Simulation Modelling Practice and Theory 28 (2012) 42–54

Contents lists available at SciVerse ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

An online optimization method for bridge dynamic hybrid simulations

Yuan-Sen Yang [a,*], Keh-Chyuan Tsai [b], Amr S. Elnashai [c], Tung-Ju Hsieh [a]

[a] National Taipei University of Technology, No. 1, Zhongxiao E. Road, Sect. 3, Taipei 10608, Taiwan
[b] National Taiwan University, Taipei, Taiwan
[c] University of Illinois at Urbana Champaign, USA

ARTICLE INFO

Article history:
Received 7 February 2012
Received in revised form 20 June 2012
Accepted 21 June 2012
Available online 25 July 2012

Keywords:
Bridge experiments
Hybrid simulation
Online optimization
Seismic response

ABSTRACT

An online optimization method was proposed in this paper to improve the accuracy of numerical–experimental hybrid simulations of bridges subjected to earthquake forces. The online optimization method aims to solve the problem induced by the inconsistency of the multiple identical bridge piers where only one or a few of them are simulated experimentally by physical specimens, while the others are numerically simulated within a hybrid framework. This method adopts multi-variable nonlinear optimization in order to find the optimal material parameters of the numerical models, and updates the numerical models instantaneously during the hybrid simulation. A numerical verification of a bridge hybrid simulation was conducted using the proposed online optimization method. The numerical results showed that the online optimization method is capable of obtaining better material parameters during the first few seconds of a hybrid simulation, which results in more accurate nonlinear dynamic response under earthquake loading.

1. Introduction

The numerical–experimental hybrid simulation method, sometimes called pseudo-dynamic testing, was originally published in 1980s [1]. The dynamic response of a new type of bridge subjected to earthquake forces can be simulated by running numerical simulation and experiments concurrently taking into account any interactions between them. Bridge decks and other devices having well established mechanical properties are simulated by numerical sub-structures, while new types of piers or bearings without reliable numerical models are simulated by experimental sub-structures. Interaction forces between numerical and experimental sub-structures are measured and analyzed, and instantly applied to these sub-structures in every time step of the process. The hybrid simulation method has been improved and modified for various purposes. Several numerical time integration algorithms have been proposed and evaluated to reduce the numerical errors and to improve numerical stability [2,3]. Facility controlling methods have been developed for real-time hybrid simulations to compensate for control and measurement errors induced by facility control and measurement time lags [4,5]. Some of the past research has conducted hybrid simulations with nonlinear and/or multiple experimental sub-structures [6,7], while software platforms and communication protocols have been implemented for network-based, geographically distributed, multi-laboratory collaborative hybrid simulations [8–13].

Unfortunately, researchers generally encounter difficulties when running a multi-pier bridge hybrid simulation. Due to the high cost of constructing an experimental environment of a bridge pier specimen, a hybrid simulation normally has only

* Corresponding author. Tel.: +886 2 27712171; fax: +886 2 27814518.
E-mail address: ysyang@ntut.edu.tw (Y.-S. Yang).

1569-190X/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.simpat.2012.06.002

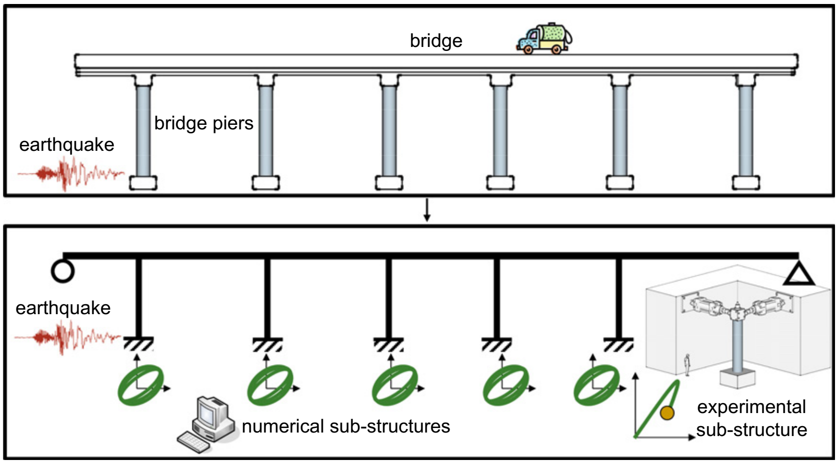

Fig. 1. Conventional hybrid simulation of a bridge subjected to earthquake forces.

one or a few experimental piers simulated by physical specimens, as shown in Fig. 1. Hybrid simulations with nonlinear sub-structures are generally a challenging task and require advanced models [6]. They are even more difficult to handle if there are multiple identical sub-structures and one of them is a physical specimen. It is very likely that the physical specimens and numerical sub-structures possess different structural nonlinear behavior, despite their identical structural design, leading to inconsistent sub-structure response or improper system behavior such as overestimated torsion effects.

This paper proposes an online optimization method for hybrid simulations with multiple identical sub-structures. During a hybrid simulation, a set of parameters that matches the experimental data measured from the physical specimen are optimized. The models of the numerical sub-structures are then updated online according to the optimized parameters, ensuring that their response matches the experimental behavior.

2. Theory and methodology

This section briefly describes the concepts of a conventional hybrid simulation, elaborating on the concepts and formulations of the proposed online optimization method that can be used to perform a hybrid simulation with multiple identical or similar sub-structures. In order to distinguish hybrid simulation methods, a hybrid simulation without online optimization is referred to as a conventional hybrid simulation herein.

2.1. Conventional hybrid simulation

A conventional hybrid simulation is much alike running a numerical time integration dynamic structural analysis in which a part of the structure (i.e., experimental sub-structure) is simulated by a real physical specimen. Data of analyzed displacements and measured reacting forces are instantly exchanged between the numerical program and the experimental controllers. Fig. 2 presents the flowchart of a conventional hybrid simulation. The time integration estimates the required displacements to assign to the numerical and experimental sub-structures at time $t + \Delta t$. The $\{u\}_t^N$ and $\{u\}_t^E$ denote displacements of numerical and experimental sub-structure(s) at time t, respectively.

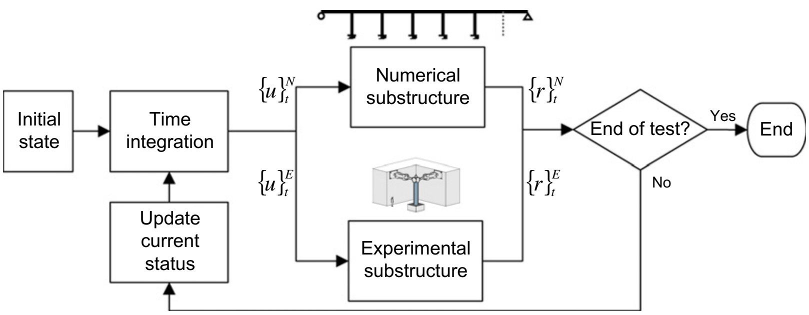

Fig. 2. Flowchart of a conventional hybrid simulation.