PEDESTRIAN BRIDGES HEALTH ASSESSMENT STRATEGY USING NDT

Gokhan Kilic*

ABSTRACT

This research provides the details of the application of multiple NDTs (Non-Destructive Techniques) conducted on a pedestrian bridge situated in Izmir, Turkey. The techniques which were carried out include: Visual Inspection, Ground Penetrating Radar (GPR), and Wireless Sensor Network (WSN). The results of these applications deliver essential structural information including deflection, rebar position, and moisture ingress. The main contribution of this study is the integrated bridge health mechanism presented, which, by comparing the various results, is able to identify the part of the bridge with the greatest deterioration. This paper allows for a potentially enhanced judgment of the physical and mechanical behaviours of the structures of pedestrian bridges which could ultimately lead to better overall assessment of their functionality and life expectancy. In theory, this mechanism could be utilized in the near future by engineers in order to facilitate detailed assessment of pedestrian bridge structures.

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This research provides the details of the application of multiple NDTs (Non-Destructive Techniques) conducted on a pedestrian bridge situated in Izmir, Turkey. The techniques which were carried out include: Visual Inspection, Ground Penetrating Radar (GPR), and Wireless Sensor Network (WSN). The results of these applications deliver essential structural information including deflection, rebar position, and moisture ingress. The main contribution of this study is the integrated bridge health mechanism presented, which, by comparing the various results, is able to identify the part of the bridge with the greatest deterioration. This paper allows for a potentially enhanced judgment of the physical and mechanical behaviours of the structures of pedestrian bridges which could ultimately lead to better overall assessment of their functionality and life expectancy. In theory, this mechanism could be utilized in the near future by engineers in order to facilitate detailed assessment of pedestrian bridge structures.

Introduction

An essential role is played by bridges in communal, environmental, and financial terms. This clearly signifies a need to protect them against all the various processes that contribute to the deterioration of their structures over time. Although some of these causes may be natural, such as the ageing of the materials used in the construction, cycles of freezing/thawing, and flooding, others are rather more direct, such as heavy loads which create damaging vibrations. This results in cracks which can cause several visible and invisible structural deficiencies (delamination and moisture ingress, respectively). Any form of crack is potentially dangerous to the bridge’s lifespan, weakening the bridge supports and decks, or even causing structural failures in worst case scenarios. Since part of the bridge’s construction is underground, visible inspection is not always possible. In order to avoid the deterioration of bridge structures, it is essential to carry out an effective monitoring strategy for the health of these constructions which provides structural maintenance and assessment.

A majority of pedestrian bridge structures in current daily use require attention as they are constantly undergoing the conditions stated above, which are potentially destructive. Currently, inspections which utilize both non-destructive and destructive testing techniques can be conducted in order to monitor these structures. These inspections include detailed inspection, routine inspection, and initial inspection, as well as structural assessment.

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NDTs of assessment including electrical, infrared, electromagnetic, and sonic/ultrasonic thermography are each capable of providing information regarding the physical state of the given bridge, but so far, hence studies have been predominantly carried out within the lab. NDT may require high operational costs and time, but thanks to the continued advancement in its technology, costs are on a steady decline, making WSN and GPR technologies more attractive. The information gained through the use of these technologies is combined with the data gathered from more traditional methods of surveying, in order to provide engineers the output needed to make decisions about bridge maintenance [1] [2].

The latest recognizable approach to NDT, which makes use of combined NDT methods, is likely to provide the best possible outputs. As an example, GPR and ultrasound combined provide a detail evaluation of the modulus of elasticity, and extensive information, however, individually they suffer from reliability vulnerable [3]. For GPR, vulnerable is caused by the presence of water, and, to a lesser extent porosity, while ultrasound is vulnerable in conditions of density and moisture. Some researchers believe this combination is the way to the future regarding strength evaluation of concrete [4]. This approach provides impressive results in terms of visualization and detection, both of which add to the effective diagnosis, minimizing measurement noise as a result. The additional financial implications of this combinative approach are entirely acceptable if the diagnostic results are enhanced. In simple terms, the extra information extracted as a result of this approach is useful rather than redundant. The purpose behind this study is to test and recommend a precise approach that combines multiple NDTs, which has a significant potential to facilitate the diagnosis of pedestrian bridges [5].

The main problem with current NDT methods is that evaluations are mostly conducted with the use of a single method. Given the fact that pedestrian bridges are vulnerable to several deteriorative causes (moisture ingress, delamination, etc.), the use of a method which combines multiple NDTs would provide far more effective results [6]. Another problem with NDT methods is that these are often applied to older bridge structures with a limited amount of drawings, structural repots and other such paperwork, as with the study in hand. In such cases, the issue cannot be resolved by traditional NDT because critical information such as support position and rebar remains, unknown, which limits the ability design and structural engineers to facilitate the bridge through modelling and simulating structural behaviour via numeric means [5] [7] [8].

This study focuses on addressing the above mentioned gaps in the subject, proposing a reliable healthy assessment strategy for pedestrian bridges as a result. In order to achieve this, the paper assesses the results of several parametric studies and NDTs used in combination. The study offers the outcomes of the application of combinative approaches consisting of WSN, GPR, and visual inspection techniques, all of which were chosen for their reliability in the field of pedestrian bridge diagnosis. As stated before, only limited information can be found in terms of case studies of bridge structures. As a result, the fully-accurate evaluation of structural deterioration of pedestrian bridges is highly unlikely, even when, as in this study, surveys are carried out utilizing the two techniques stated above.

This implemented approach can be utilized to facilitate a comprehensive monitoring plan for pedestrian bridges in order to evaluate health of their structures, producing a detailed structural healthy analysis. Such an analysis enables precise decisions to be made in terms of remedial work. Additionally, this combinative approach delivers valuable information, including the identification of anomalies concealed inside the bridge’s structure (moisture
ingress, delamination, cracks, cavities, etc.) and rebar positioning. This information is otherwise not available.

**Case Study (Pedestrian Bridge)**

There is little or no information available about the structure of the bridge (Fig.1), which is similar to other bridges. Thus, it is an ideal candidate for a case study. The bridge mechanism implemented in this study is likely to be of value in the wider context of bridge evaluation.

![Figure 1. View of the pedestrian bridge [9]](image)

**Methodology**

The combinative process is a result of the application of multiple NDTs, including GPR, WSN, and visual inspection. A comparison of these results can provide information of greater accuracy regarding the structural health of the provided pedestrian bridge.

### 3.1 Visual inspection

Visual Inspection is a cost effective and convenient approach which can identify any superficial issues within a bridge’s structure, including beam delamination and moisture ingress. However, as it fails to provide detailed information, it needs to be combined with alternative methods. The author conducted a visual inspection on the 16th of February, 2014. The process took place within touching distance of all the elements involved, including the deck slab soffit, which was checked from the footway as well as the carriageway below to identify any exposed reinforcement, spalling, cracking, staining, and seepage. The primary results, and the main impressions gained during the visual inspection are all stated in section 4.1.

### 3.2 The GPR Survey

GPR (Ground Penetrating Radar) is a well-known non-destructive technique that facilitates monitoring and assessment of tunnels as well as bridge structures. In this process, a source antenna (commonly a transmitter) sends electromagnetic pulses through the structure. The reflected pulses are received by another antenna, which provides subsequent details of disturbances in the pulses, if any. The analysis of these disturbances helps identify the issues. The features of structural health of bridges which can be determined through GPR include cover length and condition of rebar, length of cracks, delamination, moisture presence, and
settlement. These factors are assessed among these varies structural features, including bridge abutments (cracks, settlement, leakage, etc.), beams, and columns [10] [11] [12].

A GPR survey was also conducted during this case study, in order to specifically identify the presence of underlying structural issues, such as moisture, cracking, and rebar. The GPR survey was carried out using the TR-HF GPR Antenna, including a 2GHz antenna (as shown in Fig. 2) on the 16th of February 2014.

![The TR HF (2 GHz) Antenna](image)

**Figure 2.** The TR HF (2 GHz) Antenna [9]

Before conducting the GPR survey, the marked grid paper with 10cm intervals was used and it enabled the GPR equipment to be moved around in the area in transverse and straight longitudinal directions (as shown in Fig. 3). The reference of the grid is in accordance with the coordination of points to a fixed area.

![GPR Survey](image)

**Figure 3.** GPR Survey [9].
The GPR equipment is capable of providing densely-sampled high quality data, as the equipment is easy to move and lightweight. The GPR survey facilitates a sample of higher density, which provides higher quality 3D data and tomography. IDS GRED data analysis software was used to create 2D tomography subsurface layers along with the surveyed volume’s 3D picture. The reliability of the outcome can be improved by combining datasets from both transversal and longitudinal scans, but this is only possible if an identical tomographic map is used.

### 3.3 WSN Monitoring Procedure

The WSN approach was utilized in order to calculate the structural responses of the pedestrian bridge. Inspection was carried out using the Oracle SunSPOT wireless sensor node (as shown in Fig.4 and Fig.5). The figures demonstrate the WSN method, which utilizes 8 SunSPOT sensor nodes and a base station. A complete dataset was transmitted to the base station, which is integrated with a laptop. After collection the data was analysed using GSMA (Global System for Mobile Applications).

**Figure 4.** View of WSN system [9]

**Figure 5.** Position of the Wireless sensor nodes
A Java-based software application is used to control the wireless nodes. The system of this application is contained in a single chip, powered by the Atmel AT91RM9200 processor, based on ARM (or the Acorn Reduced instruction set computer Machine). The system’s flash memory is 4 MB, whereas the RAM is 512 KB. The communication board uses a standard IEEE 802.15.4 radio, and was constructed for the 2.4GHz band [13].

Results

4.1 Visual Inspection

In addition to the GPR survey, a visual inspection was carried out on the bridge structure. The inspection showed that the deck surface of the bridge was in very poor condition, with some areas of reinstatement in substandard condition. Fretting and potholes were also found. The results of the visual inspection are shown in Fig. 6.

![Visual Inspection Images](image)

Figure 6. Concrete deterioration at Zone C (a) cover delamination, water is easily seeping, (b) efflorescence, significant cracks

4.2 GPR Survey

Although the GPR analysis covered the entire bridge structure, Zone C is the primary focus (as shown in Fig 7). The figure below displays the radargram of zone C and its centre cross section, to a depth of 0.3m.
Figure 7. Processed 2GHz data and possible explanations (interpretation) within Zone C

The Fig 7. clearly identifies the areas possibly damaged by moisture ingress, in addition to the locations of the supports. The information processed, and the subsequent translations are conclusive regarding the signified structural components and features.

Figure 8. (a) Vertical sliced processed data, (location of possible moisture ingress and cracks).

Fig. 8 depicts a comparison of the results calculated by the GPR survey using the 2GHz antenna. The figure depicts a data of vertically sliced depths of 25 cm below the deck’s surface. Black circle is used to highlight features that occur consistently, and their appearance is also shown. As it is viewable, the moisture ingress is found across the deck of the bridge, which clearly identifies a considerable amount of damage in the cover’s upper layers due to
penetration of moisture to depths of greater than 10 cm.

4.3 WSN Monitoring

Using the WSN technique, it was found that the bridge structure was experiencing its maximum level of deflection. Fig. 9 displays the deflection experienced by all sensors at the time the bridge was in use.

![Figure 9. WSN results](image)

**Discussion**

This study displays shows how it was possible to determine previously-unknown regarding the pedestrian bridge’s internal structure (such as possible defects and rebar position), including the discovery of a specific area of the structure in need of urgent repair. The output was obtained through the comparison of the areas where interior and exterior defects portray excessive deflection, which provides a complete image of the health of the pedestrian bridge. Such information is extremely important in making decision regarding remedial action.

This implemented method has benefits for the civil engineering industry, as it is a comprehensive and reliable tool for evaluating structural deterioration in pedestrian bridges. Currently, this area is very complex due to the vast choice of equipment and techniques available. However, this combinative approach reduces the complications by determining complementary NDTs, enabling a convenient assessment of the structure without the requirement for additional testing, unless indicated by specific circumstances.

The simplicity and cost effectiveness of the initial evaluation (visual inspection) provides an advantage to this technique over other old health monitoring procedures. Previously, most NDTs were conducted in isolation and as such, failed to provide a comprehensive health evaluation for use by engineers. To illustrate this statement, although the GPR survey on the pedestrian bridge revealed moisture ingress over the entire deck, it was not clear how this affected the bridge's structural behaviour. Subsequently, this information was revealed through the application of the WSN procedures. However, the collection of geometric data was made possible through visual inspection. Thus, WSN helped provide actual bridge deflection, visual inspection provided geometric data collection, and GPR delivered the internal composition (rebar position) in detail. The combination of approaches allowed a far more accurate assessment as compared to the processes which are typically used currently.

This method is currently only suitable for pedestrian bridge structures, and not recommended
for other bridge types. Given that some testing methods, (e.g. WSN for measuring deflection) are applicable on all bridge types, however, it is probable that, this implemented technique can be modified in order to make it applicable for all bridge types, although this would certainly require some additional NDTs specific to the construction of each bridge type.

**Conclusions**

GPR, WSN, and visual inspection methods were conducted on the bridge structure as part of the integrated pedestrian bridge health monitoring strategy. The bridge utilized was ideal for the study as there was no substantial data in terms of its structural composition available. These approaches were taken: first, upon conducting visual inspection, a significant amount of cracking was found. Second upon carrying out a GPR survey, the position of the rebar was corrected and the detection of existing moisture was also made possible. Finally, with the GPR survey, other areas affected by moisture were also identified. As a result of the comparison between these results along with the results calculated using other testing techniques, it was possible to determine the area suffering from the greatest amount of damage due to moisture.

For the reasons already discussed, this implemented approach proved useful in terms of the specific pedestrian bridge used as the case study. However, the application needs to be repeated on other structures to prove its value. This study adds to the current knowledge base, further increasing the understanding of the behaviours of pedestrian bridges and other related structures. In particular, it provides detailed information on durability, functionality, stability which is of great value to researchers and structural engineers.

**References**


