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Thermal based damage identification in RC beams

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ABSTRACT: Damage detection in different types of structures is becoming an increasingly concern among the engineering community. Proper damage detection can increase the safety and service life of different civil, aeronautical or mechanical engineering structures. As a result, a large number of methods and/or techniques have been proposed in the field of aeronautics, civil and mechanical engineering for this purpose. So far, in all existing methods ambient temperature or thermal excitation has been treated as the noise or disturbance in the damage identification system and numerous methods have also been proposed to eliminate the effect of temperature. In this paper a damage identification technique for RC beam like structures is presented which considers temperature distribution along the length of the beam. The fundamental of the technique analyzed herein is based on changes in the temperature profiles as a heat flux travels through the material. A finite element simulation was carried out to verify the proposed technique. The finite element simulation results show the capability of the proposed technique to detect the presence of damage and its exact location. The influence of various damage parameters, such as damage depth, width, distribution etc. is also studied. The main advantage of the proposed damage identification method is that practically temperature can be measured very easily with the available devices and with a high precision and distributedly.

1 INTRODUCTION

Civil infrastructures are not built for eternity and the number of aged structure is increasing rapidly all over the world. The need for damage identification system in structure is also continuously growing to maintain existing civil infrastructures. The trend in the development of new damage identification technology is triggered after the recent earthquakes that posted the problem of rapid evaluation of damage in the structures. Bridges are one of the important infrastructures; their continued safe performance is very important to human and economic activities. Most of these structures accumulate damage due to long term aging or degradation, due to natural hazards such as wind and earthquakes.

The available damage identification techniques may be broadly classified into three categories such as (1) methods based on statically measured data (2) methods based on dynamically measured data or vibration-based approach and (3) non-destructive evaluation (NDE) approach. In the vibration-based approach, damage in a structure is evaluated by correlating the change in mechanical properties (i.e. stiffness, flexibility etc.) of the structure to its change in modal properties (i.e. modal frequency, mode shape and modal damping ratios) when the considered structure is subjected to a certain dynamic excitation. In the NDE approach, damage detection for a structural system is done by performing some non-destructive tests (NDT) like visual inspection, ultra-sonic test, acoustic test, magnetic field test, radiograph, eddy-current and some others. Excitation is one of the important issues in a damage identification scheme. Excitation techniques can be classified into two main categories: forced excitation and ambient excitation. In the first category, the excitation is intentionally applied to a structure. Therefore, the location and magnitude of excitation are well characterized. In the second category, excitations act on the structures during their normal operating condition. By these methods the whole structure is excited, however the location and magnitude are totally random and very difficult to control. Wind, wave motion, traffic load and seismic ground motion are considered as ambient excitations (Farrar *et al.*, 1999). In the NDE approach, structural elements or members are examined. In fact, only material is excited by a specific physical excitation (ultra-sonic, eddy current or magnetic).

So far, most of the damage identification techniques consider that cracks or localized damage in structures reduces stiffness. Based on this concept numerous techniques have been developed utilizing the static or dynamic test data. In these damage identification techniques environmental temperature change has been treated as noise in the measured data although temperature can alone change the structural dynamic properties significantly which may lead the damage identification process unreliable (Serker and Wu, 2009). Therefore, many efforts have also been made to overcome this problem e.g. use of long-gage distributed fiber Bragg grating sensor for damage identification under changing environmental conditions (Serker et al., 2010).

In recent days, some efforts have been made to detect damage by measuring only the temperature of the structural member or component. Most of these techniques are based or infrared thermography. For example, Nancy and Philip (1996) used infrared cameras and image processing techniques to develop thermal NDE tool to quantify structural damage within airframes and bridge decks. Shih et al. (1999) examined the possibility of detecting geometrical defects in concrete specimens using thermal imaging and characteristics of heat flow phenomenon. Lerma et al. (2007) used visible and thermal infrared imagery to analyze and map structural alterations on a masonry brickwork building. Banks et al. (2009) developed a model by using the heat equation for detecting damage in a heterogeneous porous material. In this method, temperature data along the source and back boundaries are recorded and then analyzed to distinguish differences between the undamaged and damaged materials. In this paper a damage identification technique for concrete beam is presented which considers temperature distribution along the length of the beam. The temperature can be measured continuously by using thermometer, thermocouples or fiber optic sensors.

2 BASIC CONCEPT

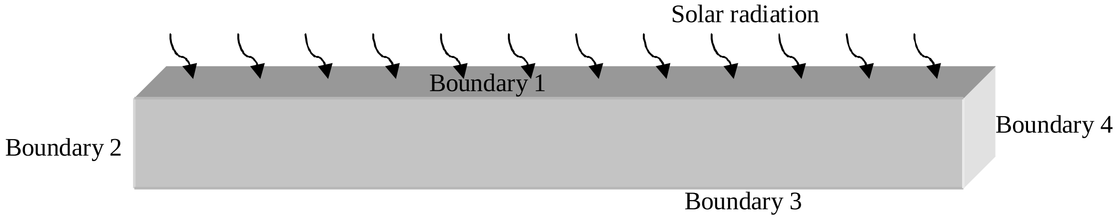
Damage identification using the thermal measurement is based on the concept that heat diffuses around a damaged zone or zone with high porosity, rather than strongly interacting with it. Structural cracks, imperfections or localized zones of high porosity have different thermal properties, e.g. thermal conductivity, than the rest of the concrete, so under heat flux they will produce zones with different temperatures than the surrounding concrete. A heat flux develops if there is a temperature difference between two areas of the body. Heat will flow from the hotter to the cooler zone. In general, the upper part of the structural member is exposed to solar radiation and is hotter than the beam soffit. In a beam, concrete areas with cracks, voids or imperfections have lower thermal conductivity than the areas with normal concrete or undamaged part. Therefore, their presence will create a thermal anomaly in the temperature distribution of the concrete structure under heat flux. Solar radiation is considered as excitations and under the effect of solar radiation, temperature of a sunlight-exposed structure will be changed. In other word, solar radiation induces an ambient thermal loading on the sunlight-exposed structure. This type of loading can be measured very easily in terms of temperature by thermometers or thermocouples at any point and any time with a sufficient accuracy. The temperature difference between sunlight-exposed and underneath area of the structure depends on the intensity of solar radiation. Therefore, the difference in temperature may be high during daytime, when the sunlight is available and low during nighttime, when sunlight is not available i.e. heat enters the concrete structure is typical of a warm day and heat flows from the concrete structure happens during a cold night, for instance. According to Weil (1991), the best thermal contrast is obtained two or three hours after sunrise or sunset. The concept of damage identification is illustrated in Figure 1.

3 NUMERICAL SIMULATION

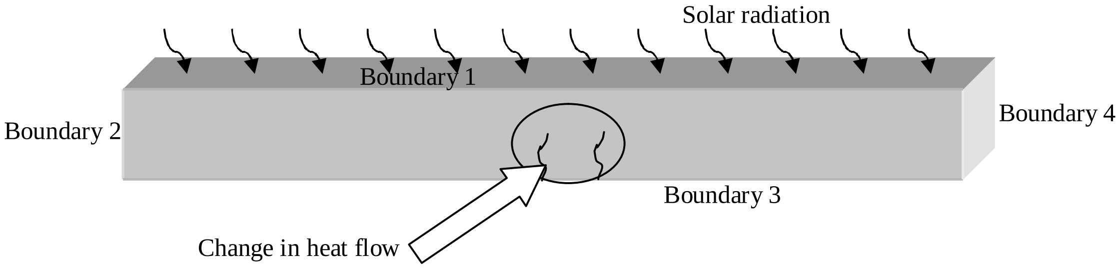
3.1 *Model Description*

The proposed damage identification method is demonstrated using simulation case studies on a concrete beam. The simple supported beam model chosen in this study is one of the common types of civil structures. The beam is 3m long and 0.5m deep (Figure 2). The beam is modeled with 600 plane elements of size 0.05m x 0.05m having 2-D thermal conduction capability. The element has four nodes with a single degree of freedom, temperature, at each node and is applicable to a 2-D, steady-state or transient thermal analysis.

Numerical simulations were performed with the commercial finite element analysis software, ANSYS (2005). Thermal conductivity gives the heat flux transmitted through an area of a material under temperature gradient. The thermal conductivity of concrete is influenced by the mineralogical characteristics of aggregate, moisture content, density as well as temperature of concrete. The thermal conductivity of dry concrete is estimated within the range of 0.62-2.77 W/mK (Haghighi, 2010). In this study thermal conductivity of concrete was arbitrarily chosen as 1.30 W/mK. It is also assumed that air will flow into the cracked or damaged section and the section will have the thermal conductivity of air. Therefore, damage was introduced by reducing the thermal conductivity of the corresponding element. Single and multiple damages were introduced by reducing the thermal conductivity at single element and multiple elements of different locations respectively. The effect of damage depth and width is also investigated in the study. The different damage scenarios considered in this study are listed in Table 1. Temperature at upper and lower boundary was considered as 45°C and 30°C respectively.



(a) Intact system



(b) Damaged system

Figure 1. Basic concept of the damage identification

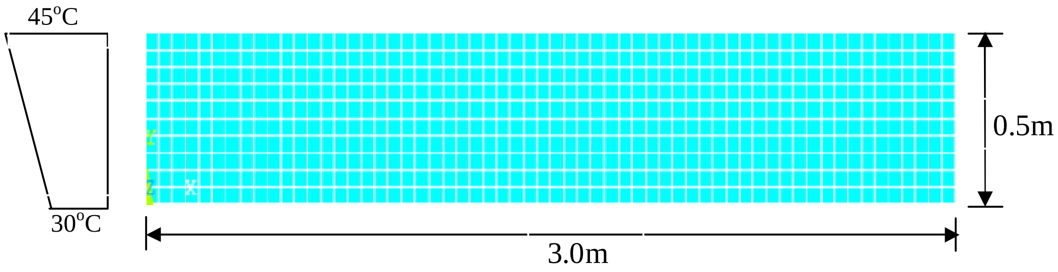


Figure 2. Details of the model beam

Table 1. Damage scenarios

Damage scenario	Damaged element	Location From left end
Case 1	None	---
Case 2	Element 32	1.6m
Case 3	Elements 32 and 92	1.6m
Case 4	Elements 32 and 33	1.6m and 1.65m
Case 5	Elements 32 and 43	1.6m and 2.15m
Case 6	Elements 32, 92 and 43	1.6m and 2.15m

3.2 *Damage Identification Results*

Different damage scenarios considered in this study are presented in Table 1. In each case, the temperature profile of the beam at a distance 0.10m was considered for comparison. Damage identification results from the simulation case studies are presented in Figures 3-5. No damage was considered in Case 1 and the temperature profile of selected depth of the beam for Case 1 shows no variation. In Case 2, a single damage was applied to element 32 and the damage can easily be detected from the temperature profile shown in Figure 3.

There is a distinct change in temperature at the damage location of the beam. A single damage was also applied in Case 3. However, in this case the damage depth was twice that of Case 2. Damage location can easily be characterized from the change in temperature profile. It is to be noted that the change in temperature for Case 3 is larger than that of Case 2. Therefore, a relationship between the temperature change and degree of damage can be established and damage depth can also be quantified. In Case 4, the width of the damaged area was considered twice that of Case 2 however the damaged area for Case 3 and Case 4 are same. From Figure 4 it is depicted that damage width has greater influence on the heat flow than damage depth. Damage identification results for Case 5 and Case 6 are presented in Figure 5 and the temperature profile is compared with that of Case 3. In case 5, same degree of damage was applied to two different locations and damaged area can be easily be noticed from the temperature changes at similar locations. Similar type of damage was applied in Case 6 except that the degree of damage was different in each location. Damage identification for case 6 also revealed the same. By comparing the temperature change of same location for Case 3 and Case 6 it can be concluded that the same degree of damage will produce same quantity of temperature change.

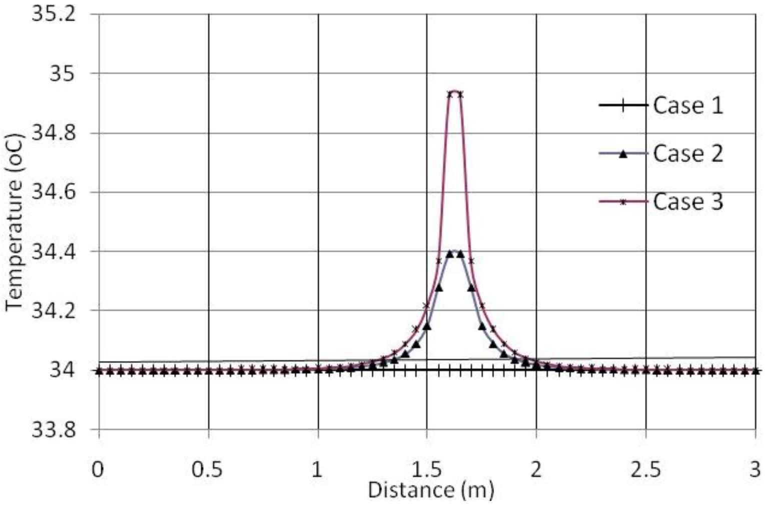


Figure 3. Damage identification results for single damage of varying depth

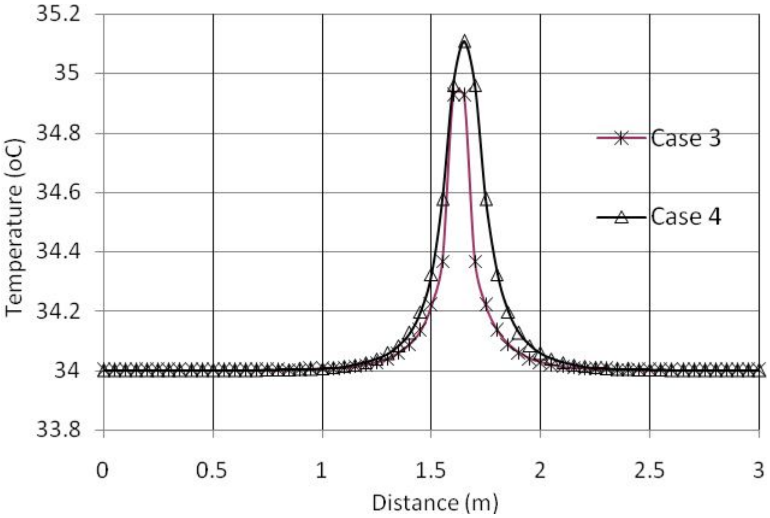


Figure 4. Damage identification results for single damage of varying depth and width

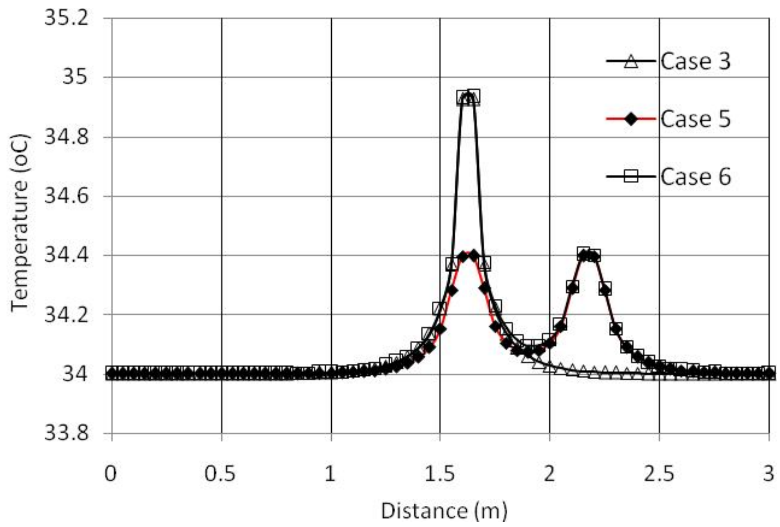


Figure 5. Damage identification results for multiple damage

4 CONCLUSIONS

In this article, a thermal based approach for damage identification is presented. This approach can be applied by measuring only the temperature profile of the selected structure. The proposed approach is demonstrated and verified using the numerical simulation data. Simulation results show that the method can detect damage qualitatively by using the temperature profile only. The simulation results also depict that the change in temperature can be correlated with degree of damage and damage degree can be quantified accordingly. It is well established that temperature can be measured very easily with sufficient accuracy. Recent advancement in fiber optic sensing technology has also opened the door of distributed sensing of temperature and it is also possible to embed temperature sensors in the material. Therefore, the proposed damage identification strategy may also be applied for continuous monitoring of structures with necessary spatial resolution.

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