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COMBINATION OF NONDESTRUCTIVE EVOLUATIONS FOR RELIABLE ASSESSMENT OF BRIDGE DECK

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Abstract. *Non-destructive evaluation (NDE) has offered unprecedented utilize for bridge management body to monitor structural health. None of these evaluation methods can provide all the damage information (damage category, quantitative assessment) alone which is required for necessary repair activity and condition rating of structure. In most of the cases, the response of one evaluation method implies the presence of a defect among the multiple defects to which the evaluation method is sensitive. This paper is concerned with the combi-nation of different non-destructive testing to find out the type of damage with the most effi-cient way. The different response (positive or negative) obtained from each combination and how it confirms the defect is shown through the mathematical set operation. Thus, this study would assist field investigator to ascertain the type of defect which subsequently aids to rate structure based on damage type.*

Key words: *non-destructive evaluation, bridge deck, reliable assessment.*

1. INTRODUCTION

There are lots of nondestructive evaluations (NDE) available for concrete inspection, but, unfortunately a few number is in practical use in deck evaluation. The commonly used NDE methods for deck evaluation are visual inspection, chain drag, Impact echo, Ground penetration radar, Infrared thermography and Half-cell potential (Scott et al. 2003). None of these methods can provide all required damage information alone, because evaluation methods are of different principles (acoustic, electromagnetic, electrochemical) that restrict a degree of capability in evaluation addressing different types of damage in attention. Non-destructive techniques (NDT) can assess the state of health of structures, but they can only provide an indirect approach to their performances (Brevsse et al. 2008). Combination of NDE is required because, in majority of cases, response of one evaluation method does not specify particular damage; rather it provides prediction

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among a number of defects to which the signal is sensitive. While one evaluation method fails to screen a particular type of damage, the other could easily identify it. In addition, the use of third evaluation method can yield quantitative evaluation for the damage. That is why combination of NDE is recommended by various authors to bring reliability in assessment in conjunction with detailed information of anomaly (Christoph & Streicher 2006). However combination of NDE does not refer to employ all available NDE during assessment, rather it makes use of combination concerning damage area, type, location, sensitivity and orientation and find out best combination that is rapid, effective and cover all the damage types utilizing least number of evaluation methods in application.

There have been controversial experiences gathered by various researchers in evaluation by various methods. Some researchers state that GPR and IR cannot yield ground truth data as compared to conventional evaluation methods (Chain drag, Half-cell potential) (Barnes & Trottier 2004) while other reported to have insignificant variation in result obtained between conventional and comparatively recently developed evaluation methods like GPR and IR thermography (Cardimona et al. 2001). However, both statements are factual and the probable cause of the inconsistent experience could be the damage sensitivity to evaluation response, unfavourable environmental condition or lack of monitoring controlling factors that should have been brought under consideration during the time of investigation. Combination of non-destructive testing can improve the overall damage evaluation as the controlling factor for each testing is different from the other. Eventually, the enrolment of right combination can improve the evaluation with characterization of defect including the efficient use of the methods.

2. SIGNIFICANCE OF NDE COMBINATION

Last five decades have experienced satisfactory improvement in nondestructive evaluation methods and several models to predict remaining service life of bridge structures. Furthermore, several researches reveal the improvement of nondestructive evaluation by combination that improves assessing damage features in deck. The application of nondestructive evaluation is to do condition rating of structure which implies the degree of repair or rehabilitation required for safety and longevity of structure. However, several prediction methods to ascertain remaining life span of structure is significantly related to reliability of nondestructive evaluation methods that require (prediction methods) information of the present damage condition or value of condition rating as an input data. In fact reliable condition rating and prediction cannot be attained unless a combined approach of nondestructive evaluations is introduced. The effort provided from one group of combination (evaluation methods) may differ from evaluation using a different group, thereby altering the efficiency of damage assessment in structure. Therefore, effective combined approach of NDE is necessary to categorize the defect inside the bridge deck and this knowledge would guide the investigator to apply the combination that discriminates particular damage(s) from defected portion of bridge deck.

3. Problem with Deck and Evaluation

It has been found that the usable life of the bridge deck is only one half of the useful life of the bridge. The average age of bridges when replaced is 68 years, and the average length of service of bridge decks before replacement is 35 years (Bettigole 1990). But sometimes this length could be as low as 10 years (Silano 1993). For this reason, deck slab requires special attention for damage assessment and repair at early stage. The damages that are common problem in concrete deck are cracking, leaching, scaling, spalling, corrosion of reinforcement, poor quality concrete, and delaminations (Yehia et al. 2007).

Unlike other parts of bridge, deck offers some extend of difficulty in evaluation that are as follows (Rhazi 2001): 1) The concrete slabs are inaccessible to the both sides at the same time, 2) the asphalt coating may have variable thickness, even within the same deck (5 cm to up 15 cm) and 3) the thickness of the defects looked for (delamination) is small, in the order of 1 to 2 mm. Furthermore, some methods require closure of lanes during investigation operation which urges non-destructive evaluation methods or combination that are not only effective, but also rapid and cause less or no traffic interruption. Therefore, closure of bridge lanes and resulting traffic hazard during investigation plays an important consideration for bridge deck evaluation by non-destructive methods.

4. Potentiality of Evaluation Method

This section describes the non-destructive evaluation methods potentiality and controlling factors governing assessment of damage. Although, it has been seen that more than one method can determine certain damage in same time, one method can prove reliable compared to other including added damage information. A short description of commonly used evaluation methods are as follows.

4.1. Ground penetration radar

Ground penetration radar relies on electromagnetic wave theory and damage is characterized in terms of dielectric constant that differs from sound concrete. The theory and working principle of GPR is reported in previous publications [10]. The rapid evaluation by GPR can be applicable in field at vehicle speed of 72 Km/hr (Bungey 2004) when air coupled antenna is attached with vehicle. While ground couple antenna is used for evaluation, then the evaluation can be operated at walking speed of an investigator. This evaluation method does not require direct contact with the investigation surface. As a result this method is comparatively rapid. The evaluation result can be presented in 2-D or 3-D view at the end of the evaluation, thus making the method very simple in damage evaluation. Moreover, the GPR data collection is not adversely affected by traffic noise. GPR evaluation can be operated with minimum traffic interruption, thus making the method more popular for bridges with high volume of traffic.

When dielectric constant of damaged portion alters from sound portion of concrete, a substantial deflection is observed in reflected signal and thus the presence of damage is ensured. Reinforcement corrosion, chloride contamination and increase of moisture in concrete can induce substantial increase of dielectric constant of concrete. The studies for radar show that radar is quantitatively sensitive to moisture and chloride conditions associated with delamination and freeze/thaw damage, but cannot directly sense delamination cracks (Fedaral land highway program 2010). Thus GPR method cannot directly assess delamination defect, rather it can predict it from the sense that the area of high chloride contaminated and corroded area possess the high possibility of delamination crack. Therefore, GPR method is more suitable to detect anomaly in concrete rather than being more specific in damage category. The use of other evaluation method is required at those defected area to be sure of type of damage inside the anomaly.

4.2. Infrared thermography

Infrared thermography evaluation method is based on electromagnetic theory and this method can collect the data in field at the vehicle movement of 16 km/hr (Rhazi 2001). ASTM D4788 (2006) describes the testing guideline for infrared thermography evaluation. In passive method of infrared thermography the surface of bridge deck is heated by the sun's infrared radiation, the delaminated areas heat at a faster rate than the adjacent thicker sound concrete. The fracture plane of the delamination acts as a small insulator and trapping the heat near the surface. During a summer day, these "hot spots" on the surface are generally 2° C to 5° C warmer than the surrounding solid concrete (Manning & Masliwec 1990) and those spots are clearly detectable by an infrared camera. Active method of infrared thermography uses external source of heating to observe the thermal differences attributed from embedded defects.

The presence of moisture inside concrete has a clear influence on the thermal properties and thus on the phase image. The phase images provide a deeper probing up to 10-15 cm in relation to the interpretation of the thermograms and to the amplitude images (Weritz et al. 2005). Studies for infrared thermography show that this technique is capable of detecting delamination, but is limited in capability when the asphalt cover is large, the delamination openings are small, and the cracks are deep (Maser & Roddis 1990). An experimental study conducted by Qader et al. (2008) reports that active infrared thermography can identify delamination and void with the maximum depth to be evaluated at 7.62 cm (3 inch) from investigating surface.

4.3. Impact echo

Impact echo method is based on stress wave theory and P wave and R wave gets sole importance in evaluation. In impact echo method, P wave speed gets the most significant influence on damage assessed in investigating element and this method is point impact and point receiving in nature for damage characterizing. The common practice of impact echo evaluation is to mark the deck slab to grids (typically 1 m × 1 m) and undergo testing by impact echo method on those grids. Being as a point impact and point received method, impact echo is not a rapid evaluation method as compared to electromagnetic evaluation methods like GPR and IR thermography. Moreover impact echo method is adversely affected by vibration noise provided from traffic activity on bridge. Thus it requires the closure of bridge lane during investigation of decks.

Impact echo method is applicable to assess delamination (Sansalone & Carino 1989; Cheng & Sansalone 1993), void (Pratt & Sansalone 1992), compressive strength of concrete (Lee et al. 2003), depth of slab. The evaluation of damage by impact echo method is done in frequency domain analysis. To run the impact echo analysis without manual interpretation is developed by Das et al. (2009) which would cut short the overall duration of testing by the method. Impact echo method has negligible influence at the presence of moisture in concrete (Hamid et al. 2004). The current technology implementing acoustic techniques, such as the chain drag method and IE, are generally consistent with results from coring when they are carefully performed (Scott et al. 2003).

4.4. Chain drag

Chain drag method falls within acoustic method which uses dragging of chain over the concrete surface. When there is discontinuity like delamination or void inside the concrete the characteristic drummy sound is heard that ensures the presence of defect. The chain drag testing procedure is explained in ASTM D 4580, 2006. Chain drag method is suitable for near surface damage assessment and it is subjective. For convenience, two-person team allows the tasks of dragging the chains over the deck, clarifying defect boundaries using a rock hammer (Scott et al. 2003). In spite of being subjective, this method is simple, easy to operate and cheaper method of concrete testing.

4.5. Half cell potential

Half-cell potential method is an electrochemical method to identify the area where there is a high probability of active corrosion in the reinforcement inside the bridge deck. When there is corrosion in bridge deck, the anodic and cathodic zones are initiates in the rebar, resulting the flow of electron from anode to cathode. The half-cell electrode probe is placed above the corroded zones and potential in voltage is recorded. Based on the voltage difference, the corrosion severity of reinforcement is determined. The result obtained from half-cell potential does not indicate the delamination defect directly, but it follows that, over time delamination will occur in those areas in which there is active corrosion. Thus the use of half-cell potential is to assessment of corrosion severity and probability of delaminarion induced from corrosion. Test equipment and procedures can be found in ASTM standard C 876, 2006. Table 1. summarizes damage evaluation potentiality by non-destructive methods commonly applied for bridge deck evaluation.

Table 1. Assessment of different damages by non-destructive methods.

Evaluation methods	Damage set (*S*) to which the evaluation method is sensitive	Damage/ damage Parameters determined	Damage/ damage parameter to be assessed	Remarks
Visual inspection	Crack, Potholing, spalling, Chemical attack, section loss	Width of crack, Damage area	Depth of crack, Type of chemical attack	Subjectivity in assessment
Chain drag	Delamination, void	Location of damage on deck surface	Depth of damage	Suitable for near surface damage, qualitative assessment & subjective
Ground Penetration Radar	Anomaly that can be either of delamination, void, moisture, chloride attack or corrosion in reinforcement	Depth of the anomaly, area of damaged portion	Type of defect	Difficult to discriminate among damages
Infrared thermography	Delamination, Void, moisture damage	Area of delamination, void and moisture damage	Depth of damage mentioned before, thickness of void	Difficult to discriminate among damages
Impact echo	Delamination, Void, Crack, honeycombing	Depth of delamination, void and crack		
Half-cell potential	Corrosion in reinforcement	Corrosion severity in reinforcement		

5. METHODOLOGY OF NDE COMBINATION

Based on the duration of evaluation, NDE could be divided into two categories. Those are rapid and comparatively slower methods. While investigating over a bridge deck, the closure of bridge lane on evaluation demand should also be taken into consideration. The evaluations which are comparatively fast represent overall damage area of deck. Thereafter, the slower evaluations should bring under the selected damaged points to be sure or characterize the types of defect. Although information of damage and their extension are often not fully defined with satisfactory degree, rapid evaluation methods can assess pathological area in a deck, further investigation (with other evaluation method) of which disclose damage type with broader information. Some NDE are slow, tedious and make traffic hazard during testing. Moreover the application of time consuming evaluation is less preferred option for bridge management body for inconvenience in traffic movement during investigation. Nevertheless those methods are essentially required for precise characterization of damage. Hence application of those NDE following by the rapid evaluation methods point out area to be investigated by slower NDE, thus making efficient use of available NDE for a deck.

Most of the evaluation methods are responsive to a number of damages. Thus response of damage implies prediction of those different types of defects. While the combination is applied for overall evaluation of damaged area in deck, the combination must be such that two methods are sensitive to different type of damages. In the stage of rapid screening, the sensing damaged areas get sole interest. The type of defect within those areas is not important in this stage of evaluation. Now if the damages under consideration are represented by universal set U and n number of evaluation methods are employed in assessment then

$$S_1 \cup S_2 \cup S_3 \ldots\ldots \cup S_n = U \tag{1}$$

Where S_1, S_2, S_3 and S_n are the damage set to which the evaluation methods E_1, E_2, E_3 and E_n are responsive respectively. Mathematical operator "U" refer to union of sets. For a reliable assessment, the sensing of all damages under consideration should be covered by the rapid evaluation methods employed in this stage.

In the second stage of assessment, the slower evaluations are in use for detail information of damage type in the damaged area marked by rapid evaluation methods. Due to time constraints and traffic hazard during investigation, those methods are not generally recommended to implement throughout the whole area of a deck. The qualitative information obtained from the previous stage can be upgraded to the quantitative information in this stage. Also, rapid evaluation methods can overestimate the damage inside the deck and proper selection of evaluation method can ascertain the overestimation of defect. Now, if the other NDE methods (slower) are employed in evaluation then the combination could only provide valuable information when the two evaluation methods have some common damage(s) to be responded during investigation. In this case, either positive or negative response of the following evaluation method can confirm or predict among the selected number of defects. Therefore, if two non-destructive testing are involved in evaluation and, S_1 and S_2 represents the damage sets to which each evaluation methods are responsive respectively, then the damages that bring under consideration are $S_1 \cup S_2$. In case when there are positive responses by both methods from a defected portion, the most probable defects within the portion are $S_1 \cap S_2$. Lastly, in case there is alternating response from the combination i. e. positive response obtained from one evaluation method (evaluation method E_1), but negative response from the other (evaluation method E_2), then the most probable damage(s) at the selected damage area are $S_1 - S_2$. However, the negative response from both evaluation methods refer to no defect that are included in the damage set $S_1 \cup S_2$. Table 2 shows the characterization of defect based on the different response for evaluation methods.

Table 2. Assessment of defect type from different combination of NDE.

Type of response	Assessment by combination
E_1^N & E_2^N	The investigation portion does not have any damage that has been included in set S_1 U S_2
E_1^Y & E_2^Y	The investigation portion has damage that has been included in set $S_1 \cap S_2$
E_1^Y & E_2^N	The investigation portion has damage that has been included in set S_1 - S_2

Here E_1^N refers no response obtained from the evaluation method E_1 and E_1^Y indicates there is positive response from evaluation method E_1. The mathematical operator "U", "∩" and "-" indicate the union, intersection and subtraction by set operation, details of which can be found in Bourbaki (1968).

6. Result obtained from Different Combination

The damage sets that can be evaluated by evaluation methods are shown in Table 1. As the capability of some evaluation methods are limited to near surface damage assessment, the use of other evaluation though get the information throughout the depth of the slab, the combination is also limited to near surface damages only. IR thermography and chain drag methods are capable to assess near surface damages. Thus combination with those methods is concentrated to evaluate at the near surface damages only. In such cases, if possible, the evaluation by those methods (near surface damage assessment) should be conducted at both the surfaces (top and bottom) of bridge deck.

The different combination of NDE is discussed with different response as explained in Table 2. The example of GPR and IR thermography combination is described as follows. GPR evaluation is sensitive to moisture, chloride attack, corrosion, void and delamination associated with substantial dielectric increase in concrete. But IR thermography is only responsive to delamination, void and moisture in concrete. Both the positive and negative response from this combination is significant to characterize the type (among the types) of defects in the defected zone. Equation 2 and Equation 3 show the damage set for GPR and IR methods which is obtained from Table 1. From those equations it is observed that delamination, void and moisture damages are common in two damage sets. Thus, the positive response from IR but negative response from GPR would confirm the delamination defect without the attack of chloride inside the defected area. Because, if there would have void, moisture or delamination associated with delamination, then there should have positive response from GPR method and such response uses subtraction of IR thermography damage set from GPR damage set as shown in Table 2. Again, positive response by those two methods would confirm the presence of any defects (void, delamination or moisture damage) that intersects between these two methods. At the same time it has also confirmed that there could have no possibility of the defects (those which are not common to both NDE) chloride attack and corrosion in reinforcement without cracking of concrete (observing damage sets of GPR and IR thermography). Similarly, the other combination of NDE and categorization of defects are shown in Table 3. The combination of IE and

CD is not effective because both of these NDE methods are assigned to assess delamination and void only and different or identical response cannot provide any further information.

GPR= {Chloride attack, corrosion, void, delamination associated with dielectric increase} (2)

IR={Delamination, void, moisture} (3)

Table 3. Damage evaluation from different NDE combination.

	Type of response	Confirmation of damage	Possible damages
GPR & IR (Combination in near surface damage)	GPR^Y & IR^N		Corrosion in rebar, chloride contamination
	GPR^N & IR^Y	Delamination	
	GPR^Y & IR^Y		Delamination, void, moisture damage
GPR & Chain drag (CD) (Combination in near surface damage)	GPR^Y & CD^N		Chloride contamination, moisture, corrosion
	GPR^N & CD^Y	Delamination	
	GPR^Y & CD^Y		Void or delamination
GPR & IE (Combination throughout the depth of slab)	GPR^Y & IE^N		Corrosion in rebar, chloride contamination, Moisture damage
	GPR^N & IE^Y	Delamination	
	GPR^Y & IE^Y		Void, delamination
IR & IE (Combination in near surface damage)	IR^Y & IE^N	Moisture damage	
	IR^N & IE^Y		Delamination, void
	IR^Y & IE^Y		Delamination/ void associated with moisture
GPR, IR & IE (Combination throughout the depth of slab)	GPR^Y, IR^N & IE^Y		Void, Delamination (around bottom rebar mat)
	GPR^N, IR^Y & IE^Y	Delamination (around top rebar mat)	
	GPR^Y, IR^Y & IE^N	Moisture damage	

The use of half-cell potential method is not shown to have combined in other evaluation method in Table 3. The use of half-cell potential should be brought under evaluation when it is required to discriminate corrosion damage from other damage. For example, Table 3 shows the positive response of GPR and negative response from IE indicates the possible damage of corrosion in rebar, moisture damage or chloride attack in defected area. Now, when this type of response is obtained form a combination, the use of half-cell potential can determine whether there is corrosion in rebar or not.

Figure 1 shows the combination of different non-destructive testing usually applied for bridge deck application.

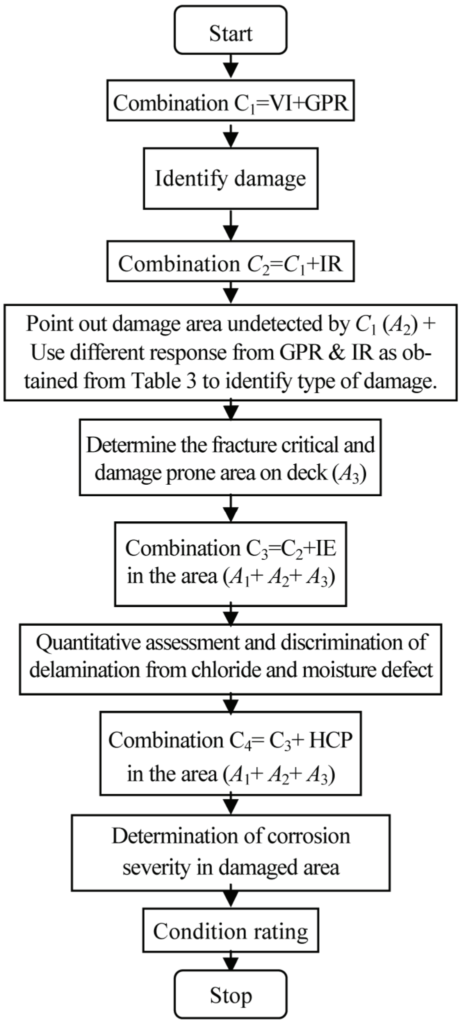

Fig. 1. Combination of non-destructive testing to categorized damage in bridge deck.

The methods that fall within the rapid assessment of evaluation are visual inspection, ground penetration radar and infrared thermography. These three methods are done in first stage to determine the damaged portion in deck. Although those methods are used for rapid screening of defect, the different response among those methods within defected portion has provided additional information of defect type. Then, impact echo and half-cell potential methods over those pathological areas would discriminate the delamination, void and rebar corrosion and improve the overall evaluation of bridge deck. The fracture critical area of the structure elements should provide special attention and those area should preferably investigated by the slower evaluation methods, although those might not have any damage mark by slower evaluation methods. Thus right combination of NDE can determine the damage type in defected zone with minimum duration of lane closure.

7. CONCLUSION

The efficient combination of non-destructive evaluation can reduce the duration of lane closure and identify the type of damage within the damaged area. The right management of non-destructive evaluation methods through the effective combination make use of slower or time consuming evaluation methods to be employed in bridge deck assessment. In this paper the different NDE combination and the damage types addressing the different response from combination is explained. It is shown, how the damage type is determined from different response from different combination of evaluation methods. Especially in bridge deck where duration of investigation restricts the NDE methods that require prolonged closure of lane, the combination of methods can clarify the damage type within comparatively less time to spare providing minimum effort by those methods. Therefore, the assessment of bridge deck with individual damage type would help to rate the structure element, which subsequently improve overall condition rating of bridge. Finally, when the type of damage is known, it certainly assists the management body to take right repair activity after those have been identified. The subsequent paper by the authors focuses the combined approach NDE methods to calculate evaluation efficiency and how the condition rating of the structure is normalized based on different evaluation combination.

REFERENCES

1. ASTM 4788. 2006. Standard Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography. *American Society of Testing and Materials*, West Conshohocken, PA
2. ASTM C 876. 2006. American Society for Testing and Materials. Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete. *American Society of Testing and Materials*, West Conshohocken, PA.
3. ASTM D 4580. 2006. Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding. *American Society of Testing and Materials*, West Conshohocken, PA.
4. Barnes, C.L. & Trottier, J.F. 2004. Effectiveness of Ground penetrating radar in predicting deck repair quantities. *Journal of infrastructure systems.* 10(2): 69-76.
5. Bettigole, N.H. 1990. Designing Bridge Decks to Match Bridge Life Expectancy in Extending the Life of Bridges, *ASTM Special Technical Publication 1100, ASTM Committee D-4 on Road and Paving Materials,* Philadelphia, Pennsylvania.: 70-80.
6. Bourbaki, N. 1968. Elements of mathematics, Theory of sets. *Addison-Wesley*, USA (Translated from French).
7. Breysse, D., Klysz, G., Dérobert, X., Sirieix, C. & Lataste, J.F. 2008. How to combine several non-destructive techniques for a better assessment of concrete structures. *Cement and Concrete Research.* 38: 783–793.
8. Bungey, J.H. 2004. Sub-surface radar testing of concrete: a review. *Construction and Building materials*. 18: 1-8.
9. Cardimona, S., Willeford, B., Wenzlick, J. & Anderson, N. 2001. Bridge Deck Condition Studies in Missouri Utilizing Ground Penetrating Radar; *Final report submitted to University of Missori- Rolla*. Department of Geology and Geophysics, USA.
10. Cheng, C. & Sansalone, M. 1993. The impact echo response of concrete plates containing delaminations: numerical, experimental and field studies. *Materials and Structures* 26: 274- 285.
11. Christoph, K. & Streicher, D. 2006. Results of reconstructed and fused NDT-data measured in the laboratory and on-site at bridges. *NDT & E International*. 28: 402-413.
12. Das, S., Khalim, A. R. & Hamid, R. 2009. Development of Algorithm for Automatic Defect Identification of Plate Structures in Impact Echo Assessment; *Proceedings of the 2nd WSEAS International Conference on Engineering Mechanics, Structures and Engineering Geology,* Greece: 186-191.
13. Fedaral land highway program 2010. Vehicle Mounted Ground Penetrating Radar(GPR)Systems. (http://www.cflhd.gov/agm/engapplications/BridgeSystemSuperStructure/345VechicleMountedGrdPenRadar.htm)
14. Hamid, R., Nayan, K.A.M., Yousuf, K.M. & Chua, Y.W. 2004. Assessing concrete quality using impact echo method. *Proceeding of 3rd National Conference in Civil Engineering.* Pulau Pinang, Malaysia 6C06: 1-5.

15. Lee, H.K., Yim, H.J. & Lee, K.M. 2003. Velocity-strength relationship of concrete by impact echo method. *ACI Material Journal* 100(1): 49-54.
16. Manning, D.G. & Masliwec, T. 1990. Operational Experience Using Radar and Thermography for Bridge Deck Condition Survey; *Proc. NDE of Civ. Struc. and Mater.*, Boulder (CO): 233-244.
17. Maser, K.R, & Roddis, W.M.K. 1990. Principles of thermography and radar for bridge deck assessment. *Journal of transportation engineering.* 116(5): 583-601.
18. Pratt, D. & Sansalone, M. 1992. Impact-echo signal interpretation using artificial intelligence. *ACI Materials Journals.* 89(2): 178-187.
19. Qader, I.A., Yohali S., Abudayyeh, O. & Yehia S. 2008. Segmentation of thermal images for non-destructive evaluation of bridge decks. *NDT & E International.* 41: 395–405.
20. Rhazi, J. 2001. NDT in civil engineering: the case of concrete bridge decks. *The e-Journal of Nondestructive Testing & Ultrasonics* 6 (5).
21. Sansalone, M. & Carino, N.J. 1989. Detecting delamination in concrete slabs with and without overlay using the impact echo method. *ACI Materials Journal.* 86(2): 175-184.
22. Scott, M., Rezaizadeh, A., Delahaza, A., Santos, C.G., Moore, M., Graybeal, B & Washer, G. 2003. A comparison of nondestructive valuation methods for bridge deck assessment. *NDT & E International.* 36: 245-255.
23. Silano, L.G. 1993. Bridge Inspection and Rehabilitation: A Practical Guide, John Wiley & Sons Inc, USA.
24. Weritz, F., Arndt, R., Rolling, M., Maierhofer, C. & Wiggenhauser, H. 2005. Investigation of concrete structures with pulse phase thermography. *Materials and Structures* 38: 843-849.
25. Yehia, S., Abudayyeh, O., Nabulsi, S. and Abdel-Qader, I. 2007. Detection of Common Defects in Concrete Bridge Decks Using Nondestructive Evaluation Techniques. *Journal of Bridge Engineering*. 12(2): 215-225.

KOMBINACIJA NEDESTRUKTIVNIH MTODA ZA POUZDANU OCENU STANJA NADGRADNJE MOSTOVA

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Nedestruktivna ocena stanja (NDE) je našla ogromnu primenu kod osmatranja stanja konstrukcija mostova. Nijedna od metoda ocene ne može sama da obezbedi sve potrebne informacije o šteti (kategorija štete, kvantitativna procena) koje su potrebne za neophodne opravke mostova i ocenjivanje stanja konstrukcija. U većini slučajeva, rezultat samo jedne metode ocene stanja otkriva prisustvo samo jednog mogućeg defekta, za koje je metoda optimizovana, u mnoštvu drugih. Ovaj rad se bavi kombinacijom različitih nedestruktivnih ispitivanja u cilju najefikasnijeg otkrivanja vrste oštećenja. Kroz matematički skup operacija je prikazano kako su različiti rezultati (pozitivni ili negativni) dobijeni iz svake kombinacije kako se utvrđuju oštećenja. Stoga će ova studija pomoći istraživačima na terenu da utvrde vrstu oštećenja i da shodno tome daju ocenu upotrebljivosti konstrukcije na temelju vrste oštećenja.

Key words: *kombinacija nedestruktivnih metoda, mostovi, puozdana procena.*