DOI: 10.3217/978-3-99161-057-1-129

Numerical dataset for benchmarking of drive-by bridge monitoring methods

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ABSTRACT: Publicly accessible vehicle measurements for testing and validating drive-by bridge monitoring techniques are currently insufficient. Although relevant monitoring campaigns have been conducted, their results are limited and generally inaccessible to the research community. Consequently, this paper introduces a numerical dataset designed to advance drive-by monitoring methods. The dataset is freely available and can be downloaded from an online repository. It comprises numerically simulated vehicle responses generated using an open-source vehicle-bridge interaction model. The repository includes over half a million individual vehicle crossing events, covering various monitoring scenarios, bridge spans, damage locations, damage magnitudes, road profile conditions, and vehicle properties. This dataset is intended to serve as a reference solution and benchmark for future developments in drive-by bridge monitoring.

KEY WORDS: Indirect Monitoring; Damage Detection; Vehicle-Bridge Interaction; Drive-By Inspection.

1 INTRODUCTION

To facilitate the advancement of data-driven drive-by bridge damage assessment techniques, this paper presents an openly accessible dataset [1]. The dataset consists of numerically simulated vehicle responses from crossings over diverse bridge spans with varying damage conditions. Additionally, it includes results that consider variations in road profiles, vehicle models, mechanical properties, and speeds. The objective is to offer the research community a valuable resource that serves as a reference for testing and benchmarking new developments in the field.

2 THE DATASET

This section offers an in-depth overview of the NuBe-DBBM dataset (Numerical Benchmark for Drive-By Bridge Monitoring methods), which is available to the public in [1]. The dataset encompasses vehicle response data from over half a million numerically simulated vehicle-bridge crossings, spanning a broad spectrum of road, bridge, and vehicle conditions. Furthermore, the repository provides additional materials to support users of the dataset.

The dataset was generated using VBI-2D [2], an open-source MATLAB tool designed to simulate vehicle-bridge interaction (VBI) for road traffic crossing bridges. This tool allows for the specification of various vehicle models, road irregularities, bridge characteristics, and structural conditions. In VBI-2D, bridges are modelled as beams within a finite element framework, while vehicles are represented as mechanical systems with multiple degrees of freedom. The coupled vehicle-bridge response is determined through direct integration of the corresponding equations of motion. For more detailed information on the numerical model, solution method, and user manual, readers are referred to [2]. Figure 1 provides a schematic overview of VBI-2D's simulation capabilities. Specifically for the dataset, simulations involved simply supported bridge configurations of single vehicles crossings at constant speeds under varying road, vehicle, and bridge conditions.

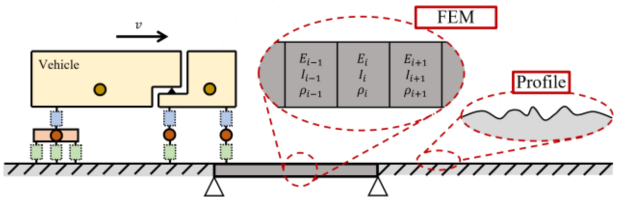

Figure 1. Illustration of VBI-2D model.

The dataset consists of individual MATLAB files, each containing information and vehicle responses for a single event. An event is defined as a single vehicle traveling at a constant speed over a specified road profile while crossing a bridge without any initial vibrations. The dataset includes five primary problem variables: Bridge length (B), Damage location (DL), Damage magnitude (DM), Vehicle type (V), and Profile (P). It is further divided into two subsets, named DSA and DSB, corresponding to two distinct monitoring scenarios. For each possible combination of problem variables and monitoring scenarios, 800 events are included, with vehicle properties randomly sampled.

The dataset comprises numerical results for six distinct simply supported bridges with span lengths varying from 9 m to 39 m, increasing in 6 m increments. These bridges are modelled as finite element representations using beam elements, each 0.25 m in length. The numerical properties of the beam models were chosen to represent typical bridges of these span lengths, with detailed values of the properties for the beam models provided in [3].

Bridge damage is modelled as a decrease in stiffness affecting either 2 or 4 elements, which equates to bridge lengths of 0.5 m or 1 m. The severity of the damage is expressed as a percentage reduction in stiffness, with the dataset providing results for three levels: 0% (undamaged bridge), 20%, and 40%. Furthermore, two damage locations are examined,

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specified in relation to the bridge span L, namely at quarter-span (L/4) and at mid-span (L/2).

The dataset encompasses results for three distinct vehicle models, which are numerically represented through combinations of concentrated masses, rigid elements, springs, and dashpots. These models, generated using the open-source tool VEqMon2D [4], are schematically depicted in Figure 2, illustrating the names of all mechanical properties, relevant dimensions, and degrees-of-freedom (DOF) notation. The vehicles are classified based on their total number of axles: a 1-axle model (V1), a 2-axle model (V2), and a 5-axle model (V5). The V1 model, often referred to as a quarter-car model, has been extensively utilised in previous studies to evaluate the performance of drive-by methods. The V2 model represents a car or a 2-axle heavy vehicle, such as a van or truck. The V5 model characterises an articulated heavy vehicle, comprising a tractor and trailer connected by an articulation.

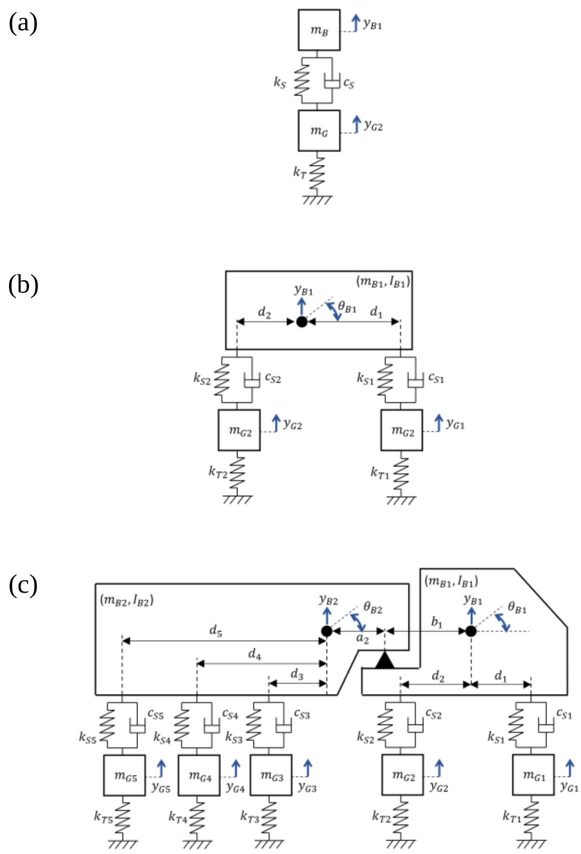

Figure 2. Vehicle models; (a) V1: 1-axle vehicle model; (b) V2: 2-axle vehicle model; (c) V5: 5-axle articulated vehicle model.

Each event in the dataset models the response of one of the vehicle types. For each simulation, the actual speed, along with the mechanical and geometrical properties, are randomly sampled based on probabilistic descriptions provided in the repository [1]. The variability in vehicle model parameters is intended to represent fleets of similar vehicles, although no two are identical. While the geometry of all vehicles within a specific model type remains consistent, their mechanical properties differ between simulations. This mirrors real-world conditions, where vehicles vary due to differences in payloads, suspension characteristics, and tyre pressures.

The dataset also incorporates the impact of road conditions. Some simulations assume a perfectly smooth road surface, labelled as P00. Additionally, the dataset features simulations with two randomly sampled Class A road profiles, generated according to the standardized procedure specified in ISO 8608. To simulate the actual wheel footprint, a moving average filter with a window size of 0.25 m is applied to the generated profiles. These profiles are 600 m in length, with their reference system centred at the midpoint. The profiles are consistently used across all bridge spans, with the left beam support positioned at the origin of the profile's reference system. For all simulations, vehicles include a 100 m long approach distance before crossing the bridge.

The dataset encompasses two distinct monitoring scenarios. Scenario A (DSA) depicts a situation where the target bridge has substantial damage, necessitating more controlled and detailed drive-by inspections while maintaining regular operational conditions. In this scenario, the bridge damage spans 4 elements (1 m), and the vehicle fleet gathers signals at high sampling rates while travelling at controlled, nearly uniform speeds. Scenario B (DSB), in contrast, represents normal operational conditions aimed at detecting early signs of bridge deterioration. Here, the damage spans only 0.5 m (2 elements), with vehicles travelling at varying permitted speeds (resulting in high variability) and signals collected at a lower sampling rate. Table 1 outlines the specifications for both scenarios, reflecting different levels of difficulty for drive-by methods. Scenario A, with more extensive bridge damage and less variability in vehicle speeds, is anticipated to enhance the performance of data-driven damage detection methods. Conversely, Scenario B presents a more challenging environment due to smaller damage and greater variability in operational conditions.

Table 1. Monitoring scenarios specifications.

Dataset code name	DSA	DSB
Number of damaged elements	4	2
Sampling rate of signals (Hz)	1024 (210)	256 (28)
Speed variation (km/h)	70 to 80	30 to 80

Table 2 gives an overview of all dataset dimensions together with their possible values.

Table 2. Summary of dataset's dimensions.

Property	Notation	Possible values
Monitoring scenario	DS + letter	DSA – DSB
Bridge	B + span in m	B09 – B15 – B21 – B27 – B33 – B39
Damage location	DL + location in % of span	DL25 – DL50
Damage magnitude	DM + % of stiffness reduction	DM00 – DM20 – DM40
Vehicle	V + number of axles	V1 – V2 – V5
Road profile	P + Class + Number	P00 – PA1 – PA2
Event number	E + number	E0001 – E0002 – ... – E0800

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As mentioned earlier, the dataset consists of individual files containing numerical results and other relevant details for each vehicle crossing event. Each file is uniquely named to indicate the specific characteristics of the simulated event based on the dataset dimensions (see Table 2). The naming convention for each file is:

DS*a* + _ + **B***bb* + **DL***cc* + **DM***dd* + **V***e* + **P***fg* + **E***hhhh* + .mat

for:

DS*a* = Dataset name, where *a* indicates either A or B monitoring scenario
B*bb* = Bridge type, where *bb* indicates span length
DL*cc* = Damage location, *cc* indicates the location as % of span length
DM*dd* = Damage magnitude, *dd* indicates % of stiffness reduction
V*e* = Vehicle type, *e* indicates the number of axles of the vehicle model
P*fg* = Profile, *f* indicates the class of profile (A), and *g* is the profile number
E*hhhh* = Event number, *hhhh* indicates the event number

For example, the event file *DSA_B15DL50DM20V5PA2E0327.mat* corresponds to event number 327. This event features a 5-axle truck traversing the 2nd Class A profile and a 15 m simply supported bridge, which has a 20% stiffness reduction at mid-span, under monitoring scenario A.

The dataset includes 518,400 events, totalling 52GB of files that are freely available for download [1]. These files are organised into compressed subfolders based on bridge span and monitoring scenario. Each event file contains the simulated acceleration responses from all degrees of freedom (DOFs) of the vehicle model, including both off-bridge and on-bridge responses, i.e., the vehicle's responses while approaching and crossing the bridge. The file also records the exact time the vehicle enters the bridge. Additionally, it includes the specific realisation of the vehicle's mechanical properties for the simulated event, along with the corresponding natural frequencies of the vehicle model.

Moreover, the repository includes supplementary files that detail the vehicle models and their DOF notation (*Vehicles_DOF.zip*), the road profiles used in generating the dataset (*Profiles.zip*), and the bridge model parameters (*Bridges.zip*). It is important to note that the vehicle responses in the dataset are clean signals. To simulate real measurements, these signals should be corrupted with noise. To assist with this, the file *Noise.zip* offers two equivalent implementations (for MATLAB and Python) to add noise to the signals.

Readers are referred to the documents *ReadMe.pdf* available in the repository [1] for further information about the stored content and practical guidelines to read the event files. Also refer to the original publication [3] for additional details about the problem variables, vehicle property variability, and the stored information within the dataset.

3 CONCLUSION

This paper has introduced a publicly accessible dataset designed as a benchmark for drive-by monitoring techniques. The dataset comprises numerically simulated vehicle responses during bridge crossings. A wide array of configurations and conditions have been modelled and systematically stored in files, which are readily available at [1]. The dataset's variability includes different bridge spans, damage locations, damage magnitudes, road profile irregularities, monitoring scenarios, and vehicle properties. It contains over half a million files with vehicle responses and additional information for individual crossing events. This paper encourages the research community to employ this dataset to test and enhance drive-by monitoring methods.

ACKNOWLEDGMENTS

The UNSW authors would like to thank Australian Research Council (ARC) for the provision of support under Discovery Early Career Researcher Award (DECRA) scheme with grant number DE210101625.

The UCD authors wish to express their gratitude for the financial support received from the Irish Research Council (IRC) GOIPD/2023/1588 and the financial support of Science Foundation Ireland under Grant number 20/FFP-P/8706.

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