# RESEARCH ACTIVITIES ON THE ASSESSMENT OF INFRA-STRUCTURES IN KOREA - CONCERNING THE RESEARCH ACTIVITIES OF ISARC -

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## SUMMARY

In this paper, recent research and application activities on the assessment of building and civil infra-structures in Korea are briefly introduced. The developments of structural health monitoring systems, assessment code, and effective retrofit / maintenance methodologies for infra-structures have become active in Korea since the middle of 1990's, as the number of the deteriorated infra-structures, mostly built on the rapidly industrialized period of 1970's, has increased very rapidly. Discussions are made on the research activities for the assessment of infra-structures from pre-built one required to be strengthened to newly constructed one, on the basis of the research activities of ISARC (Infra-Structure Assessment Research Center).

***Keywords:*** *ISARC; concrete structures; durability; load bearing capacity; serviceability; evaluation system; measuring equipments.*

## INTRODUCTION

Developments and applications of assessment technologies for infra-structures have been strongly required in Korea, since the early 1990's. The number of the deteriorated infrastructure systems, mostly built in the rapidly industrialized period of 1970's, has increased rapidly, and the recognition of the potential devastating disruption of the infrastructure systems due to natural and man-made hazards has also increased. Particularly after several tragic collapses of bridges and buildings in the middle of 1990's, the Korean governmental authorities issued more stringent requirements on infra-structures management and operational programs. They include systematic visual inspection, instrumentation, load capacity tests and field measurements for design and construction verification, and long-term performance monitoring and assessment. In advance, the integrated management system of infra-structures is getting spot-lighted and is to be an essential key for public safety. The details of this system should be taken into account for the maintenance and life-cycle prediction of structures for comprehensive evaluation. Moreover, additional need for the

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development of assessment code for more systematic management of infra-structures has also been increased.

In this paper, current status of research activities on the assessment of infra-structures in Korea is reviewed. Discussions are focused on construction of (1) evaluation system on durability issues, (2) evaluation system on load bearing capacity, (3) evaluation system on serviceability, and (4) structural integrity evaluation system. Representative research results in these four issues are briefly explained. In addition, development activities for many NDT methods and measuring equipments are introduced, and finally, a brief introduction to the research activities of ISARC scheduled at the second phase is followed.

## INFRA-STRUCTURE ASSESSMENT RESEARCH CENTER

Infra-Structure Assessment Research Center (ISARC) was established at Korea Concrete Institute (KCI) in 2004 (http://www.assess.or.kr), as an engineering research center sponsored by Ministry of Construction and Transportation (MOCT). The final research goal is the development of assessment codes relevant to the assurance of operational and structural safety and the improvement of life-cycle cost effectiveness for large infra-structures. To reach this goal, the following four research activities are emphasized: (1) construction of a performance-based evaluation system; (2) development of structural performance evaluation criteria; (3) introduction of new nondestructive testing (NDT) techniques; and (4) systematic prediction for life cycle. The key technologies include evaluation system including model and analysis program related to the durability issues, development of an integrated analysis package to predict the strength and deformation of concrete structure, structural health monitoring and integrity assessment. The present research team consists of 20 investigators who are professors or senior researchers at major universities or other institutions. Cooperative research projects are carried out with various government-sponsored research institutes and leading construction companies. The researchers in ISARC consist of those from various fields of engineering, such as civil, architectural, mechanical engineering and material science. ISARC hosts regular and special seminars and organizes technical courses by the invited experts in the field of assessment technologies to provide opportunities for the researchers/engineers in industries and academia to learn the advanced technologies on the assessment technologies and to develop cooperative research activities among the participants. In addition, ISARC is making an effort to cooperate with international research groups. For example, joint committee between KCI (Korea Concrete Institute) and JCI (Japan Concrete Institute) was organized on mid-June. The major purpose of this joint committee is to develop a common assessment code applicable to both countries, and the first meeting is scheduled to be held in Gyeongju, Korea on 13-14 October 2006. Other major research institutions related to maintenance and assessment activities in Korea are:

- Korea Institute of Standards and Science (KRISS), Safety Metrology Group: http://www.kriss.re.kr
- Korea Infrastructure Safety & Technology Corporation (KISTEC): http://www.kistec.or.kr
- Smart Infra-Structure Technology Center (SISTeC): http://www.sistec.re.kr
- Complex for Technology Fusion in Construction (C4TF): http://www.c4tf.re.kr

## EVALUATION SYSTEM ON DURABILITY

### Chloride Attack and Carbonation

The durability limit state of reinforced concrete structures is defined as a time for the corrosion initiation, i.e., the time to reach the critical chloride threshold value at the surface of the rebar in reinforced concrete structures. In order to predict the service life of reinforced concrete structures under combined mechanical and climate loads, it is necessary to develop an analytical approach to predict the time and space dependent deterioration of concrete structures up to the durability limit state and additional deterioration like cracking of cover concrete due to corrosion. For more accurate prediction of the service life, the pre-existing cracks in concrete and coupled deterioration should be considered.
To improve the accuracy of prediction, Song *et al.* (2005) carried out a service life prediction of reinforced concrete structures subjected to chloride attack and carbonation by using a micro-mechanics based deterioration analysis tool. In the tool, the pre-existing cracks and the coupled deterioration, i.e., chloride attack at carbonated concrete, in reinforced concrete structures were additionally considered. The prediction approach can evaluate the initiation of corrosion, corrosion rate and cracking of cover concrete. For the verification of the analysis tool, service life predictions were carried out for two major reinforced concrete structures (Incheon Grand Bridge and Busan-Geoje Fixed Link Bridge) designed for 100 years of service life in marine environment. The effect of crack widths and the coupled deterioration on the service life of the reinforced concrete structures were also analyzed and discussed.

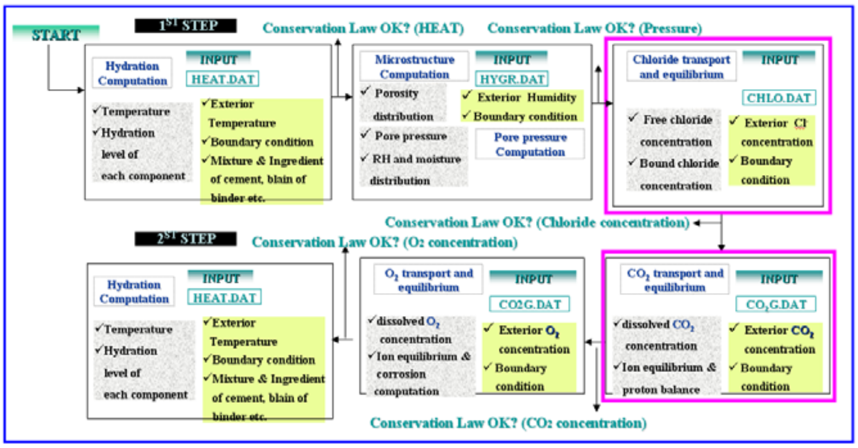



Figure 1 Overall scheme of a durability analysis

### Surphate Attack

There are many causes of the degradation of hardened cement-based materials such as carbonation, AAR, F-T cycles, DEF, seawater attack and sulphate attack. Deterioration of concrete structural components exposed to soils and groundwater contaminated with sulphate salts is a serious problem in durability of concrete, and especially, the deterioration of concrete due to sulphate attack in environments such as wastewater treatment facilities is an important factor degrading the durability of concrete structures. Although there have been numerous studies on the efforts to reduce the deterioration of concrete by sulphate attack in the laboratory as well as in the field, there are some difficulties in defining precisely the deterioration mechanism because of its complex behavior. To overcome this problem, Lee *et al.* (2006b) observed the micro-structure of the concrete deteriorated by sulphate attack using instrumental analysis such as XRD, SEM, and EDS. According to the results of the study, deterioration materials, ettringite/thaumasite, gypsum, and brucite, peaked on the surface of concrete due to $SO_4^{2-}$, $Mg^{2+}$ ions in waste water.

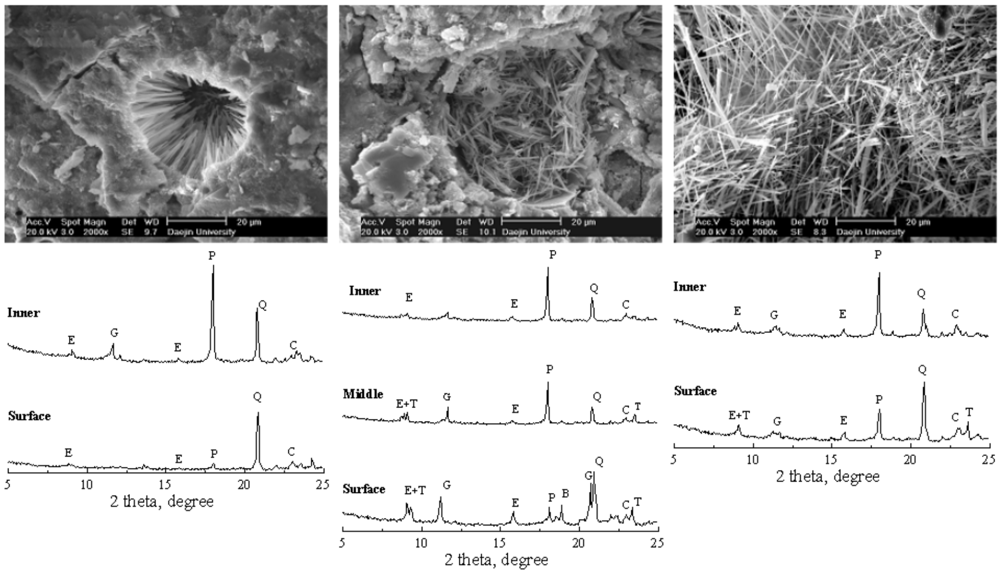



Figure 2 Scanning electron microscopy images of deteriorated sample and XRD profiles

## EVALUATION SYSTEM ON LOAD BEARING CAPACITY

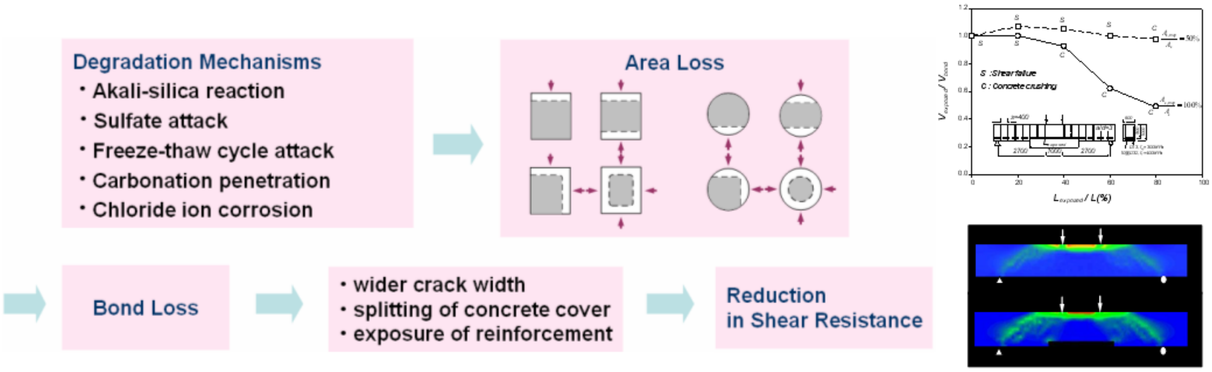
### Shear Load Carrying Capacity Evaluation

The principal causes of reduction of shear strength of reinforced concrete members are area loss of concrete and reinforcement. The area loss of concrete is due to various causes of concrete deterioration and the reinforcement corrosion is the principal cause of the area loss of reinforcement. The reduction of shear strength caused by the area loss can be considered using the site-specific data. On the other hand, in addition to the obvious loss of dowel capacity due to splitting of concrete cover, the reduction in bond will lead to wider crack widths, which in turn reduces aggregate interlock. As the exposure of the corner of a stirrup reduces the shear strength, it is therefore expected that the loss of bond would lead to a reduction in shear strength. Unfortunately, full bond is, however, assumed in all existing shear load-carrying capacity evaluation systems. It is therefore very important to enhance the understanding of how reduced bond influences the load carrying capacity particularly for shear, and Myung *et al.* (2005) proposed a residual shear strength evaluation model for reinforced concrete members considering the bond loss as well as the area loss of concrete and reinforcement.

### Seismic Performance Evaluation for RC Bridge Piers

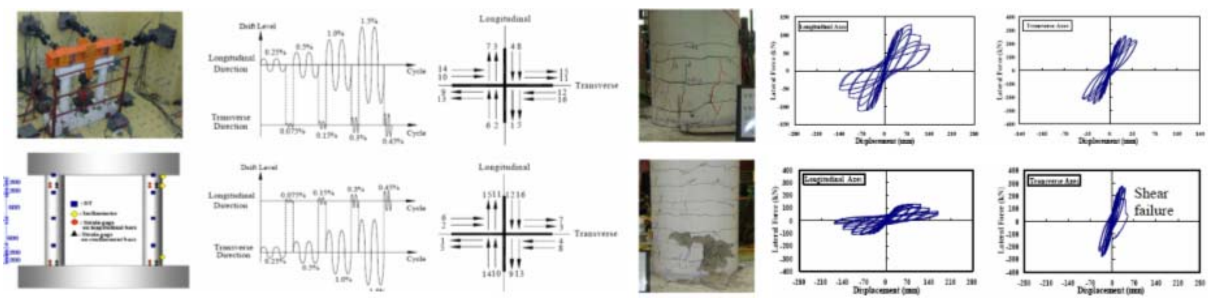
Bridges are potentially one of the most seismically vulnerable structures in the highway system. They may respond elastically or in-elastically to minor or moderate earthquakes. The damage of RC column-bent piers in regions that experience inelastic action depends on the characteristics of earthquakes as well as column details. The extent of this damage affects their seismic performance during the design-level earthquake and the feasibility of restoring the pier to its pre-earthquake condition. RC frame structures generally develop inelastic deformations when they are subjected to strong seismic loadings. Earthquake-induced energies dissipated through the formation of plastic hinges. It may not be possible to prevent hinging of reinforced concrete columns in bridge column-bent piers. Therefore, it is essential to design and detail earthquake-resistant columns such that their design strengths are maintained during a large number of inelastic deformation cycles. Meanwhile, it has been observed in the Korean peninsula that the occurrence of low or moderate earthquake motions have increased year by year even if Korea is located relatively far away from the active fault area. Thus, an extensive experimental and analytical investigation has been conducted at the following areas by Lee *et al*. (2005b, 2006a), Park *et al*. (2005a, 2006a) and Chung *et al.* (2005):

- A seismic performance analysis of circular RC bridge piers
- A study on influence parameter of seismic performance for circular RC bridge piers
- Suggestion for confinement steel ratio of circular RC bridge piers
- Seismic performance of RC bridge piers retrofitted with steel bands
- Displacement ductility based seismic performance evaluation of circular RC bridge piers




(a) Principal causes of reduction in shear resistance (b) Effect of bond loss

Figure 3 Shear load carrying capacity evaluation



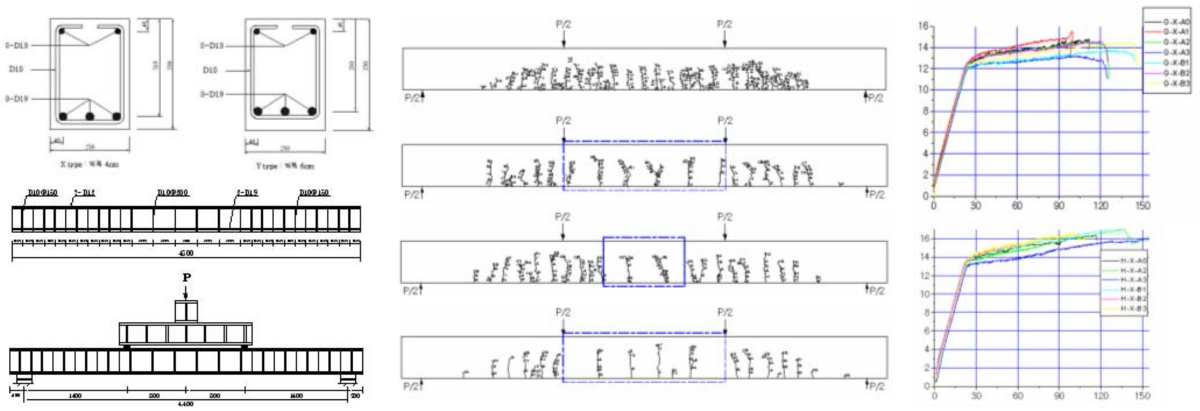

(a) Test setup (b) Load history (c) Crack pattern and force-displacement hysteresis curve

Figure 4 Seismic response and damage assessment of circular RC column-bent piers

## EVALUATION SYSTEM ON SERVICEABILITY

### Evaluation Technique of Cracked Members Considering Tension Stiffening Effect

As various loads are applied to a reinforced concrete beam, cracks may occur by the influence of shear and bending moments. These cracks propagate as the applied loads are increased. In addition, the deflection of the reinforced beam is also increased at the same time. Even though it is commonly accepted that the cracking and the deflection of a reinforced concrete beam are very closely related, many studies have not been conducted to provide basic data and to develop the relationship between them. To verify the characteristics of cracking and deflection behavior of RC beams, several specimens subjected to bending were tested with different concrete strength, coverage, amount of steel and de-bonding bars by Kim *et al*. (2006). Furthermore, until recently tensile stresses in concrete have not been considered as it does not affect the ultimate strength of reinforced concrete flexural members significantly. However, to verify the load-deflection relationship, the effect of tensile stresses between reinforcing bars and concrete, so-called tension stiffening effect must be taken into account. To evaluate the effective flexural rigidity in RC members considering tension stiffening effect, Kim *et al*. (2005) tested several specimens with different concrete strength, coverage, and de-bonding length of longitudinal bars, and the effects of these parameters on the flexural rigidity, crack initiation and propagation were carefully checked and analyzed.

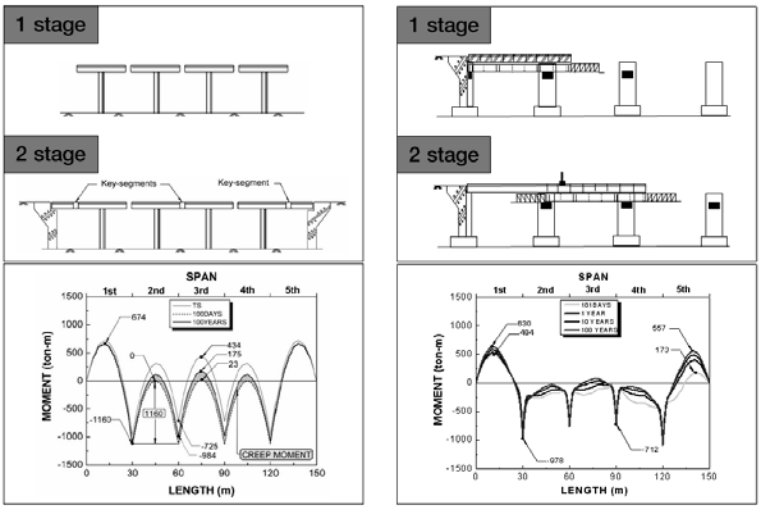


(a) Geometric configuration (b) Crack pattern (c) Force-deflection curve

Figure 5 Experiment on the cracking and deflection behavior of RC beams

### Time-Dependent Analysis of Bridges Constructed by FCM and MSS

The design and analysis of bridges constructed by the balanced cantilever method (FCM) and movable scaffolding system (MSS) require the consideration of the internal moment redistribution which takes place over the service life of a structure because of the time-dependent deformation of concrete and changes in the structural system repeated during construction. This means that an analysis of bridges which considers the construction sequence must be performed to preserve the safety and serviceability of the bridge. All the related bridge design codes have also mentioned the need to consider the internal moment redistribution due to creep and shrinkage of concrete when the structural system is changed during construction. On the basis of the compatibility condition at every construction stage, Kwak *et al.* (2004, 2005) derived basic equations which can describe the moment variation with time in the balanced cantilever and movable scaffolding constructions. Through time-dependent analyses of RC bridges, considering the construction sequence and creep deformation of concrete, structural responses related to the member forces were reviewed.




(a) FCM (b) MSS

Figure 6 Time-dependent analyses of bridges constructed by FCM and MSS

## STRUCTURAL INTEGRITY EVALUATION SYSTEM

### Integrity Evaluation of Environmentally Damaged Structural Members

In order to detect the damage of structures, visual inspection, non-destructive evaluation method (NDE) and specific loading test have been employed. However, obscurities for visual inspection and inaccessible members raise difficulty in evaluating structure condition. For these reason, detection of location and quantification of the damage in structures via structural response have been one of the very important topics in system identification research. Yoo *et al.* (2005) develop a methodology for the damage identification via static responses of the members damaged by durability and the study consists of (1) damage detection using the static deflection (single value decomposition, optimization, conjugate beam method), (2) inverse analysis and damage detection using health index, and (3) algorithm of damage detection process.

### Integrity Evaluation of Retrofitted Structures

As time goes up, structural capacity of members decreases in RC structures. The deterioration of the capacity is mainly due to the corrosion of materials, environmental pollution, etc. Thus it is necessary to develop the method for repair and retrofit of structures in order to ensure structural safety of members. Choi *et al.* (2005, 2006) examined the emission of acoustic signals from repaired/strengthened structure. Acoustic monitoring techniques are mainly applicable to dynamic situations where processes generate acoustic emission. Choi *et al.* (2005, 2006) also used the technique to detect acoustic energy emitted as concrete cracks under load, and efficient methods have been developed to accumulate and process data generated by such events as they occur. In the study, concrete members under axial, fatigue, and flexural loads were used to evaluate cracking and failure process.

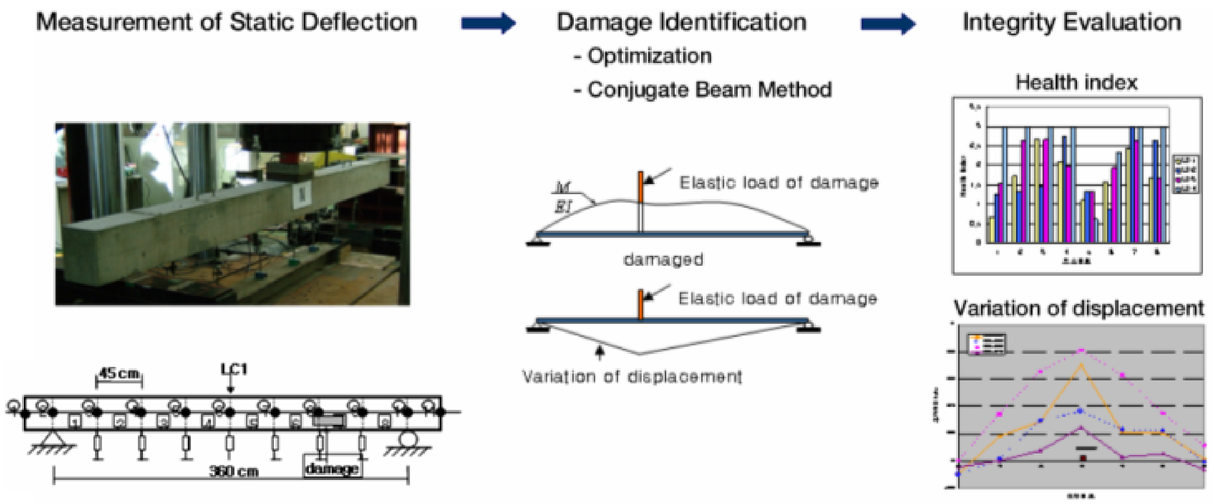
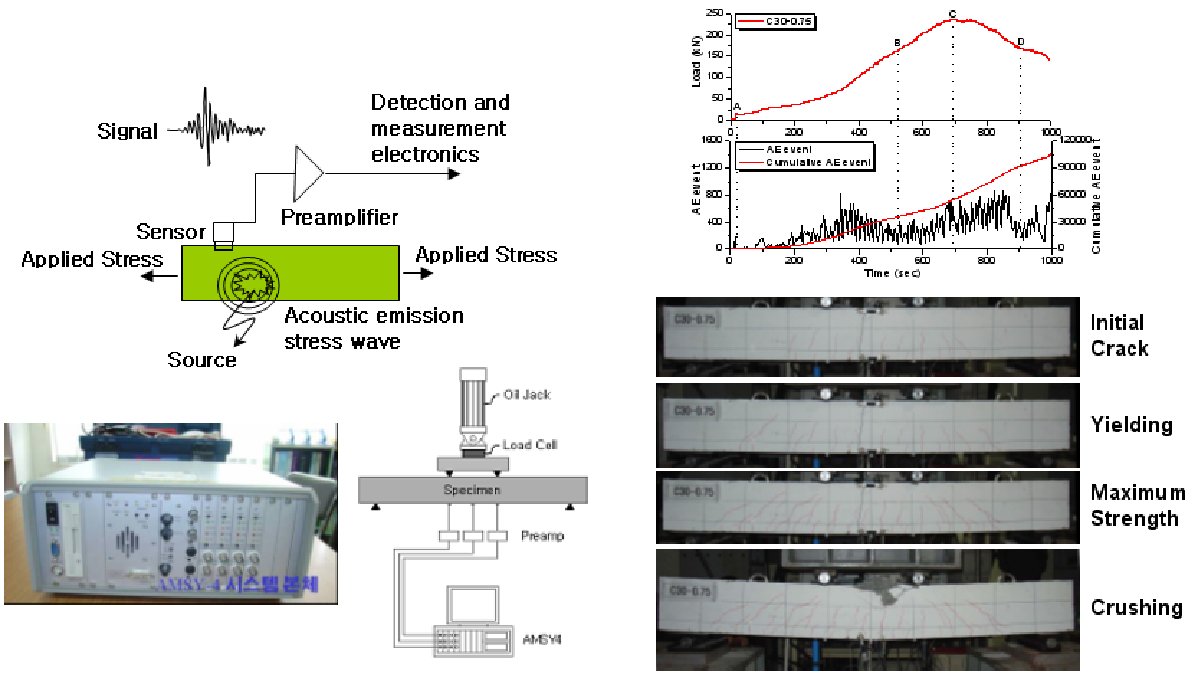



Figure 7 Integrity evaluations of structural members using static deflection



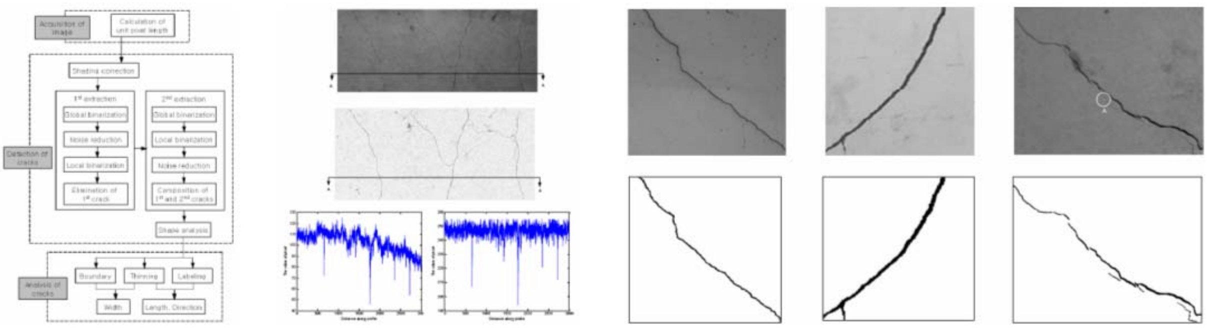

(a) AE measurement system (b) AE characteristics

Figure 8 Integrity evaluations of retrofitted structures using AE technique

## DEVELOPMENT OF NDT METHODS AND MEASURING EQUIPMENTS

### Image Processing Technique for Measurement of Concrete Surface Cracks

Presently, efforts are being made to minimize the effects of cracks in concrete structures on safety, durability, and aesthetic problems. Accordingly, it is necessary both to measure accurately crack features, such as width, length, and direction, and to establish a database of them under crack-control. However, a great deal of time and manpower are required to make measurements and to compile the relevant data, because crack measurements are generally made via inspectors' handwork. To develop faster and more efficient concrete crack measurements, many researchers have adopted an image processing technique. Lee *et al*. (2004, 2005a) develop an automatic image processing technique to detect cracks and to calculate the crack features on images taken with a digital camera. The basic procedure of the proposed technique is similar to that developed in previous studies (Ito, 2002; Kaseko, 1993), with the main difference being an improvement of detection performance using enhanced binarization and shape analysis. In addition, they applied a morphology technique for shade correction, by varying the light and proposed a detail algorithm to calculate the width, length, and direction of cracks.



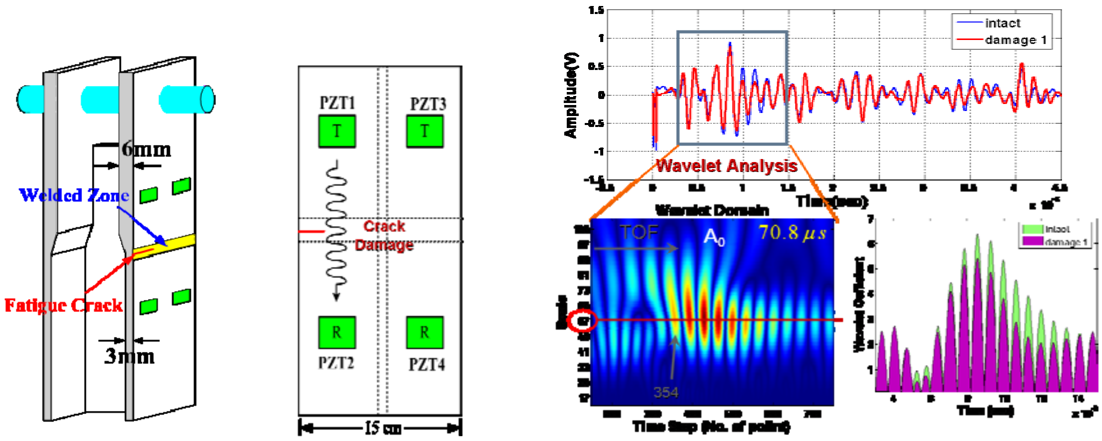
(a) Flow chart (b) Shading correction (c) Crack detection for specimens

Figure 9 Crack detection and analysis using image processing technique

### Structural Damage Assessment Using Piezoelectric Sensors

Piezoelectric sensors are ideal for a built-in structural health monitoring system, because they are small, light, and cheap. They can be used as actuators as well as sensors, owing to their piezoelectricity. Among various types of piezoelectric sensors, PZT (lead-zirconate-titanate) sensor has been most frequently used for nondestructive testing and structural health monitoring. Some of the important related R&D activities are as follows (Park *et al*., 2004, 2005b, 2005c, 2006b, 2006c; Yoon *et al*., 2005, Yun *et al*., 2006):

- Smart active layers consisting of PZT arrays for monitoring defects on industrial facilities, steel, and concrete structures
- Impedance-based damage detection on steel members
- Guided wave-based crack monitoring on critical steel structural components
- PZT-based crack detection on concrete structures
- Wavelet-based crack monitoring methods
- Statistical pattern recognition techniques for damage identification such as neural networks, probabilistic neural networks, support vector machine, and outlier analysis
- On-line PZT-based crack monitoring system using MEMS and wireless sensors




(a) Test specimen (b) Lamb waves (c) Received signal and wavelet analyses

Figure 10 Piezoelectric sensor-based nondestructive evaluations

## CONCLUDING REMARKS

In this paper, recent R&D and application activities on assessment technologies for infra-structures in Korea are reviewed on the basis of the research activity of ISARC. The topics cover a lot of issues related to durability, load bearing capacity, serviceability and evaluation system of concrete structures. In parallel with the R&D activities on the performance assessment, development of many NDT methods and measuring equipments using more advanced sensors is also introduced. According to rapidly increasing needs for the maintenance and assessment of infra-structures in Korea, various researches to evaluate the diagnosis and, in advance, to predict the prognosis of damaged structures have been performed, and a research center ISARC takes the lead in this research area. In 2009, the first draft of assessment codes for infra-structures such as bridges, buildings and underground structures is expected to be developed as the integrated final result of successful research activities at ISARC.

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