Inspection, testing and evaluation of reinforced concrete bridges in Turkey

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ABSTRACT: Maintaining transportation infrastructure facilities, particularly bridges, at all times is an expensive task for service authorities. To assist in conducting such a task, bridge management systems (BMSs) have been developed for effective asset management. Bridge management systems are based on condition state evaluations of bridges which are performed primarily based on visual inspection. The main drawback of the visual inspection is that safety in not adequately addressed and the visual appearance may not always represent the structural integrity of a bridge. Non-destructive evaluation (NDE) offers valuable data for bridge management systems to monitor the structural condition of bridges. This paper presents a study that uses a combination of different non-destructive test techniques applied on decks, piers and beams of reinforced concrete bridges to find out types of damages and to make comparisons between condition state evaluations based on visual inspections and condition assessment based on NDE.

1 INTRODUCTION

Between 2009 and 2012, as part of a research project (Tübitak, 2012) a bridge management system is developed in Turkey (named as KYS which stands for BMS in Turkish) and it is supplied by both visual and nondestructive test data obtained from a pilot group of bridges. The management system is developed to assist the bridge administration to maintain, repair and replace deteriorated bridges in a timely manner. Similar to all other countries, infrastructure system in Turkey will be inevitably aging, requiring substantial funds for upgrades in the future. The objective is to avoid the accumulation of deteriorated bridges in the future by applying preventive maintenance and repairs in advance. Primary inspection technique used is the visual inspection. However, nondestructive testing (NDT) can play a vital role in these maintenance efforts by helping to identify bridges and components that need the most attention, thereby enabling maintenance personnel to dispense limited funding in the most efficient manner. The use of nondestructive testing methods can help reduce the backlog of deficient bridges in two ways. First, these techniques will allow inspectors to get a more accurate view of the condition of a bridge. A large number of bridges listed as deficient are so classified based on a low load rating. The capacity of a bridge is currently determined based on theoretical calculations that may not be accurate. The use of NDT methods will increase the accuracy of these calculations (Washer, 1999). NDT can also improve bridge evaluations by reducing the subjectivity of condition assessment. Bridge inspectors tend to base the condition classification of a bridge member based on their own experience, leading to a high variance in assessments. A bridge may be the worst case one inspector has seen, resulting in a low rating, while another inspector may rate the bridge as ‘fair’. In one such situation, a ’fair’ bridge has received a rating of ‘poor’ by inspectors Lennetetal (1999). The second way in which NDT can help is by allowing inspectors to locate damages earlier. Many forms of deterioration, such as reinforcement corrosion, are not visible in their early stages. With corrosion in particular, by the time the problem is visible, extensive structural damage is generally occurred. Technology is available that can detect and evaluate many anomalies that are not visible on the surface of a structure. Locating these problems early will reduce the cost of repairs and increase the reliability and safety of the structure.

2 NONDESTRUCTIVE TESTING METHODS USED

2.1 Penetration Resistance Method

As part of this study, Windsor pin device is used for measuring the penetration resistance of reinforced concrete bridge members (James Instruments, 2011). An application performed during this study is shown in Figure 1. As shown, inside the pin device, a spring-loaded device pushes a steel pin into the surface of concrete and then the penetration depth is measured using a separate measuring device. The depth of penetration is inversely proportional to compressive strength of concrete. The compressive strength of concrete is then determined by using a table published by the device manufacturer. The table is prepared based on many laboratory tests.

Figure 1. Application of penetration resistance device on a reinforced concrete bridge girder.

2.2 Ultrasonic Pulse Velocity Method

In this study, for ultrasound pulse velocity measurements, V-Meter MK-III device is used. The test technique used is explained in the manual of V-Meter MK-III device (James Instruments, 2011) which is briefly summarized here as follows. A pulse is produced by an electro-acoustical transducer, which is placed on the concrete surface. Generated stress waves reach the receiving transducer. The travel time of the pulse is measured and its velocity is calculated based on the distance between the two transducers. Strength and stiffness properties of concrete affect the pulse velocity. Imperfections such as voids, low compaction or damaged material in concrete can be detected by evaluating pulse velocity measurements. Deteriorated concrete affects the pulse velocity and it can be detected by performing pulse velocity measurements at different time intervals and by comparing the results (IAEA, 2002). An application of the V-Meter Mk III device for ultrasonic pulse velocity measurement as part of this study is shown in Figure 2. If concrete member can be reached from both sides, as shown here, a direct measurement can be made; otherwise, a semi-direct or indirect measurement must be made which are relatively less efficient.

Figure 2. Application of ultrasound pulse velocity device on a concrete bridge wing wall.

2.3 Reinforcing Corrosion Resistivity Measurement Method

There are many techniques that can be used to assess the corrosion risk or corrosion activity in steel inside concrete. The most commonly used technique is the half-cell potential measurement that determines the risk of corrosion activity. In this study, for resistivity measurements, Gecor-8 device is used (James Instruments, 2011). An alternative technique to estimate the rate of corrosion is the linear polarization resistance. Gecor-8 device uses this technique. During this study, most of the time, exposed reinforcing was observed in bridges. This enabled easy attachment of the clip to the reinforcing. However, sometimes, when it is not possible to attach the clip, limited damage to the concrete surface may be unavoidable. Wetting by water is applied on concrete surface when the probes are pushed against the concrete surface to get better contact. Pre-wetting of the surface before measurement is also advised. In this study, importance of the pre-wetting of the surface is observed and it is found to be a critical prerequisite for obtaining test measurements. Without adequate pre-wetting, it was not possible to obtain any measurements at all. Small shallow holes may also be drilled into the concrete which are filled with a conductive gel IAEA (2002). The corrosion rates of reinforcements of concrete in the evaluated bridges in this study are measured mostly by using the circular sensor of the Gecor-8 device. A second sensor can also be used for mapping a corroded reinforcement area. A third sensor for underwater measurement is also available. An application of this device at the bottom of a reinforced concrete bridge girder is shown in Figure 3. The square shaped material shown in the figure under the circular sensor device is a sponge mat saturated with water. On top of this mat, the measurement sensor is pushed. Sensor is connected to the main unit of the device which is not shown here. A clip shown near the sensor attached to an exposed part of corroded reinforcing steel is also connected to the main unit through the cable shown. Corrosion resistance between the piece of reinforcing at the clip location and the reinforcing embedded in concrete located under the mat is read from the monitor of the main unit.

Figure 3. Application of reinforcement corrosion resistivity (corrosion rate) device on a reinforced concrete bridge girder.

3 NONDESTRUCTIVE EVALUATION OF MEMBERS OF EXISTING BRIDGES

For each element of a reinforced concrete bridge, four condition states are defined where 1= No damage or very small damage, 2= Small damage, 3= High level of damage and 4= Critical damage, and the condition state of each bridge is estimated from the condition states of its elements. For each element (or member), there are possible damage types, and for each damage type, the criterion which indicates the condition state of damage are pre-defined. This study is a part of a larger network level bridge inspection study. As part of the larger study, visual inspections of 200 bridges in Western Turkey are conducted and based on these inspections, condition states of all damage types of all bridge elements are determined. Among selected bridges, 10 bridges with highest condition states (i.e. 10 most deficient bridges) were determined, and for detail assessment of these bridges, nondestructive tests were applied on their members. For estimation of compressive strength of concrete, Windsor pin test is applied on piers, slabs and beams of these bridges. It is recommended, according to ASTM standards, that in each application, the test must be repeated for 7 times and the mean value of these measurements must be calculated. This process was followed in this study. The presence of reinforcement inside concrete affects the results of Windsor pin test since, as a first step, the locations of rebar is determined by a another NDT device called R-Meter Mk III, and then penetrations are performed on vertices and center of a hexagonal drawn on the concrete member before testing as shown in Figure 4. The Windsor pin test has been applied 45 times on different elements of 10 existing bridges and the results are shown on Figures 5 and 6. In Figure 5, all of the micrometer readings are plotted versus the condition states of the elements which are estimated based on visual inspections. There is no notable relationship between micrometer readings and visual condition states of elements. In Figure 6, the micrometer readings are converted to condition states and two types of condition states are compared, the first set is condition state based on visual inspections and the second set is condition state based on results of Windsor pin tests. Generally, the Windsor pin test gives higher condition states.

For evaluation of concrete quality, ultrasonic pulse velocity method by V-Meter Mk III device is used on piers and beams of 10 deteriorated bridges. As shown in Figure 7, concrete with higher pulse velocity have lower condition states based on visual inspections. This means that there exists a correlation between condition states based on visual inspections and the results of ultrasonic pulse velocity tests on beams and piers.

Figure 4. Application of Windsor pin test on vertices and center of a hexgonal marking drawn on a bridge pier wall. Measurements ate each point are written on the bridge member and photographed.

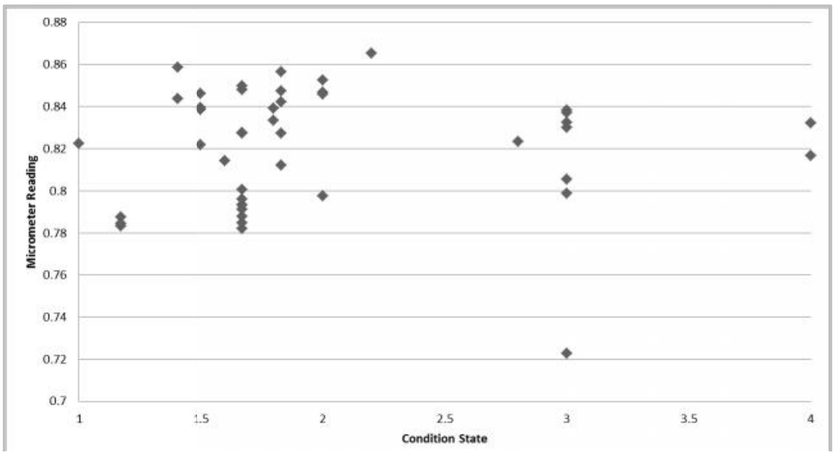

Figure 5. Results of Windsor pin tests on 10 existing bridges. Micrometer readings vs. condition states based on visual inspections.

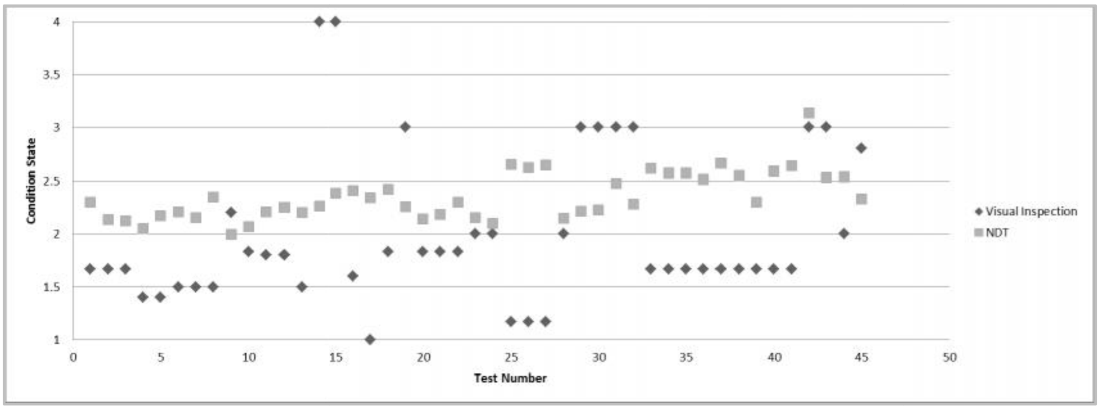

Figure 6. Comparison of condition states from visual inspections and from NDT.

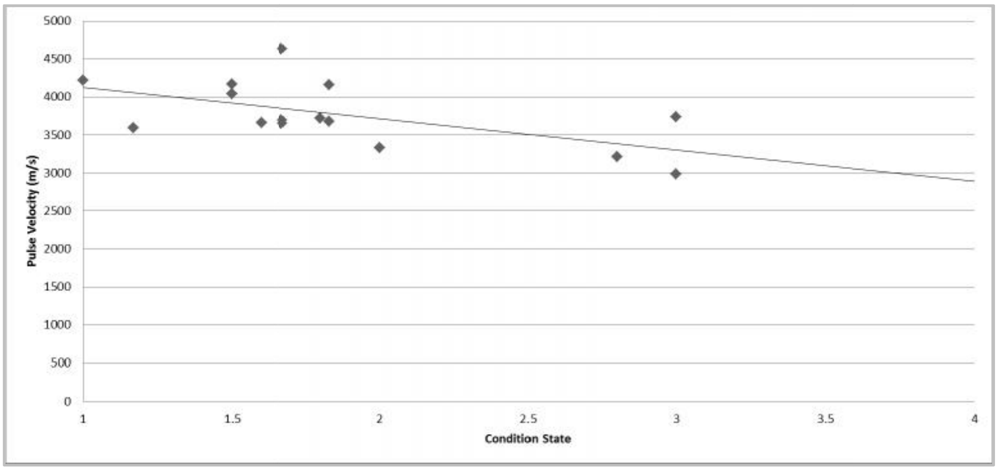

Figure 7. Pulse velocity measurements of concrete elements vs. condition states of bridge a member and the associated trendline.

For measurement of corrosion rate, the resistivity measurement method by Gecor-8 device is used on slabs and beams of 10 deteriorated bridges. As shown in Figure 8, the elements with higher corrosion potential also have higher condition state based on visual inspections, which indicates the existence of correlation between corrosion resistivity and visual condition states.

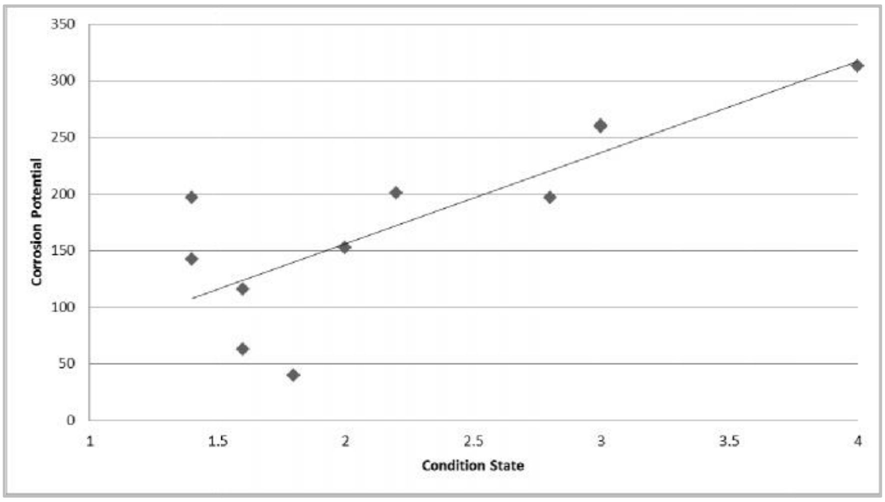

Figure 8. Corrosion potential results of concrete elements of 10 deteriorated bridges vs. visual inspection based condition states and the associated trendline.

4 CONCLUSIONS

Some correlation is observed between results of nondestructive test results and condition states based on visual inspections. Correlations are observed for the ultrasound pulse velocity measurements for concrete members and for corrosion resistivity measurements for reinforcing steel. However, the results of penetration resistance tests do not match with the visual inspection results. Therefore, further field investigation is necessary to verify the existence of any correlation between penetration resistance results and condition states for this testing technique using the particulate device used.

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REFRENCES

Akgül, F and Masoumi, F. (2012) "Evaluation of Condition States of Bridge Elements Based on the Intensity of Different Damage Types," ACE 10th International Congress on Advances in Civil Engineering, Ankara, Turkey.

IAEA (2002) "Guidebook on non-destructive testing of concrete structures", International Atomic Energy Agency, Training Course Series No. 17

James Instruments (2011) "Non-destructive testing equipment for concrete, NDT James Instruments, Inc.", www.ndtjames.com (Accessed Mar 3, 2011).

Lenett, M. S., Greisman A., Helmickiand A.J, Aktan A.E. (1999) "Subjective and Objective Evaluations of Bridge Damage", paper no. 99-0411 in Transportation Research Record 1688, Transportation Research Board, National Research Council, Washington, DC.

Masoumi, F. and Akgül, .F (2012) "A Damage-based Maintenance and Repair Optimization Method Using Linear Programming for Bridges," International Journal of Engineering and Technology vol. 4, no. 5, pp. 668-671.

Tübitak (2012) Final Report-KAMAG Project No:108G018, "Development of a bridge management system for the general directorate of highways in Turkey".

Washer, G. (1999) "Developing NDT Technologies for Highway Bridges", in Materials Evaluation, American Society for Nondestructive Testing, Columbus, OH.