

Condition Assessment of Reinforced Concrete Bridges by Combined Nondestructive Test Techniques

F. Masoumi, F. Akgül, and A. Mehrabzadeh

Abstract—In some countries, collapse of bridges initiated the formal requirements for the inspection of highway bridges. Almost in all developed countries, the bridge management systems have been developed for cost-effective allocation of limited budgets for deteriorating bridges. Visual inspections are one of the most important parts of a bridge management system. On the other hand, many new and promising techniques for the non-destructive evaluation (NDE) of highway bridges have emerged in the past decades. NDT methods are costly and time consuming as well; since they cannot be used widely in bridge management systems. However, NDT methods can be used as verification of visual inspections in bridge management systems. This paper discusses visual inspections of 200 reinforced concrete bridges in Turkey and non-destructive testing applications performed on 10 bridges, which were most deficient. Penetration resistance, ultrasonic pulse velocity, rebar locating and reinforcement corrosion tests are performed on decks, piers and beams of reinforced concrete bridges and the results are compared with the results of visual inspections.

Index Terms—Bridge, condition assessment, nondestructive tests

I. INTRODUCTION

Highway networks of most of the developed and developing countries are either completing or being completed, however high maintenance and repair costs of these deteriorating networks become a major concern. When highway networks are completed, fewer new bridges would construct and maintaining existing bridges becomes more important. In Turkey, a large part of existing bridges must be maintained and repaired properly before they become deficient in the future. A report has indicated that approximately 50% of bridges in Turkey are 50 years of age or older [1]. This trend makes it vital for engineers to be able to accurately assess the condition of concrete bridges for maintenance and repair decisions. Given that most bridges have a design life of 70 years or less, a large portion of this infrastructure will need extensive repairs or rehabilitations in the near future. Nondestructive testing (NDT) can play a vital role in these rebuilding efforts by helping to identify the bridges and components that need the most attention. In this paper, four different nondestructive test techniques which are applied on 10 reinforced concrete bridges are presented. The goal of the study is to discover a relationship between results of nondestructive tests and results of visual inspections.

Manuscript received May 22, 2012; revised July 23, 2013.

The authors are with Researcher at the Department of Engineering Sciences of Middle East Technical University, Ankara, Turkey (e-mail: e168221@metu.edu.tr, akgul@metu.edu.tr, e170611@metu.edu.tr)

II. CONDITION STATE MODEL

The condition state is the best description of the current status of a bridge or element in terms of deterioration, necessitates actions for improvement of the system. Categories of indices representing different levels of deterioration are used in literature as the condition state models for bridge elements. However, general definitions of condition states cause many difficulties in the estimation of parameters like transition probability matrices, maintenance costs and the condition states of bridge elements based on inspection because the estimated damage level for a bridge has different meanings for elements of that bridge. In this research for each element of a bridge, four condition states are defined, and definitions are shown in Table I [2].

TABLE I: THE DEFINITIONS OF CONDITION STATES

Condition State	Definition
1	No damage or very small damage
2	Small damage
3	High level of damage
4	Critical damage

As a part of a research for development of the bridge management system of Turkey, a network of bridges which contains 200 bridges is chosen, and visual inspections of selected bridges are conducted [3]. As shown in Fig. 1, the results of visual inspections are presented as probability mass functions for condition state of different element types of bridges. The Fig. 1 indicates that high percentages of elements have condition state of 1 or 2, which means that the major part of elements is in a good condition.

III. NON-DESTRUCTIVE TESTING DEVICES

Nondestructive tests are performed by four different devices. As shown in Fig. 2, R-Meter Mk III is used for rebar locating inside the concrete. The photographs presented here are taken during applications as part of this study. This device also determines the rebar diameter and concrete cover of rebar. For a number of different tests such as ultrasound or penetration resistance, in order to obtain accurate results, it is essential to locate rebar before applying these tests. The second device used is the Windsor pin device as shown in Fig. 3. It is a spring loaded device that pushes a steel pin into the concrete surface. The penetration amount is inversely proportional to compressive strength of concrete. The third device used is the V-Meter Mk III which is shown in Fig. 4. This device generates ultrasonic pulses which identifies the

quality of concrete. For determining the rate of corrosion of steel inside the concrete, resistivity measurement method is applied by using the Gecore 8 device shown in Fig. 5.

Resistivity measurement is a fast, simple and cheap in situ non-destructive method to obtain information related to the corrosion hazard of embedded reinforcement [4].

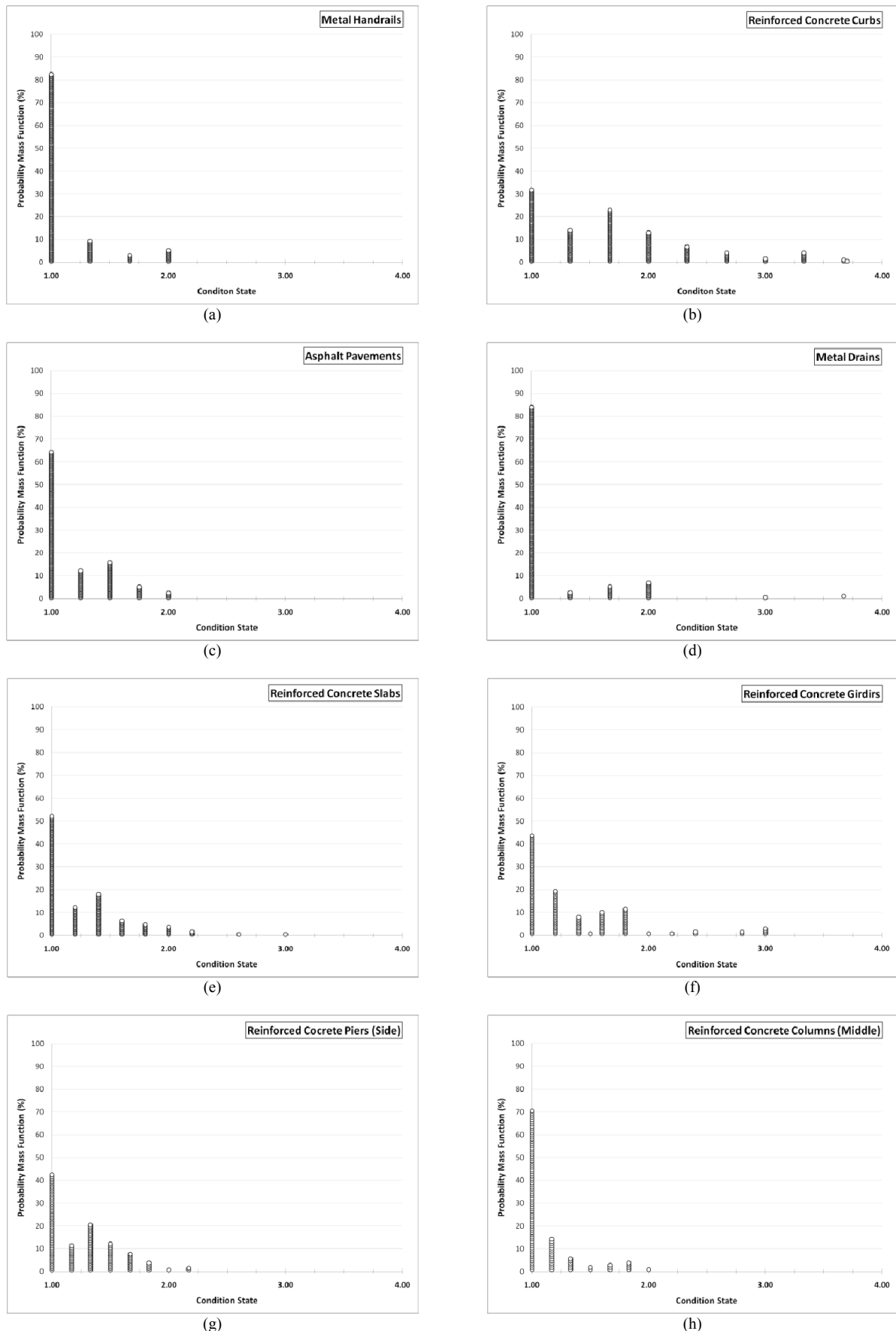


Fig. 1. Probability mass functions for condition state of element types of 200 bridges.



Fig. 2. Application of rebar locator device on concrete bridge pier wall.



Fig. 3. Application of pin device on concrete bridge pier wall.



Fig. 4. Application of ultrasound pulse velocity device on a concrete bridge wing wall.



Fig. 5. Application of reinforcement corrosion resistivity (corrosion rate) device on a reinforced concrete bridge girder.

IV. NON-DESTRUCTIVE EVALUATION OF REINFORCEMENT CONCRETE BRIDGES

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 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. The physical characteristics of bridges are listed in Table II.

The Windsor pin test is applied 45 times on different bridge elements of 10 existing bridges. As shown in Fig. 6, there is a good correlation between Windsor pin results and condition states which are obtained based on visual inspections. The equation of linear regression and R squared value (square of the correlation coefficient) are also shown on Fig. 6. 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 [5]. Fig. 7 shows the V-meter results versus condition states based on visual inspections. The R squared value of 0.561 indicates that there is not a perfect correlation between two sets of results. The V-meter test results shows that reinforced concrete elements with higher pulse velocity have lower condition states based on visual inspection. 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 Fig. 8, the elements with higher corrosion potential also have higher condition state based on visual inspections. The R squared value of 0.802 shows almost a perfect correlation between two sets of results.

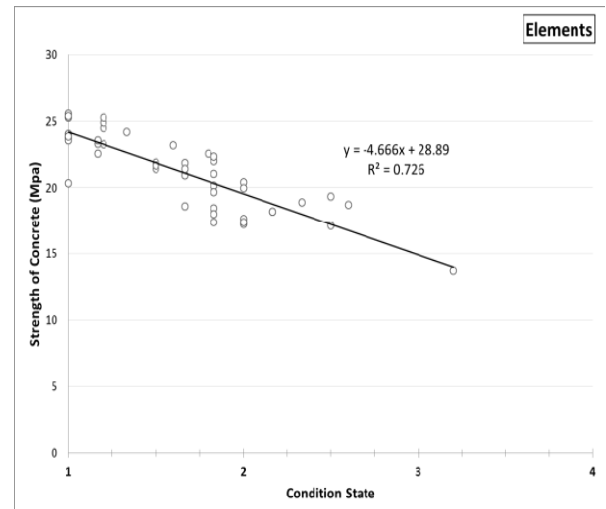


Fig. 6. Windsor pin test results versus condition state of elements.

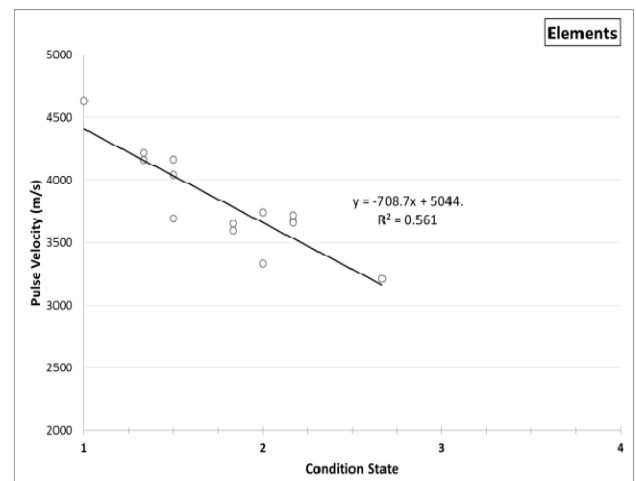


Fig. 7. V-meter test results versus condition state of elements.

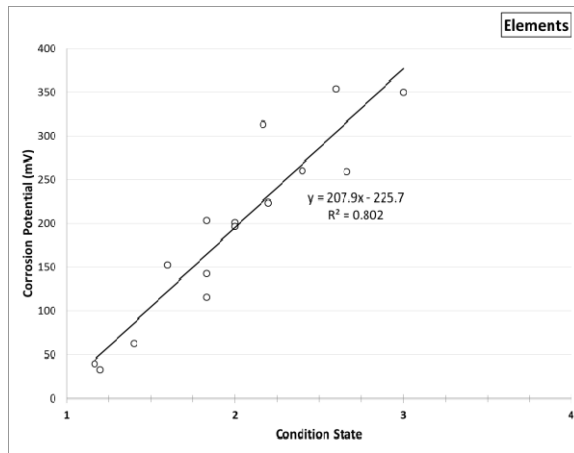


Fig. 8. Gecore test results versus condition state of elements.

TABLE II: PHYSICAL CHARACTERISTICS OF BRIDGES EVALUATED BY NDT AND VISUAL INSPECTIONS

Bridge	Type	Year Built	Span length	Width	AADT1
Ahmetli	RC Gerber	1951	37.8	7	14271
Akcapinar	RC Gerber	1951	37.6	7	14271
Armutova	RC Simple Girder	1968	82.15	8.6	17332
Burhaniye	RC Simple Girder	1973	86.8	8.5	7181
DDY	RC Simple Girder	1969	44.05	8.5	10288
Emirdogan	RC Slab	1953	25.3	7.5	18939
Fetrek	RC Slab	1954	43.75	8	8036
Ilicay	RC Slab	1952	30.7	7.5	11051
Nesetiye	RC Gerber	1998	59.6	7.5	6459
Tabakhane	RC Simple Girder	1977	43.15	7.5	18939

AADT=AVERAGE ANNUAL DAILY TRAFFIC VALUE.

V. CONCLUSION

Almost perfect correlations are observed between results of nondestructive tests and condition states based on visual inspections. Condition state model of Turkey bridge management system consists of 4 condition states. For bridge management systems with more condition states, more sensitive analysis can be conducted, and the correlation coefficients will be closer to 1, but on the other hand condition assessment of elements and bridges will be more difficult. In this research, the non-destructive tests are done on 10 reinforced concrete bridges and for achieving more accurate correlations further field investigation is necessary to verify the linear regression equations which are obtained so far.

ACKNOWLEDGEMENTS

The financial support, provided by TÜBİTAK (The Scientific and Technological Research Council of Turkey) KAMAG Group (Public Research Grant Committee) through the Project 108G018, is gratefully acknowledged. The opinions and conclusions presented in this paper are those of the writer and do not necessarily reflect the views of the sponsoring agency.

REFERENCES

- [1] F. Akgül and F. Masoumi, "Evaluation of Condition States of Bridge Elements Based on the Intensity of Different Damage Types," in *Proc. of ACE 10th International Congress on Advances in Civil Engineering*, Ankara, Turkey, 2012.
- [2] F. Akgül and F. Masoumi, "Optimization of Maintenance, Repair and Rehabilitation Actions in a Novel Bridge Management System," in *Proc. of ACE 10th International Congress on Advances in Civil Engineering*, Ankara, Turkey, 2012.
- [3] Tübitak, "Development of a bridge management system for the general directorate of highways in Turkey," Final Report-KAMAG Project No: 108G018, 2012.
- [4] IAEA, "Guidebook on non-destructive testing of concrete structures," *International Atomic Energy Agency*, no. 17, 2012.
- [5] J. Instruments, Non-destructive testing equipment for concrete, NDT James Instruments. [Online]. Available: <http://www.ndtjames.com>



F. Akgül received his B.S. degree in Civil Engineering from Middle East Technical University, Turkey, in 1987, and M.S. in Civil Engineering; Structural Mechanics from University of New Mexico, Albuquerque, New Mexico, in 1989 and Ph.D. degrees in Civil Engineering, Structural Mechanics from University of Colorado at Boulder, Colorado, in 2002. He is currently an assistant professor at the Engineering Sciences Department, the Middle East Technical University. He has over 10 years of teaching experience and has published many papers in national and international journals. His research interest includes Structural Reliability, Lifetime Performance Prediction of Bridges and Simulation Methods. Dr. Akgül is a member of IABMAS, International Association for Bridge Maintenance and Safety. He served as editor board member, member of technical council, member of scientific committees for several local, regional and international journals and conferences.



F. Masoumi received his B.S. degree in Civil Engineering from Azerbaijan University of Tarbiat Moallem, Iran, in 2005 and M.S. in Civil Engineering, Structure from Islamic Azad University, Maragheh Branch, in 2007. He is currently Ph.D. Candidate in METU.



A. Mehrabzadeh received his B.S. degree in Civil Engineering from Ardebil University, Ardebil, Iran, in 2005. He will receive his M.S. degree in 2013, Middle East Technical University, Ankara, Turkey. His research interests are in the areas of Structural Health Monitoring and Bridge Engineering with emphasis on non-destructive bridge evaluation and condition assessment.