# Catch a Soundless Cry from Aged Infrastructure

Developed a technique for sensing fatigue degradation using strain measurement "SI-F method-based fatigue degradation sensing technique" toward advancing a monitoring method

As social/industrial infrastructure is aging, demand to realize safe and secure operation at low cost is increasing. To ensure structural health, "monitoring techniques" using various types of sensors have been widely utilized, and methods for automatically sensing/diagnosing the presence of degradation have been widely developed towards practical use. In this article, IHI's unique "SI-F method-based fatigue degradation sensing technique" is introduced together with peripheral techniques.

MIYAZAKI Shinya
Structural Strength Department,
Research Laboratory,
Corporate Research & Development,
IHI Corporation

Monitoring target   Strain measurement   Data acquisition/analysis → Fatigue degradation sensing

Outline of SI-F method-based fatigue degradation sensing technique
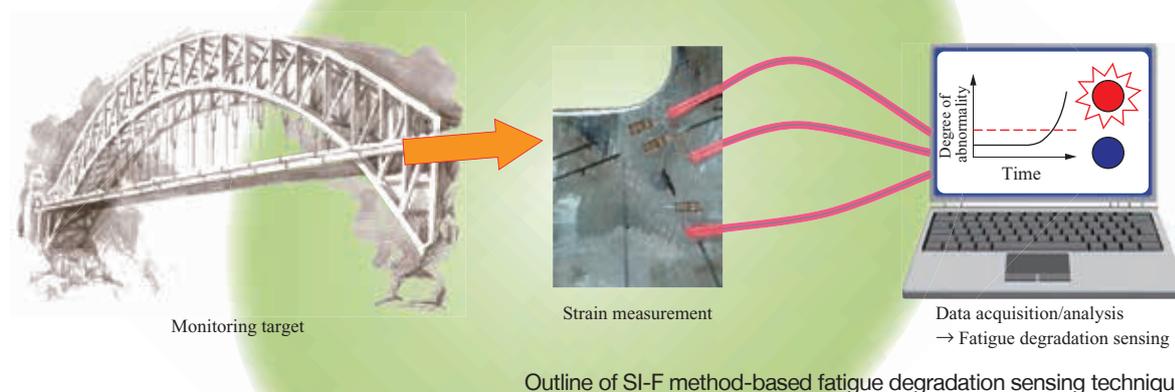
Actual circumstances of infrastructure aging

Social infrastructure such as bridges and tunnels, and industrial infrastructures such as chemical/storage plants and cargo handling machines are aging, giving rise to social problems. A reduction in strength along with aging may cause fatigue failures which can give rise to large-scale accidents; resulting in injury or death, and also economic losses.

Specific examples of fatigue failure of bridges include the cases of "Honjo Ohashi," Akita prefecture (built 41 years ago), and "Kisogawa Ohashi," Mie prefecture (built 44 years ago), where corrosion had caused fatigue fractures in structural members. In both of these cases the fractures were found by inspection and repaired, but if they had been overlooked, a large-scale collapse would have occurred.

Even aged bridges can be prevented from collapsing on a large scale by performing regular inspections and maintenance. However, Japan has 157 thousand road bridges with a length of more than 15 m, and more than half of them will exceed 50 years of age by 2030. To prevent failure due to rapidly progressing degradation, it is necessary to perform inspection more minutely and frequently. However, this causes concern about increasing inspection costs. For this reason, putting a low-cost inspection technique into practical use is desirable.

The industrial infrastructures also include facilities that were manufactured more than 50 years ago during the high economic growth period of Japan, and their aging is becoming a serious problem. Further, along with the globalization of industrial activities, domestic facilities have been reduced, and an unexpected stop of operations under limited facilities significantly impacts company's production activities. In order to stably operate aged facilities in such circumstances, preventive maintenance techniques to prevent trouble from occurring are increasing.

Spread and problems of monitoring techniques

To reduce inspection costs and realize preventive maintenance which are socially demanded, monitoring techniques using sensors to constantly monitor various states may be effective, and are being widely developed in the world.

Examples of the monitoring techniques include monitoring of acceleration, strain, displacement, etc. of "Tokyo Gate Bridge." This is a large-scale case of accumulating various pieces of data from sensors and monitoring various states in real time. However, the presence of abnormalities is manually diagnosed, and not applied with techniques for sensing fatigue failure in real time (Nikkei Construction, August 26, 2013).

In order to practically use the monitoring techniques for the reduction in inspection and preventive maintenance costs, it is important to establish a high accuracy diagnosis technique
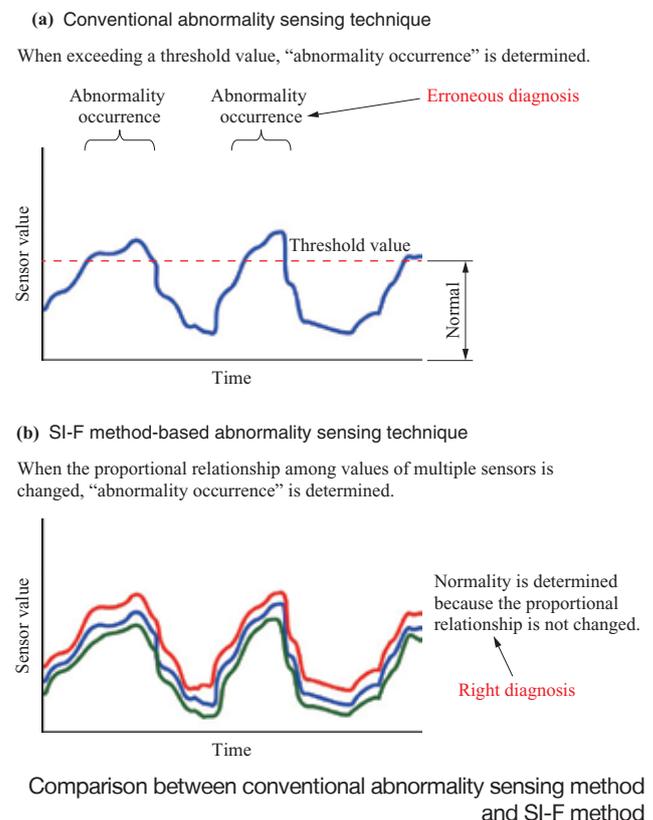
which is capable of automatically sensing and analyzing abnormalities without the need of manual operation.

The automatic diagnosis technique used in monitoring aged infrastructure is seen as a medium-to-long-term technical development target from a political aspect as well. The Ministry of Internal Affairs and Communications is setting a goal of realizing "Verification of multi-sensor maintenance systems for social infrastructure" by 2018 after establishing a low-cost data acquisition technique (ICT Strategic Meeting). Also, the Ministry of Economy, Trade, and Industry has launched a development project towards establishing "Data analysis technique for presuming time interval of repair" by 2020 (Strategic Market Creation Plan). They both will be developed using the technical strengths of the private sector.

Since the private and public sectors are collaboratively pursuing the technical development, a number of demonstration experiments will be performed around 2020 to put the technique into commercial use. IHI is currently developing the "SI-F method-based fatigue degradation sensing technique," an automatic abnormality sensing process, in order to establish a unique monitoring capability for maintaining structural health at low cost.

Fatigue degradation sensing technique based on SI-F method

The SI-F method is a statistical method proposed by the Todoroki Laboratory of Tokyo Institute of Technology, and a technique for sensing the occurrence of abnormalities.

(a) Conventional abnormality sensing technique

When exceeding a threshold value, "abnormality occurrence" is determined.

(b) SI-F method-based abnormality sensing technique

When the proportional relationship among values of multiple sensors is changed, "abnormality occurrence" is determined.

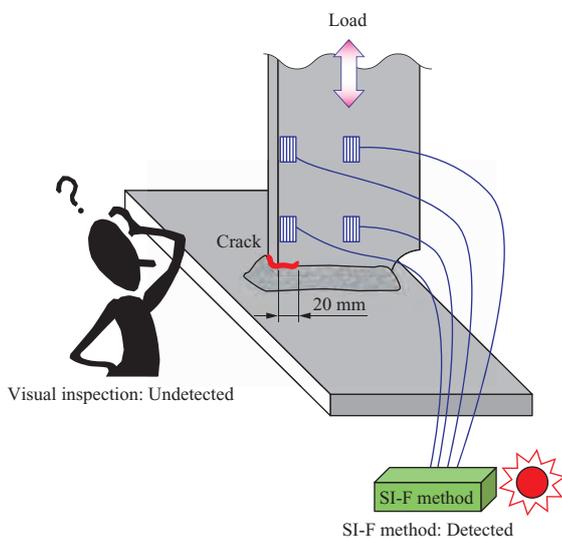Comparison between conventional abnormality sensing method and SI-F method

Conventional abnormality sensing techniques are mainly based on a method that compares individual sensor data with a threshold value. This method often makes an erroneous diagnosis because sensor data may exceed a threshold value due to disturbances (variation in temperature, variation in load, etc.). Furthermore, setting a threshold value larger to prevent the erroneous diagnosis may reduce sensing accuracy, potentially masking the occurrence of true abnormalities.

To prevent this, it is effective to focus on the proportional relationship among multiple pieces of sensor data, and determine the occurrence of abnormalities from a change in their relationships. The relationships among the multiple pieces of sensor data is unlikely to be affected by disturbances such as a change in temperature or a change in load, and consequently prevents both erroneous diagnosis, and increases accuracy.

The SI-F method determines whether or not a proportional relationship at the time of diagnosis can be regarded as the same as a proportional relationship at the normal time. In the event they both cannot be regarded as the same, it can diagnose the cause of the abnormality. An F-test, a statistical approach for testing the equivalency between pieces of data, is used to determine this. A calculated F-value is unlikely to be affected by disturbances, and gives a single numerical value which increases if the degree of abnormality becomes higher. As a result, an automatic diagnosis can be performed with a threshold value set. IHI has already completed basic programs for F-value calculation and automatic diagnosis processing, and is ready to put the programs into practice.

The SI-F method is a technique to sense the occurrence of various abnormalities. This article introduces a technique for catching strain abnormality to sense fatigue degradation (crack occurrence/crack growth) with high accuracy. Note that in the following, the "fatigue degradation sensing technique based on the SI-F method" is referred to as an "SI-F method."

Preparation of automatic diagnosis guidelines

It is said that the length of a fatigue crack findable by visual inspection in an actual welded part is 30 mm or more. In this development, the SI-F method that can detect a crack below 30 mm in length has been established by performing fatigue tests on bodies with shapes close to those of actual bridges and load machines. We have already finished the basic research stage, and are currently working on development toward applying the SI-F method to products.

In order to practically apply the SI-F method, the guidelines for monitoring methods were prepared. Also, a welded part was set as an application target, and to sense fatigue degradation faster than visual detection, we decided to sense the occurrence of a fatigue cracks that had a length of less than 20 mm. Further, with reference to the welded joint category of the fatigue design guidelines for steel structures, five different shapes were selected, and also in consideration of a difference in how a load is applied, eight types of targets were selected. A state with no crack, and a state with a crack

Crack detection by visual inspection and SI-F method
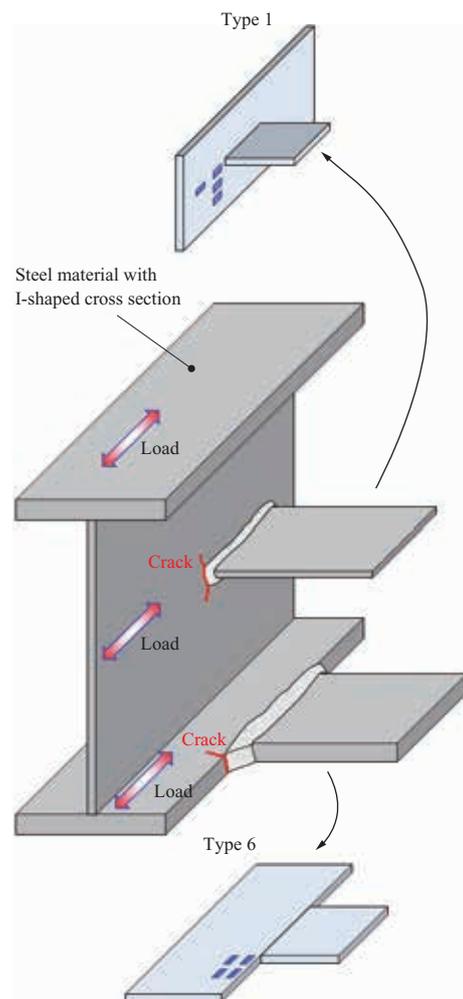
Example of application of SI-F method guidelines

with a length of 20 mm were modelled using the finite element approach, and stress analyses were made to grasp the tendency of a change in strain due to the occurrence of a crack. By fixing three or more strain measurement positions to examine the change in proportional relationship, the occurrence of a fatigue crack can be sensed with high accuracy.

To perform automatic diagnosis using the SI-F method, a welded joint of a similar type is selected from among those listed in the guidelines in accordance with shape and how a load is applied, then the strain at a position suitable for monitoring fatigue degradation of the type is measured.

To practically use the SI-F method, a technique to acquire pieces of data on strain change under loading over a long period of time, and a data transmission system for monitoring products around the world is required. The following describes such peripheral techniques.

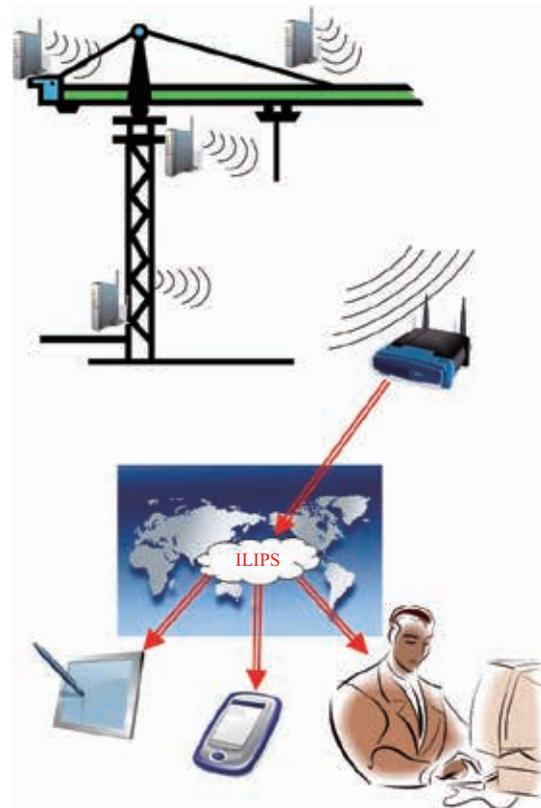## Development of wireless data acquisition technique

IHI group's products include machines having a 100 meter long member, and several kilometer long bridges. Wired acquisition of pieces of strain data on long structures causes high costs. Wireless communication is effective at reducing cost.

IHI is working on the development of a wireless strain data acquisition system with functions suitable for the SI-F method. Using digital communication leads to practical stability and reliability. However, the biggest problem when using the SI-F method for practical measurement lies in a power source.

A monitoring device is expected to be operable without maintenance such as battery replacement for a period of one to five years (a regular inspection period). We are currently aiming to extend an operable period to several years by utilizing power feeding based on "energy harvesting techniques" such as solar power generation, a vibration power generator, and thermoelectric power generation, together with power saving of measuring instruments.

Practical use of ILIPS

To monitor products around the world in real time, a technique to transmit data to remote places is required. To realize it, the IHI group has developed a common remote maintenance platform – IHI Group Lifecycle Partner System (ILIPS), and will use ILIPS for the SI-F method as well. ILIPS is a system that accumulates and transmits pieces of data acquired on-site through the Web. In addition to this, ILIPS has a function adapted to transmit an alarm mail when sensing an abnormality, and can therefore find abnormalities of many products without omission.

Collaboration between wireless data acquisition system and ILIPS

Spread of monitoring techniques

The SI-F method is currently at the verification test stage following the completion of accuracy verification and guidelines preparation. Long-term strain measurement has been and is still being performed on a jib crane in Yasuura Works (Hiroshima prefecture) of IHI Transport Machinery Co., Ltd since November, 2012.

In the future, we are applying the SI-F method to a verification test on more products with the aim of putting it into commercial use. If there are any candidate products for such applications, we would like you to inform us about them.

Inquiries:
   Corporate Research & Development,
   IHI Corporation
   Phone: +81-45-759-2213
   Website: www.ihi.co.jp/en/