Engineering Structures 33 (2011) 2110–2119

Contents lists available at ScienceDirect

Engineering Structures

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

Reliability-based design optimization of adhesive bonded steel–concrete composite beams with probabilistic and non-probabilistic uncertainties

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ARTICLE INFO

Article history:
Received 7 November 2010
Received in revised form
11 February 2011
Accepted 28 February 2011
Available online 17 April 2011

Keywords:
Composite beam
Adhesive bonded
Structural optimization
Reliability
Uncertainty

ABSTRACT

It is meaningful to account for various uncertainties in the optimization design of the adhesive bonded steel–concrete composite beam. Based on the definition of the mixed reliability index for structural safety evaluation with probabilistic and non-probabilistic uncertainties, the reliability-based optimization incorporating such mixed reliability constraints are mathematically formulated as a nested problem. The performance measure approach is employed to improve the convergence and the stability in solving the inner-loop. Moreover, the double-loop optimization problem is transformed into a series of approximate deterministic problems by incorporating the sequential approximate programming and the iteration scheme, which greatly reduces the burdensome computation workloads in seeking the optimal design. The validity of the proposed formulation as well as the efficiency of the presented numerical techniques is demonstrated by a mathematical example. Finally, reliability-based optimization designs of a single span adhesive bonded steel–concrete composite beam with different loading cases are achieved through integrating the present systematic method, the finite element analysis and the optimization package.

1. Introduction

The steel–concrete composite beam, which integrates the high tensile strength of steel and the high compressive strength of concrete, has been widely used in multi-storey buildings and bridges all over the world. At the beginning of the 1960s, an efficient adhesive bonding technique [1,2] was introduced to connect the concrete slab and the steel girder by an adhesive joint, not by the conventional metallic shear connectors. This so-called *adhesive bonded steel–concrete composite beam* is considered to be a very prospective alternate structure because it has the advantages of relieving stress concentration, avoiding site welding, and using the prefabricated concrete slab. Recently, a number of studies on the experimental tests and numerical simulation of adhesive bonded steel–concrete composite beams have been presented in literatures [3–5].

With the ever increasing computational power, the past two decades have seen a rapid development of structural optimization in both theories and engineering applications. In particular, the non-deterministic optimal design of steel or concrete beams incorporating stochastic uncertainties has been intensively studied by using the reliability-based design optimization (RBDO) method [6,7]. Based on the classical probability theory, this conventional RBDO method describes uncertainties in structural systems as stochastic variables or random fields with certain probability distribution and thus provides an effective tool for determining the best design solution while explicitly considering the unavoidable effects of parameter variations [8]. As the most mature non-deterministic design approach, the RBDO has been successfully used in many real-life engineering applications [9,10]. However, the primary challenge to apply the conventional RBDO in practical applications is the availability of the precise statistical characteristics, which are crucial for a successful probabilistic reliability analysis and design. Unfortunately, these accurate data usually cannot be obtained in some practical applications where only a limited number of samples are available.

The early treatment [11,12] for insufficient uncertainties is to construction a closest uniform probabilistic distribution by using the principle of maximum entropy. In 1990s, Elishakoff [13,14] explored that a small error in constructing the probabilistic density function for input uncertainties may lead to misleading assessment of the probabilistic reliability in particular cases. This conclusion illuminates that using the traditional probabilistic approach to deal with those problems involving incomplete information might be inconvincible. Consequently, an alternative category, namely the non-probabilistic approach [15], has been rapid developed for describing uncertainty with incomplete statistical information by a fuzzy set or a convex set. In the fuzzy set method [16,17], the fuzzy

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doi:10.1016/j.engstruct.2011.02.040