Long Term Bridge Monitoring In Seattle WA., USA

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ABSTRACT:

The City of Seattle is located on Puget Sound in the Northwest corner of the U.S. The Seattle Department of Transportation (SDOT) is responsible for evaluating and maintaining 149 bridges in the City of Seattle. Thirty four of these structures are 70 years old or older with an average age of all bridges being 54 years old. Seattle is also located in an active seismic area; with the latest earthquake of magnitude 6.8 (Richter) was in February of 2001. Because of visible degradation induced by earthquakes along with age-related and load rating considerations, SDOT has implemented a monitoring program on several of their bridges. The goals of the program are:

- To monitor known structural defects such as cracks or tilt
- To monitor critical members in an administratively load rated bridge
- To monitor change over time

SDOT is anticipating that a relatively small investment in developing their own in-house expertise in both installing and maintaining these systems will pay off in improved monitoring and significant savings in structure replacement.

This paper will first outline the rationale for developing the in-house expertise for installing and maintaining these systems, then discuss how instrumentation plans are kept as simple as possible in order to obtain the required information. This will be followed by a discussion of the hardware and software details. Data histories will also be provided along with an outline of how it will be useful in making decisions regarding the structure's maintenance or replacement schedule.

1 THE NEED FOR A MONITORING PROGRAM

The Seattle Department of Transportation realized the need for a monitoring program in the year 2000. Several questions arose such as what was the goal of a bridge monitoring program? What bridges are we going to monitor? What specifically are we going to monitor? How are we going to monitor? All these questions and issues were evaluated and reviewed. It was determined that bridges that were administratively load rated; bridges with low load ratings and bridges with structural defects that could not be posted without significant inconvenience to the public, would all be candidates. At the same time, we wanted to be assured that if there was further decline of the structure we would be able to track and document the changes. Another need was to monitor defects such as shear cracks, to look for a change or a possible failure over time. Public safety of the traveling public was the primary concern of the program.

2. FACTORS TO BE CONSIDERED

When making plans for a long term monitoring system some of the factors to be considered are:

1. How long do we want to monitor the structure? It could be for a week, a month or for years. This relates to if there is a need to monitor change over time or if the need is a snapshot. Crack monitoring would be an example of the need for a long range program or change over time. Short term monitoring is usually related to a

specific event e.g. construction activity in the structures immediate area

2. What type of data do we want and how much data do we want to collect? More data is not always better. Data should be directly related to the answers of number one above. It should be clear and reliable and aid in decisions or policies concerning the bridge.

3. How will the data be used? Collecting data for the sake of getting it or because the data would be interesting, does not necessarily serve the purpose of the program goal. Data needs to directly support critical decisions or policy regarding the structure.

4. Data management from onsite storage, collection, processing, display and reporting. Data management should be as easy and automatic as possible. Data should be able to be read from the source in "Real Time" by connecting to the bridge site and automatically collected. The data storage and retrieval database should enable the user to view data in a graphic format from any time period.

5. What are the initial costs? What are costs for maintenance and the costs associated with data management. There are two basic approaches when developing a bridge monitoring system. The first is the proprietary black box that is attached to the bridge with some software at the office. This type of system relies heavily on support from the manufacturer. The second is to assemble a system using off the shelf items. This system is usually more flexible and can be used in many situations. Local staff can be trained to design, program, install and monitor and repair the system. If the system is in need of some type of repair, trained staff could respond quickly. Because each system uses the same components, a small inventory of on hand parts would mean the downtime is kept to a minimum.

After considering the above factors, SDOT selected these requirements for a long term bridge monitoring system:

1. The system must be able to record slow changes over time due to loading and environmental effects. This calls for sensors that are not prone to drift and some type of data display and data base that can graph the readings. The system also needs to detect and report sudden movements in the structure.

2. Structure temperature readings and individual sensor temperatures are important when monitoring changes in the structures behavior.

3. The on site system must be robust and be able to operate in a self sufficient manner. The data logger must automatically collect data from the sensors, examine the raw data for errors, and notify owner of any out of tolerance readings.

4. The process of processing raw data and summarize the results is another requirement of the on site data logger.

5. The on site data logger must be accessible from the "Main Office" so the data can be collected and any configuration changes to the logger be uploaded.

6. The on site system, must stand alone separate from the main data collector.
Alarms must be able to be relayed to key personnel regardless of the state of the data collection PC

7. Data storage must be in a database format. The need to review historical data is very important to track change over time.

3. EQUIPMENT / GAGES

After considering the above factors, SDOT selected these requirements for a long term bridge monitoring system:

GAGES

1. Vibrating wire crack gages
2. Vibrating wire tilt meters
3. Vibrating wire strain gages
4. Temperature sensors

It is important that the selected gages be a reliable simple technology with low drift. Low drift is very important for detecting change over a long period of time. Because a structure is dynamic with changes in temperatures, temperature sensors should be installed in the structure. If the structure is large, several temperature probes may be needed. Each sensor should have a thermistor for reading and recording local temperature. Gages that have direct sunlight on them during part of the day may need to be compensated. Covers should be installed over all the sensors. There are two reasons a cover is necessary; one being protection from the elements and possible vandals, the other has to do with the temperature of the structure compared to the temperature of the gage. The coefficient of expansion due to temperature is very close between the steel wire in the vibrating wire gage and the concrete (or steel) structure. If the gage is covered, it will tend to be a similar temperature as the structure, making gage /temperature drift a non issue.

Fig. 1: Vibrating Wire Extension Gage on an Expansion Joint

The advantage of a vibrating wire gage over more conventional electrical resistance (or semiconductor) types lies mainly in the use of a frequency, rather than a voltage, as the output from a gage. A very basic overview of a vibrating wire gage would be to stretch a steel wire between two fixed points that are mounted to the bridge. Deformations in the bridge (cracks, strains or tilts) will cause these two points to move relative to one another, thus altering the tension in the steel wire. The tension is then measured by plucking the wire and measuring the induced resonant frequency of vibration using an electromagnetic coil. Frequencies may be transmitted over long cable lengths without appreciable degradation caused by variations in cable resistance, contact resistance, or leakage to ground. This provides a very stable gage that is required for long term monitoring.

4. DATA LOGGERS

The data loggers are the very backbone of the system. When considering a data logger, many points must be examined.

1. Power requirements for the data logger, not only voltage but current also must be considered. Alternating current power sources may not be available readily at the bridge. SDOT's system runs on 9.6 – 16 volts direct current and draws only 1.3mA quiescent, and 13mA when processing. Between measurement routines the processor goes into the quiescent mode, conserving power. The power options for our data loggers then are 120 VAC using a power supply, Solar panels or even a car battery for temporary monitoring. A battery backup should be used in case of power outages or low voltage from the solar panel.

2. The data logger communication options should be as versatile as possible. Systems that may be used are short haul MODEM, radio, hard wired phone line, cellular phone or satellite. A RS232 port should also be available for in field direct connects.

3. The number of sensors the data logger can handle should be as high as possible. SDOT's largest number on one structure is seventy sensors.

4. Internal memory should be at least 2 M. A temporary monitoring system may be required that would involve collecting data from on site, 2 M of memory can store months of data depending on the number of sensors.

5. Analog type inputs are necessary for standard voltage loop sensors.

6. External digital I/O ports for discreet contact closures may be necessary.

When selecting a data logger for use in a long term monitoring program it would serve you well if the unit was designed to operate in a field environment. Every opportunity should be taken to protect the data logger from the environment but, heat, cold and humidity must be considered. Proper programming of the data logger is crucial to get the data results that match the goals of the project. A basic program can be written and used on many structures with only minor changes. Field crews can be trained to make these minor changes, insert calibration factors and alarm values. Developing this type of program makes startup of a new site relatively easy to do. Troubleshooting the program becomes easier because all sites are basically the same. Of course there will always be exceptions and the new site will not perform as needed unless a special program is used. In this case programming should be easy to understand and perform.

5. DATA COLLECTION AND COMMUNICATIONS

At the main office, a desk top PC can be used as the data collector. The data collection software must have these functions:

1. Communicate with the data loggers through which ever mode they require (hardwired phone, cell phone, radio, satellite)

2. Have an automatic collection routine that can be custom configured to collect the latest data from the logger at any time interval. Each site must be able to have its own interval time, that is to say, one site may need to have its data collected every two hours, while another site may only need

its data collected every month. The system must also know to collect only the added data since the last collection.

The old data stays in logger in case it needs to be retrieved; the memory in the logger should act as a FIFO (first in first out) type memory.

3. Data for each site should be saved to a unique folder on a remote drive that is backed up regularly.

4. Data should be stored in a CSV (comma separated value) format. In this format it makes it easy to display special graphs using a spread sheet program.

5. A collection history window makes it easier to see what sites have been collected and when. It will also flag any communications problems that may have occurred.

6. Within the communications package there should be a method of calling the remote data logger. The advantage of this is to be able to view data from the logger in “Real Time”. All sensors should be able to read in the raw value and Delta value, in numbers and graphically. Being able to do this makes it easy to check alarms, or troubleshoot any problems. The online ability also makes it possible to change alarm set points, or any other set point within the program.

While online with the logger, uploading a new or changed program should be possible. One word of caution, if there is a need to change the program or to halt the program the old initial readings of the sensors should be recorded first. The reason is, when the program restarts, it changes the initial readings. Changing the initial readings will reset all the sensor delta readings to zero. Because one of the primary reasons for a long term monitoring program is change over time, resetting the sensors would defeat that goal. After the program is updated, or restarted it should be possible to send the logger the old initial readings. This will result with seamless delta readings. If the initial readings are not recorded before the reset, they are gone forever unless they are included in the routine data upload. It is good practice to record the initial readings for each site when the logger is started.

6. INTERNAL AND EXTERNAL ALARMS

As mentioned previously alarms that are generated from the data logger would be considered an external alarm. What that means is that a sensor has two set points for the delta reading alarm, a high reading and a low reading. If either set point are exceeded the logger has the ability to dial a pager and send a numeric page (usually a number signifying what bridge). It is good practice to qualify the alarms by programming in a time that the gage must be out of tolerance before alarming. Consider latching the alarms, so that if the alarm condition changes back to normal it is easy to see which sensor went out of range. In the program, it is also a good idea to have the ability to shut off or ignore the alarms on individual sensors, that way if a sensor fails it would not keep sending in nuisance alarms.

Internal alarms are a secondary alarm system that originates from collected data on the data collection PC. A graphic screen shows each sensor, it’s high and low alarm setting, it’s current delta reading (as of last data collect), and if it is in alarm or not. An alarm Wav file can be assigned to any active alarm and for playing on the data PC. The purpose of the secondary alarm system is any sensor on any bridge can be quickly scanned for alarm status.

Programming of the data logger is usually unique to the type of data logger. Since there are many types of data loggers and many ways to achieve the program goals specific details of programming will not be included. There are some features that make logger management and troubleshooting easier.

1. Program notes and comments should be able to be written directly on the program. This enables easier troubleshooting and helps keep track of program upgrades.

2. Using comments and the ability to comment sections out of the program. Provides one flexible program and can be altered for many structures. Simple editing (commenting out) tailors the program for the specific site.

DATA DISPLAY / DATABASE

With any monitor program it is necessary to be able to display the data in an easy to read format. Graphing the data has been found to be the easiest method. Some considerations when selecting graphing options are:

1. Alias ability, which is the ability to rename a sensor for graphing, is a useful option. An example would be a crack sensor that is in the second bent, third girder, in the program may be called “DVal_2-1”, Not very useful information when looking at a graph. With alias ability in the graph the sensor could be renamed “Bent 2, Girder 3, Crack Gage” which is a much clearer way to show data. You may know what DVal_2-1 means but I would bet others will not.

2. Each sensor should be able to be displayed in an appropriate engineering unit.

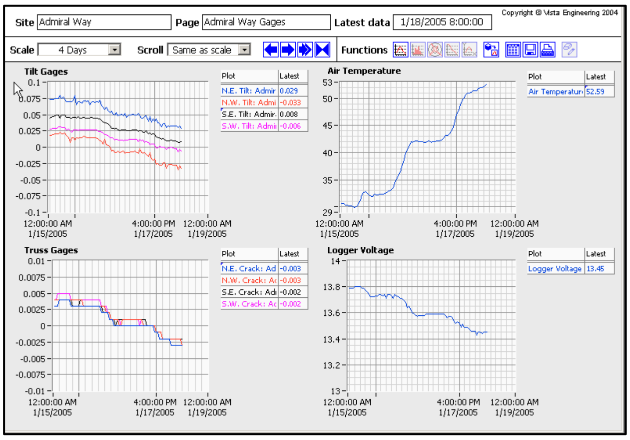

Fig. 2: Typical Web Presentation of Sensor Values, here with 4 days of data.

3. When setting up the graphing, if only one or two structures are being monitored with only a small handful of sensors keeping the graph screens straight is not a problem. As your system grows, attention must be paid to how your screens are organized. The way the SDOT system is organized each bridge is a book, within the book is a chapter. A chapter may have several themes, or graphs. There may be as many as 6 graphs on the screen. Then there are pages or individual graphs. In this way data graphs are clear.

4. Graph Y (engineering units) axis should be able to be preset or automatic.

5. Graph X (time) axis should easily be able to be varied. The SDOT system can be varied from one hour to one year. It may seem odd to have one year of data on a screen but for overall change over time at a quick glance, it is a useful tool.

6. Having a left and right hand axis makes the graphing clear. As an example, if a crack is opening and closing due to temperature changes, having the temperature (in degrees) and crack width (in thousandths of inches) makes it clear to see the changes

7. The database for the collected data makes easy work of data review. The SDOT system has a data robot that looks at the collected data from the bridges every two minutes. If there is new data in the files it is imported into a database. What this enables you to do is to rapidly look at historical data graphically. A couple quick clicks on a calendar retrieve the data for that time period, be it two days or two years ago.

When starting a long term monitoring program planning for the results that you need to make decisions is key. This paper is only a very brief overview of considerations.

CASE STUDIES

1. 15th NE & NE 103rd BRIDGE

The 15th NE Bridge is a 502 foot long, concrete, twin box beam girder, built in 1949. The HS20 Operating load rating is .17, with 1.00 being adequate to carry legal loads with no restrictions.

The structure has severe shear cracking in the box girders near the bridge piers and moderate moment cracks at mid-span.

- The bridge is on a major bus route.
- The bridge would need to be load restricted if it was not Administratively load rated
- Live load testing of the bridge confirmed the theoretical load rating

The bridge was placed on the unfunded needs list, but with the condition of the bridge it must be closely monitored.

The monitoring system was installed in 2004 to monitor the cracks and strains in the box girders. Cracks are measured to a tolerance of .001 inches. The strain gages are monitored for load path shifts within the structure.

After near 5 years of monitoring the structure it was found that the cracks are active and open and close due to temperature. It was also found that the cracks are elastic in nature, in saying the steel in the rebar is not yielding. The strain gages show no change in load path.

Because of the close monitoring of this bridge, SDOT was able to safely keep the bridge open to all traffic avoiding major re-routes of heavy vehicles.

Designs for bridge rehabilitation are completed and construction will be during 2008 – 2009

2. MAGNOLIA BRIDGE

The Magnolia Bridge is a 3008 foot long concrete structure that was built in 1929. Approximately 500 feet of the structure is on concrete trusses. While concrete is an excellent material for bridges, it does not perform well in tension as needed in a truss element. The trusses show signs of cracking in tension and has moderate to severe spalling.

- The bridge is a major bus line
- The bridge serves a large community
- The bridge is urgent to freight mobility

The bridge has been on the un-funded needs list for over 10 years and it was determined that the bridge trusses needed to be monitored.

The monitoring system was installed on the truss sections of the bridge in 2005. It was determined that the monitoring system will detect any changes in the tension areas. This was accomplished by monitoring the length of the lower cord of the truss and by measuring the horizontal distance between the vertical ends of adjacent truss units. Normal deformations of the trusses due to thermal movement could be monitored and checked. If a lower chord cracks its length will change and be recorded. If the vertical members move towards or away from each other that would also indicate an element failure.

The bridge has a preliminary design but the complete design and construction remain unfunded. With the monitoring system in place the bridge remains open to all traffic.

3. AIRPORT WAY OVER ARGO YARD

The Airport Over ARGO Bridge is a 1496 foot long bridge steel plate girder main span with concrete girder approaches. It was built in 1928 with a major rehabilitation done in 1979.

The structure has moderate shear cracking of the pre-cast girders near the crossbeams. Some of the shear cracks penetrate through the girder.

- The bridge serves a railroad yard and is very important to freight mobility.
- The bridge is on a major bus route
- Some of the girders are being supported by temporary timber structure

The bridge has been on the unfunded needs list for over 5 years. Because the bridge serves the railroad yard, and the heavy loads related to that, the shear cracks must be monitored or the bridge would need to be closed to trucks.

The monitoring system was installed in 2007. Crack gages were installed across the shear cracks to monitor growth of the cracks. As a precaution, the inside lanes were closed to trucks.

Because of the monitoring the bridge remains open to trucks. Rehabilitation plans are 60% complete with construction beginning in 2011.

4. UNIVERSITY BRIDGE

In 2007 a 24 inch water main broke and eroded the fill under the South abutment of the University Bridge. The University Bridge is one of the main crossings over the ship canal in the City of Seattle.

The bridge was closed to traffic because of the washout. Tilt gages were installed in four locations on the bridge abutment and monitored for movement. Because of the in house expertise and the flexibility of the monitoring system this was accomplished in a few hours. The abutment was able to be monitored during the repair of the water main and back fill operation. Traffic was restored within two days of the break. The monitor system was left in place for two months to see if there would be any settlement. It was concluded that the backfill was adequate and no settling occurred or was anticipated.

5. OTHER PROJECTS

S.W. Admiral WAY Bridge

Concrete truss members same as the Magnolia Bridge on a smaller scale.

Cowen Park Bridge

Gages on moment cracks in the cross beam

West Seattle Freeway

Monitoring lateral movement of girders

6. AUTHORS

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