Dynamic behavior of damaged concrete bridge structures under moving vehicular loads

Ss Law
Beijing Jiaotong University
Xinquan Zhu
University of Technology Sydney

Abstract
The dynamic behavior of damaged reinforced concrete bridge structures under moving vehicular loads is studied. The vehicle is modeled as a moving mass or by a four degrees-of-freedom system with linear suspensions and tires flexibility, and the bridge is modeled as a continuous Euler–Bernoulli beam simply supported at both ends. The damage may or may not be varying when the load is moving on top, and a damage function representing either the open crack model or the breathing model is used to model the crack zone in the reinforced concrete beam. An experimental test is performed on a reinforced concrete beam with Tee-section subjected to vehicular loadings to check on the performance of the crack models. Effect of other parameters like the moving speed of vehicle and road surface roughness are included in the simulation study, and the dynamic deflection, relative frequency change (RFC), absolute frequency change (AFC) and phase plot of the responses are studied for their possible correlation with the damage modeled as open crack or breathing crack.

Introduction
The dynamic response of a beam subject to moving loads has been studied extensively with reference to machining processes and behavior of railway tracks and bridges. Fryberg [7] presented the analytical solutions for simple problems of simply supported and continuous beams with uniform cross-section. Despite the ever-increasing number of research publications on the dynamic response of structures with moving loads, there is few publications on the dynamic response of beams with inherent cracks under the action of moving loads. Lee and Ng [15] used the assumed mode method to analyze the dynamic response of a beam with a single-sided crack subject to a moving load on the top. The beam is modeled as two segments separated by the crack. Two different sets of admissible functions satisfying the respective geometric boundary conditions are then assumed for these two fictitious sub-beams. The rotational discontinuity at the crack is modeled by a torsional spring with an equivalent spring constant for the crack. The equality of transverse deflection at the crack is enforced by a linear spring of very large stiffness. Pari and Behera[24] utilized an analytical method along with the experimental verification to investigate the behavior of a cracked beam with a moving mass. A local stiffness matrix was used to model the
crack section. Mahmoud [17] and Mahmoud and About Zaid [18] studied the effect of transverse cracks on the dynamic response of simply supported undamaged beams subjected to a moving load or mass. Majumder and Manohar [19] developed a time-domain approach to detect damage in beam structures using a moving oscillator as the excitation source and the damage is simulated as a reduction in the flexural rigidity of the finite element of the beam. Mazurek and DeWolff [20] and Lee et al. [14] investigated the feasibility of detecting structural deterioration in highway bridges using vehicular excitation in laboratory. All the above studies are related to simple open crack model.

On the other hand, there has been growing interest in studying the vibration of cracked components and structures. Dimetrodons [4] gave comprehensive survey on crack modeling approaches. These approaches fall into three categories: local stiffness reduction, discrete spring models and complex models in two or three dimensions. Frizzell and Penney [6] compared the different approaches and demonstrated that the simple model of crack flexibility based on beam elements is adequate for structural health monitoring using low frequency vibration. The non-linearity from a breathing crack has an important effect on the structural health monitoring of structures, and the bilinear stiffness model is usually used to model the behavior of the crack opening and closure. A larger stiffness value corresponds to the state of crack closure, and a smaller stiffness value corresponds to crack opening. Partial crack closure often occurs due to (1) roughness interference, (2) wedging by corrosion or wear debris, and (3) elastic constraint in the wake of the plastic zone. The closure effects on the vibration response of a fatigue cracked steel Tee-beam were investigated experimentally by Zhang and Testa [25]. Abraham and Brandon [2] employed many terms of a Fourier series to simulate the continuous change of stiffness in a breathing crack. Cheng et al. [3] also presented a simple continuous breathing crack model to examine the dynamic response of a fatigue crack at the first vibration mode of the beam. When dealing with cracks in concrete, Law et al. [11] and [12] presented a method to assess the structural condition and load-carrying capacity using the information obtained from static and dynamic tests on a scaled model reinforced concrete bridge deck at different stages of cracking and spalling. Abdel Wahab et al. [1] used a damage function to describe the damage pattern of reinforced concrete beams with three parameters, i.e. the length of damaged zone, the magnitude of damage and the variation of the Young’s modulus of material from the center to the ends of the damaged zone. Lee and Fenves [13] developed a plastic-damage model for concrete subject to cyclic loading using the concepts of fracture-energy-based damage and stiffness degradation in continuum damage mechanics. A simple and thermodynamically consistent stiffness recovery scheme was introduced for simulating crack opening and closure. Eccles et al. [5] performed a series of laboratory experiments to investigate the non-linear behavior of cracked reinforced concrete beams. A crack model was introduced including a bilinear “open crack” model and a hyperbolic tangent function to describe the
transition between the open crack and the closed crack states. Neild et al. [22] measured and analyzed the stiffness across a cracked region of a reinforced concrete beam over a cycle of static loads with four possible non-linear mechanisms resulting in amplitude-dependent natural frequencies. Furthermore, Neild et al. [23] studied these non-linear vibration characteristics by conducting impact excitation vibration tests on reinforced concrete beams using time–frequency analysis.

The present work studies the dynamic behavior of damaged reinforced concrete bridge structures under moving vehicular loads. The vehicle is modeled as a moving mass or by a four degrees-of-freedom system with linear suspensions and tires flexibility, and the bridge is modeled as a continuous Euler–Bernoulli beam simply supported at both ends. The damage may or may not be varying when the load is moving on top, and a damage function representing either the open crack model or the breathing crack model is used to model the crack zone in the reinforced concrete beam. An experimental test is performed on a reinforced concrete beam with Tee-section subjected to vehicular loadings to check on the performance of the crack models. Effect of other parameters like the moving speed of vehicle and road surface roughness are included in the simulation study, and the dynamic deflection, relative frequency change (RFC), absolute frequency change (AFC) and phase plot of the responses are studied for their possible correlation with the damage modeled as open crack or breathing crack.

Responda las siguientes consignas en Español:

1. ¿De qué trata el artículo? y ¿Cuán desarrollado está el tema en el área de la investigación?
2. Los autores mencionan dos líneas de investigación que se están desarrollando en la actualidad, ¿Cuáles son?
3. Identifique y transcriba en español la oración que menciona el vacío de conocimiento expresado por el autor.
4. ¿En qué consistió la prueba experimental llevada a cabo para la investigación? ¿Con qué objetivo se realizó?
5. ¿Cuál es el propósito del autor?
6. Determine la función del conector Furthermore resaltado en el texto. Explique qué ideas conecta.