Efficient Structural Design Using a Numerical Optimization Technique

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1 Abstract

Structural designs of complex buildings and infrastructures have long been based on engineering experience and a trial-and-error approach. The structural performance is checked each time when a design is determined. An alternative strategy based on numerical optimization techniques can provide engineers an effective and efficient design approach. To achieve an optimal design, a finite element (FE) program is employed to calculate structural responses including forces and deformations. A gradient-based or gradient-free optimization method can be integrated with the FE program to guide the design iterations, until certain convergence criteria are met. Due to the iterative nature of the numerical optimization, a user programming is required to repeatedly access and modify input data and to collect output data of the FE program. In this study, an approximation method was developed so that the structural responses could be expressed as approximate functions, and that the accuracy of the functions could be adaptively improved. In the method, the FE program was not required to be directly looped in the optimization iterations. As a practical illustrative example, a 3D reinforced concrete building structure was optimized. The proposed method worked very well and optimal designs were found to reduce the torsional responses of the building.

Keywords: structural design; numerical optimization; finite element (FE); approximate response; building structure; reinforced concrete.

2 Introduction

Structural and mechanical system optimization has been an active research field in the last few decades [1-3]. Numerical optimization methods, such as the gradient-based methods or gradient-free methods, have been well developed [4]. For application of numerical optimization to practical civil and structural engineering problems, such as reinforced concrete buildings, response simulations, i.e., FE analyses or other numerical analysis methods, are used [5-8]. Explicit expressions of response functions are usually not straightforward to derive and implement, especially for complex transient dynamic problems, in order to apply gradient-based optimization methods [6,7]. On the other hand, gradient-free methods require significant computational efforts. To alleviate the difficulties, approximate models, i.e., metamodels, have been developed to replace the implicit response functions [9]. The approximate metamodels can be directly used in a numerical optimization loop. The polynomial-based response surface method is a widely used metamodeling method [10]. In addition, various other metamodels are available,

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