第 I 部門

Python script based vehicle-bridge interaction simulation

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1. Objective

Seismic response of highway bridges has been studied deeply, but vehicle loads are often ignored. Researches show that bridge seismic responses will change when vehicles on it are treated as live loads. So, we need to find an efficient way to study how vehicle live loads affect bridge seismic responses.

The key is a contact problem called vehicle-bridge interaction (VBI). The dynamic responses of bridge and vehicle are hard to be solved directly. The Recursive Substructure Method (RSM) was proposed to solve it [1], but it is still complex and inefficient. Therefore, the research aims to improve the efficiency and flexibility of the RSM, making it suitable for various scenarios in the future.

2. Methodology

The RSM solves the dynamic responses of vehicle and bridge in two different software, MATLAB and ABAQUS, separately. The study replaces MATLAB with Python script embedded in ABAQUS to improve the coding experience and executing flexibility.

The script runs in time steps one by one. Each time step represents a new location of the vehicle. Within each time step, the dynamic responses of the vehicle and the bridge is estimated and then solved recursively as in iteration loops, as shown in Fig. 1. Each iteration loop will promote the accuracy to a higher level. At the end of each iteration loop a tolerance check is introduced to decide whether proceed to the next time step or not.

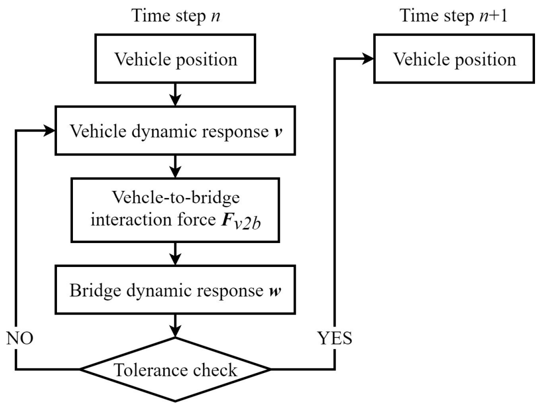

Figure 1 Flow of Algorithm

In this study, a simply supported beam model is introduced to simplify the bridge, while the vehicle is replaced by a moving sprung-mass system, as shown in Fig. 2. The bridge length is 25m, pinned on the left with a roller on the right. The Young's modulus, moment of inertia and Poisson's ratio of the bridge are 2.87GPa, 2.9m^4 and 0.2, respectively. The mass of bridge is 2303kg/m per unit length. The weight of the vehicle is 5750kg and the spring stiffness coefficient is 1595kN/m. The vehicle travels at 100km/h. Damping ratio and road roughness profile are ignored. The result is then compared with the closed-form expression, and the precision and efficiency are discussed later.

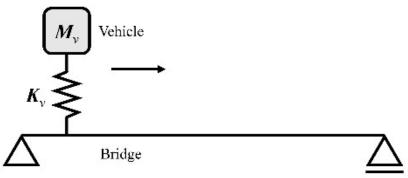

Figure 2 Simply supported beam mode

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3. Result

The closed-form expression and simulation result are plotted in solid and dotted line in Fig. 3, 4, 5 and 6, respectively. They agree well and the differences can be explained by the omitting of higher vibration modes.

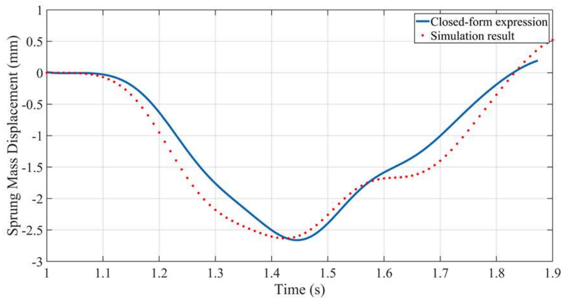

Figure 3 Vehicle vertical displacement

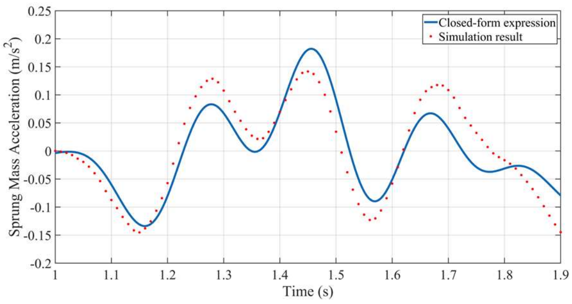

Figure 4 Vehicle vertical acceleration

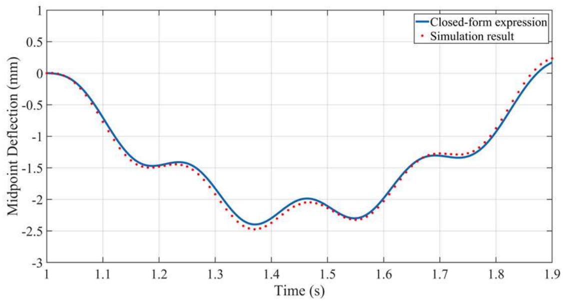

Figure 5 Bridge midpoint deflection

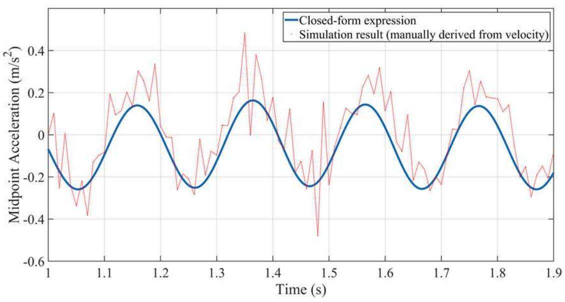

Figure 6 Bridge midpoint vertical acceleration

In Fig. 7, the upmost line and three curved lines refer to the relative error of all iteration loops. The tolerance line represents the tolerance check. Data shows that every iteration loop increases precision more than 200 times, all time steps reached 1e-6 accuracy within 4 iteration loops.

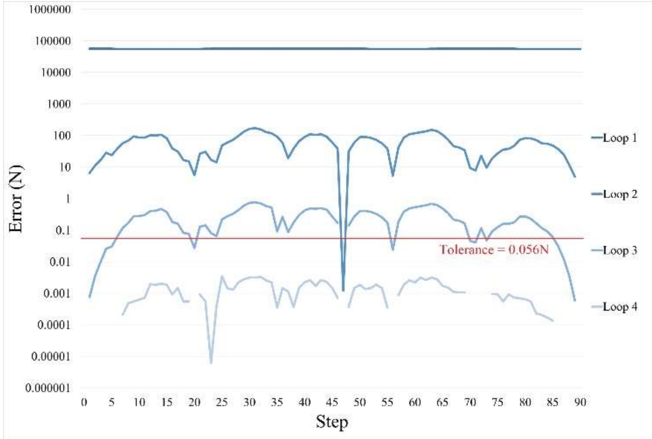

Figure 7 Relative error of all iteration loops of each time step

This simulation runs on a desktop computer, a simulation of 0.9s in real world costs 52 min, and it is quite insensitive to model complexity.

4. Conclusion

This research inherits the idea of the RSM to simulate VBI in ABAQUS using Python script. It is efficient, simple and flexible.

Damping and roughness are easy to add. Python can read and process earthquake input before feeding it to ABAQUS, so time delay of earthquake waves to each bridge pier can be calculated. Vehicle detachment can also be considered with varying length of time steps.

In the future, it will be expanded to 3D with multiple lanes, multiple vehicles and multiple vehicle DoFs. A vehicle library will be built, and driver behavior and random traffic flow will also be considered. It can be made into an open-source platform for VBI simulation, and with the help of a super computer, we might even be able to simulate seismic response of bridges under random traffic in a long viaduct such as urban highway networks.

Reference

[1] Borjigin, S., Kim, C. W., Chang, K. C., & Sugiura, K. (2018). Nonlinear dynamic response analysis of vehicle–bridge interactive system under strong earthquakes. Engineering Structures, 176, 500-521