OASIS – A REAL-TIME STRUCTURAL MONITORING SYSTEM

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Abstract: This paper presents a commercially available real-time monitoring system using dynamic measurements for continuous evaluation of the integrity of critical civil structures. OASIS - On-Line Alerting of Structural Integrity and Safety - utilizes a variety of sensors and a unique set of parameters derived by the responsible engineer to continuously monitor structures for critical behavior. Monitoring can be done during construction for safety purposes or during operation as part of a modern maintenance program. OASIS examples include the operational monitoring of a large suspension bridge in South Korea and a cable-stay bridge in Thailand, and construction monitoring of a building in Thailand.

Keywords: structural monitoring, structural health, vibration, wind, earthquake, damage, safety

1 INTRODUCTION

A vision for vibration-based structural health monitoring, as applied to civil structures, is one in which a structure can sense its condition, express the information both internally and externally, and use that information as the basis for some corrective action. The time scale for this monitoring can vary from immediate (for extreme events such as earthquake) or on a scale of years for long-term degradation due to corrosion or fatigue.

At the present time, technologies are available to perform real-time monitoring of various physical quantities such as acceleration, displacement, strain, force, temperature, etc. Technologies are also available to perform rapid, even real-time analysis on the measured data and to communicate both data and analysis results to a remote location. Many research examples, and several practical examples, exist.

Kinemetrics and Agbabian Associates have developed a real-time structural monitoring system for continuous evaluation of critical structures. The system is called OASIS: On-Line Alerting of Structural Integrity and Safety. OASIS is designed to improve management and safety decisions because:

- Response time is reduced through fast communications, intelligent processing
- On-line analysis offers better information about structural status
- Visual displays create better understanding of critical problems

This paper briefly describes the OASIS system concept and then presents three examples of its implementation.

2 OASIS OVERVIEW

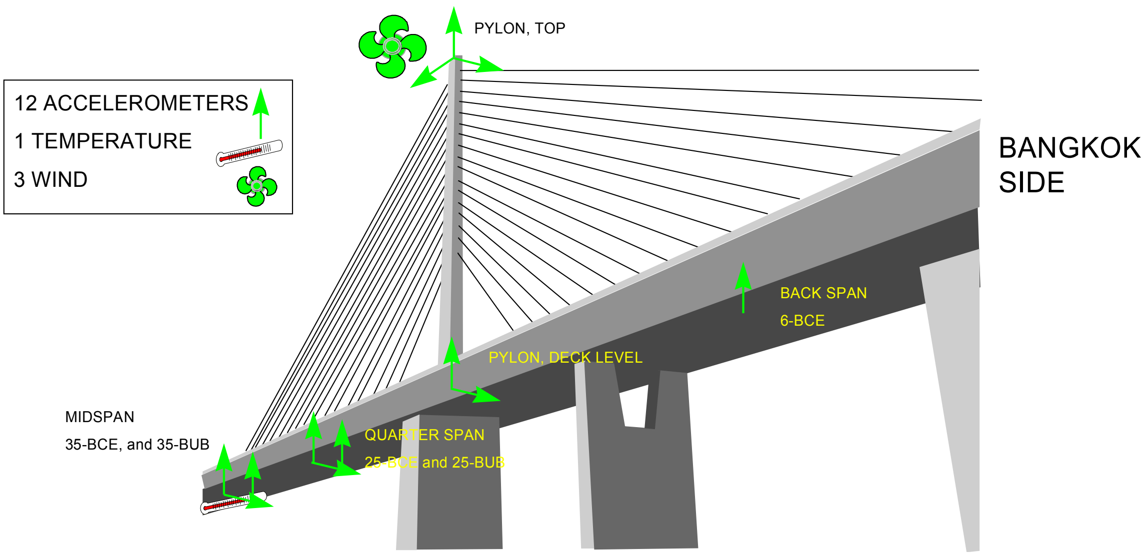
The OASIS system consists of four subsystems: Sensor, Data Acquisition, Communications, and Analysis/Display. The system performs four functions simultaneously, in real time: (1) a remote, real time alerting system using visual, on-screen imaging and audible alarms; (2) an event-triggered, high dynamic range, high speed data logger which operates in the background; (3) remote control and display of system functions through a Windows graphical environment and visual icons; and (4) real-time analysis capabilities for safety or health monitoring based upon measured vibration data.

The Sensor Subsystem consists of various types of vibration and environmental sensors. Vibration is sensed using force-balance accelerometers, displacement sensors, or strain gages. Appropriate sensor types sense environmental parameters such as wind speed/direction, temperature, and rainfall. Cables and appropriate signal conditioning complete this subsystem.

The standard acquisition subsystem utilizes a Kinemetrics Altus data recorder with 19-bit resolution (better than 1 part in 500,000). This is a high dynamic range digital event recorder with true multitasking (the Altus can monitor/record and communicate simultaneously), remote interrogation, and programmability.

Figure 1

Rama IX Sensor Locations



The communications subsystem allows real-time data transmission and bi-directional communication between the data acquisition subsystem on the structure and the analysis/display subsystem at a remote location. Technologies are changing rapidly in this field, so many options are available. Early OASIS systems used wire-based RS-232 communications. Fiber optic systems have been used, and newer systems will take advantage of wireless Ethernet technology.

The Analysis/Display Subsystem consists of a remote computer (Windows PC) running custom OASIS software. Standard OASIS system monitoring software includes the following:

- Visual display of subject structure including sensor icons
- Real-time, dual-level alerting, including location
- Sensor icon, click-on waveform display and statistics from any channel
- Remote command/control of acquisition system

Enhancements for statistical analysis of the real-time data have been implemented. Future development will look at fatigue analysis and damage detection. An ongoing collaboration (via a CRADA) between Kinemetrics and Los Alamos National Laboratory is part of the OASIS development.

Three OASIS installations are described below: Rama IX Bridge, Namhae Bridge, and a hotel building.

3 RAMA IX BRIDGE, THAILAND

In 1995 OASIS was installed on the Rama IX Bridge in Bangkok, Thailand. The purpose of this system is to continuously monitor structural motion, stresses, and related structural/environmental data and to remotely alert the bridge operators if any parameters exceed specified thresholds. The system also measures long-term changes in structural parameters.

The Rama IX Bridge is one of the world's largest cable-stayed bridges. Spanning the Chao Praya River between Bangkok and Thonburi at Wat Sai, it measures 782 meters in total length including the 450-meter main span and two 166-meter side or back spans. The reinforced concrete approaches extend the overall length to three kilometers.

The monitoring system includes sixteen channels of data including (see Figure 1):

- 12 channels of acceleration monitoring
- 3 channels of wind
- 1 channel temperature

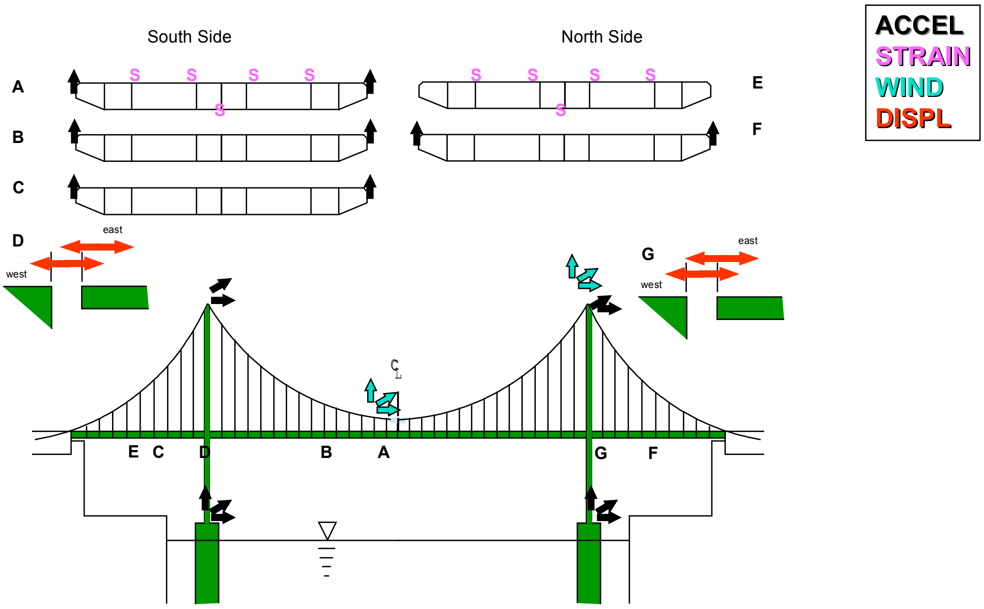
This relatively simple monitoring system utilizes the symmetry of the structure by monitoring only one side of the bridge.

Data are monitored using a Kinemetrics' Altus data logger. This is an 18 channel digital recorder with 19-bits of resolution. The Altus is located at the base of the West tower. Event triggered data is recorded using a PCMCIA recording module, in this case two 20Mbyte solid state disks.

Typically the Altus functions as an event recorder using programmable threshold trigger and weighting algorithms. However, this Altus' firmware was modified to provide a continuous, real-time, serial data stream output of all channels. This stream provides continuous data at 10 samples per second for all sixteen channels.

Figure 2

Namhae Sensor Locations



Digital data are received at the management operations center about 5 kilometers distant via short haul modem and twisted pair cable. The data are continuously processed and displayed using the OASIS software.

The system owner has until now not elected to utilize the health monitoring capabilities of the system. Nevertheless, long-term data (more than 30 minutes, continuous) has been collected by the local operator on an approximately semiannual basis for future study.

This year, the Rama IX Bridge will be subjected to a complete structural inspection. The OASIS system will play a significant role in this project. Data from long-term ambient vibration monitoring will provide a calibration of finite element model(s) used to study the bridge structure. The system will be expanded to include additional strain sensors at critical locations in the bridge deck. Data from these sensors will then be used to estimate fatigue in the bridge. The OASIS real-time software will be modified to include real-time calculation of strain cycles using a Rainflow algorithm.

To date the RAMA IX Bridge Monitoring System has successfully and reliably met every requirement by the owner. It is a useful tool for bridge management and provides and excellent base for future expansion.

4 NAMHAE GREAT BRIDGE, KOREA

In 1996/7 a more extensive and modernized version of the same monitoring system was installed on the Namhae Great Bridge in the south coast of the Republic of Korea. The Namhae Great Bridge is a suspension bridge with main span of 400 meters, and side spans of 125 meters. The towers rise 60 meters above the mean water level. The deck and towers are all structural steel.

The Namhae monitoring system provides 36 channels of data including (see Figure 2):

- 16 channels of acceleration monitoring
- 6 channels of wind
- 10 channels of strain
- 4 channels of displacement

Data are monitored using two Kinemetrics' Altus data loggers, one at the base of each tower. Event data is recorded using a PCMCIA recording module. Real time data is transmitted via fiber-optic cable to the operations center located at the North side of the bridge. There, the Analysis/Display subsystem consists of a computer with a large color monitor accepts both data streams, processes the data using OASIS software and displays the on-line data on a single screen. As with the RAMA IX system, real-time waveforms can be accessed by double-clicking any sensor icon.

The Namhae Great Bridge OASIS system was installed as part of an assessment and major maintenance of this important bridge. It has proven useful in several ways:

- ambient vibration data for calibration of finite element modeling of the bridge
- strain data for fatigue analysis
- extreme event monitoring for bridge operators
- ongoing ambient vibration data collection for long-term health monitoring

5 HOTEL BUILDING, THAILAND

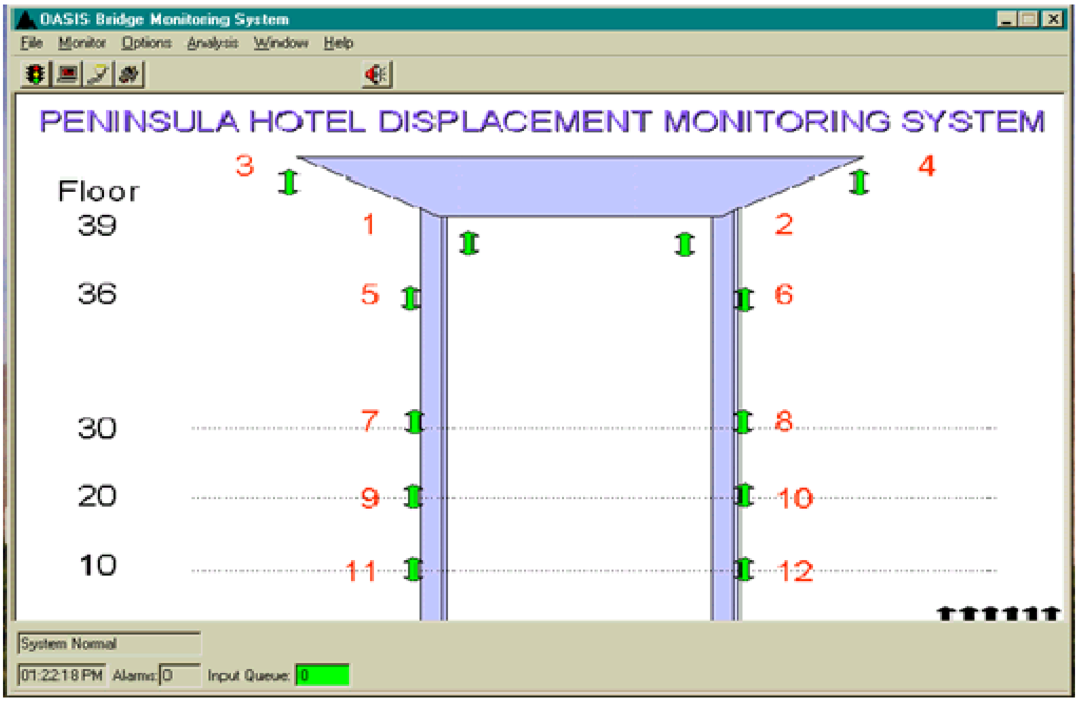


FIGURE 3: OASIS Configuration for Helipad Construction

A new 40-story hotel building in Bangkok, while under construction, was to be modified to add a helipad on its roof. The unusual retrofit involved the placement of two slender steel columns from the ground level to the roof level to support the additional dead and live loading. There was some concern about displacements during the transfer of load from the existing building frame to the two new columns.

An OASIS system was employed to monitor the new frame displacements before, during, and after the addition of the helipad. This system monitored displacements at twelve locations on the new helipad frame relative to the existing structure. The data acquisition subsystem consisted of a Kinemetrics Altus data logger. Communications were through wire using RS-232 protocol. A monitoring computer provided real-time, continuous monitoring of displacements, with alarms to alert of extreme displacements.

Figure 3 shows the OASIS real-time screen. This monitoring system proved useful during the load transfer process to confirm that the deflections were as expected. Continuous monitoring for several months after installation proved that the new structure was stable.

6 DISCUSSION OF EXPERIENCE

The two bridge monitoring systems have similar purposes. Basic elements of the Namhae Great Bridge Monitoring System have been installed since December 1996 including event recording and most of the sensor channels. The system was finally completed in May of 1997.

The Namhae OASIS system is more complex than the RAMA IX system on several levels. First, the basic number of channels is more than doubled. Second, for the first time fiber optic communications were used to transmit the data from the bridge to the operations center. This greatly improved the quality of the communications. Third, the type of data being recorded is more complex, including wind at two locations, displacement between the deck and the towers, and dynamic strain in the steel deck.

Of these the strain data are perhaps the most important for future evaluation of the bridge. One of the purposes of the system was to utilize static and dynamic strain gages to collect data on the fatigue capacity of the bridge. The static data were recorded at low data rates using a separate recording system, which could be accessed off-line using OASIS communications. The dynamic strain data recorded by the system were needed for evaluating the long-term performance of the orthotropic steel deck for several reasons:

- Need confirmation of actual strain levels at critical locations
- Continuous strain data is needed for statistical analysis

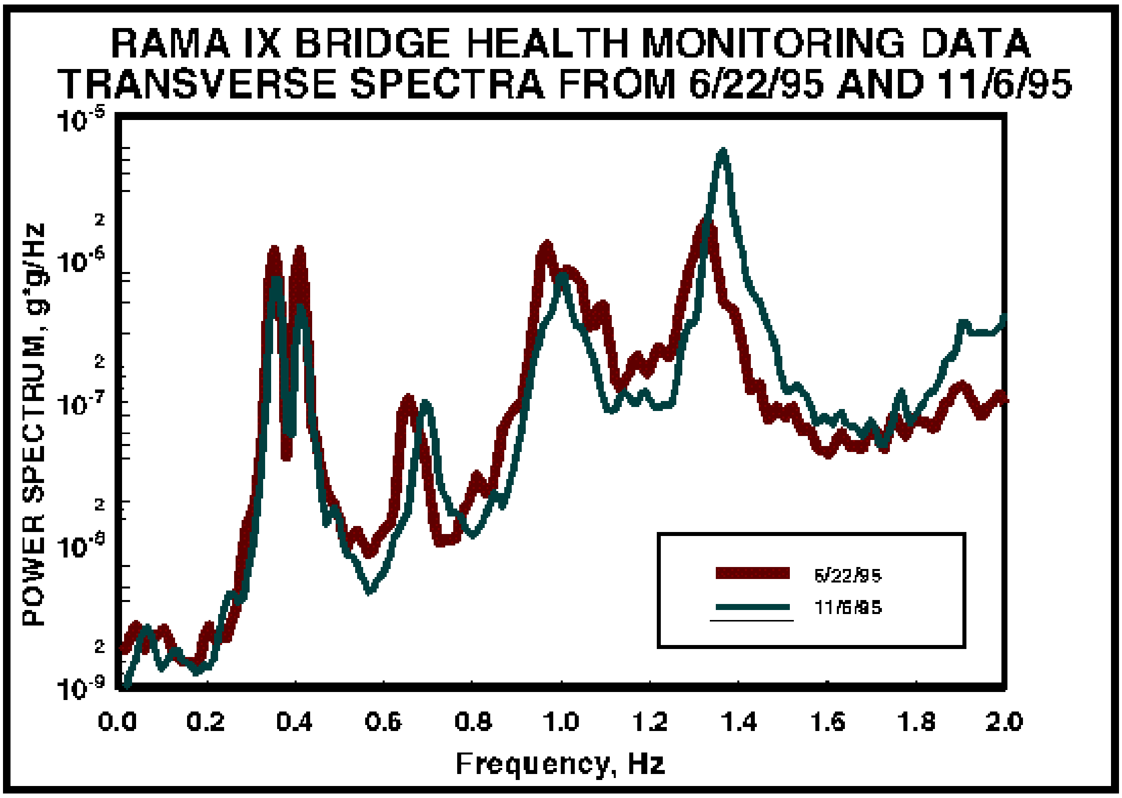


FIGURE 4: Sample Data from Rama IX Bridge

- Need to develop baseline data for future fatigue studies

During the upcoming structural inspection of the RAMA IX Bridge, it is also anticipated that the strain data will be of most use in the determination of structural condition.

Ambient vibration data for both bridges have been useful for comparison with and calibration of finite element models. This will be especially useful in the upcoming structural inspection of Rama IX. Use of these vibration data for "health monitoring" or damage detection is a more difficult issue. Changes in dynamic properties have been observed as shown in Figure 4, but these changes are likely a function of traffic loading or environmental conditions than structural properties. Much research is now being done on this topic of damage detection from global vibration data. Kinemetrics' collaboration with Los Alamos National Laboratory may bear some fruit in the next few years as far as providing useful health monitoring algorithms.

The OASIS system installed on the hotel in Thailand had a very different purpose, to monitor deflections during construction. This is perhaps a more typical application of structural monitoring. However, the addition of real-time capability and the graphical interface proved useful during the most critical part of the construction process.

7 CONCLUSION

Kinemetrics' OASIS Structural Monitoring System is a commercial system based upon standard components. Three examples of OASIS installations are described in this paper. The remote real-time data analysis and display provides simplified green/yellow/red-type indication of structural condition. Recorded high-resolution data are available for dynamic vibration- or fatigue-based condition assessments. Future augmentations, based upon ongoing research, include realizing the long-term health monitoring capabilities for which the system was originally designed.