerations as the Total Evaluation System. The unprecedented features of the system are:

- Various kinds of the trigger values are alterable to be designated into the system.

- The trigger values will be incorporated into the same graph of meteorological data and bridge behaviour data.

- The administrator will enable to evaluate the bridge soundness, confirming the current conditions, the performance requirements of the bridge and chronological transition for a long duration.

The following contents are realized utilizing the Total Evaluation System applied to the SHMS.

- Measurement and monitoring of transition of the excitation and environmental factors affecting to the Bridge.

- Quantitative evaluation relevant to both of the bridge behaviours and the excitations.

- Efficient comparison between the foregoing evaluation and the design requirements.

- Recording unexpected excitations such as over-loading lorry passing, sudden ship collision, etc., and evaluating its significance for the design requirements.

- Monitoring the bridge soundness visually and quantitatively based upon not only the real time data but also statistical processing data.

- Dispatching the critical alert based upon the trigger values or boundary values calculated in the sensitivity analysis of the Bridge.

- Dispatching the critical alert for the traffic controlling based upon designated trigger values in the software.

- Provide the informative data for efficient maintenance activities by periodical labour check.

6. TRIGGER VALUES FOR ALERTING SYSTEM BASED UPON REVIEW OF THE BRIDGE DESIGN AND SENSITIVITY ANALYSIS ON VARIOUS EXCITATIONS

One of the advantageous features for the Total Evaluation System for the bridge is to evaluate bridge soundness visually and quantitatively based upon various the trigger values and reference values relevant to meteorological alerting, design methodology and performance requirements of the bridge, the plotted lines of which will be indicated on the same graph of the meteorological data and GPS monitoring data. In this chapter, the following various related trigger values are proposed. The initial designated trigger values in the SHMS are proposed to be classified into following the 3 categories.

(1) Trigger Values for the Traffic Control

- Utilizing the statistical processing data of the wind velocity data

- Utilizing the statistical processing data of the rain fall data

(2) Trigger Values for the Performance Requirements determined in the Bridge Design Stage

- Design Wind Loads

- Design Live Loads

(3) Reference Materials of the Structural Behaviors based upon the Sensitivity Analysis

- Wind Loads

- Thermal Effects

- Live Loads

- Influence Lines

- Various reference displacements

- Frequency and Vibration of the Bridge

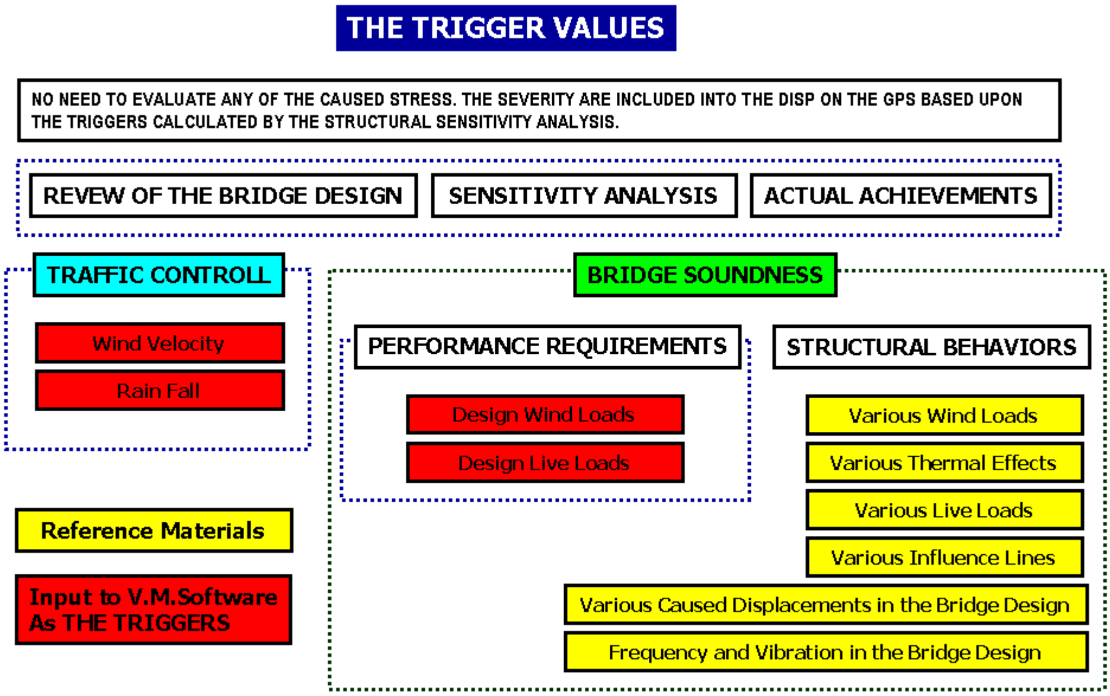


Figure 4: Conceptual Flow of Trigger Values

7. CONCLUSIONS

An actual result of the SHMS for a long-span cable-stayed bridge is introduced. The most important factor is to determine distinct the major purposes of the SHMS. Otherwise, tremendous amount of data would be wasted because it would become unclear whom and how they should be processed or analyzed; such the data would be processed without knowing failure of the devices. Additionally, to determine the specification of the software and the trigger values, which definitely are in accordance with the major purposes, are also quite important. Accordingly a package consisting of 4 elements such as measurement objects, specification of the software, trigger and reference values based upon structural /excitation analysis and efficient data processing system should be worked functionally.

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