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Structures vibration control via Tuned Mass Dampers using a co-evolution Coral Reefs Optimization algorithm

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ABSTRACT

In this paper we tackle a problem of optimal design and location of Tuned Mass Dampers (TMDs) for structures subjected to earthquake ground motions, using a novel meta-heuristic algorithm. Specifically, the Coral Reefs Optimization (CRO) with Substrate Layer (CRO-SL) is proposed as a competitive co-evolution algorithm with different exploration procedures within a single population of solutions. The proposed approach is able to solve the TMD design and location problem, by exploiting the combination of different types of searching mechanisms. This promotes a powerful evolutionary-like algorithm for optimization problems, which is shown to be very effective in this particular problem of TMDs tuning. The proposed algorithm's performance has been evaluated and compared with several reference algorithms in two building models with two and four floors, respectively.

1. Introduction

Problems in structural optimization are often characterized by search spaces of extremely high dimensionality and nonlinear objective functions [1]. In these optimization problems, classical approaches do not lead, in general, to good solutions, or in many occasions they are just not applicable, due to the unmanageable search space structure or its huge size, which implies an extremely high computation cost. In this context, modern optimization meta-heuristics have been successfully applied to an important number of structural optimization problems [2]. Meta-heuristics algorithms have been shown as a possibility to obtain a *good enough* solution to a given problem which cannot be tackled with exact algorithms.

There are different meta-heuristics that have been applied to structural engineering problems. Genetic and evolutionary algorithms [3] have been applied to the optimization of discrete structures in [4]. There have been other works that applied genetic algorithms in structural optimization problems such as shape optimization [5], optimization of 3D trusses [6], impact load characterization of concrete structure [7], the plane stress problem [8] or welded beam optimization problems [9]. The particle swarm optimization algorithm [10] is another important meta-heuristic which has been successfully applied to structural optimization problems, such as truss layout [11] or truss structures optimization [12]. The Harmony Search approach [13,1] and the teaching-based learning algorithm [14–16] have also been used to solve mechanical design optimization problems. In the last few years, alternative modern meta-heuristics based on physics process have been

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applied to structural optimization problems, such as the Big-Bang Big-Crunch algorithm [17], the colliding bodies optimization algorithm [18], the Ray optimization [19] or the charged system search algorithm [20].

In this paper, a novel co-evolution meta-heuristic, the Coral Reefs Optimization algorithm with Substrate Layer (CRO-SL) [21], is applied to the design and location of Tuned Mass Dampers (TMDs) for structures subjected to earthquake ground motions. A TMD, which can be used for passive and semi-active control strategies, improves the vibration response of a structure by increasing its damping (i.e. energy dissipation) and/or stiffness (i.e. energy storage) through the application of forces generated in response to the movement of the structure [22]. In the case of structures with spatially distributed and closely spaced natural frequencies, the TMD design may not be obvious, because Den Hartog's theory [23] cannot be applied due to the existence of a coupling between the motions of the vibration modes of the structures and the used TMDs [24]. Multi-storey buildings are good examples of structures with spatially distributed and closely spaced natural frequencies. For example, Greco et al. [25] proposes a robust optimum design of tuned mass dampers installed on multi-degree-of-freedom systems subjected to stochastic seismic actions. Other similar examples can be found in [26] and [27]. In this work, the generalized framework presented in [28] is used to formulate a N floor building where M TMDs must be installed. Unlike [28], where the position of each TMD is fixed (p.e., M TMDs in one floor or one TMD for each floor), this work proposes a modification that allows the optimization algorithm deciding the position of each TMD (i.e., a TMD can be placed at any floor to damp any vibration mode). In addition, an interval for the mass, damping and stiffness is defined for each TMD. Thus, the optimization algorithm will try to find the best solution by obtaining the $4 \times M$ parameters (3 physical parameters and the TMD location). As previously mentioned, in this paper the optimization algorithm proposed is a co-evolution approach, the CRO-SL algorithm, which is able to combine several types of searching mechanisms into just one population structure, obtaining a powerful evolutionary-like algorithm for optimization problems.

The structure of the remainder of the paper is as follows: next section describes the generalized framework used to obtain the optimal design and location for TMDs installed on a N storey building. Section 3 presents the main characteristics of the original CRO, including the different operators and the algorithm's dynamics. Section 3 describes the proposed CRO-SL version, including the definition of *substrate layer*, and, in this case, how it represents the co-evolution of different searching mechanism with the rules of the CRO. Section 4 presents the computational evaluation section, where the proposed algorithm's performance is evaluated and compared with a reference algorithm. The CRO-SL application is validated in Section 5, where a experimental set-up is used to test the optimum TMD design (location and parameters) obtaining by CRO-SL. Section 6 closes the paper by giving some final conclusions and remarks on this research.

2. Problem definition

The N storey building can be modelled as a N degree of freedom system (see Fig. 1 (a)), where the mass is concentrated at each floor ($m_1, m_2, \ldots, m_N$), k_i and c_i are, respectively, the i^{th} floor stiffness and damping coefficient (relative to $(i-1)^{th}$ floor or to the ground if $i=1$).

If the applied forces in each floor $\left(\mathbf{f} = [f_1, f_2, \ldots, f_N]^T\right)$ and the acceleration of the ground (a_g) are considered as inputs, the differential equation of the building can be represented as follows:

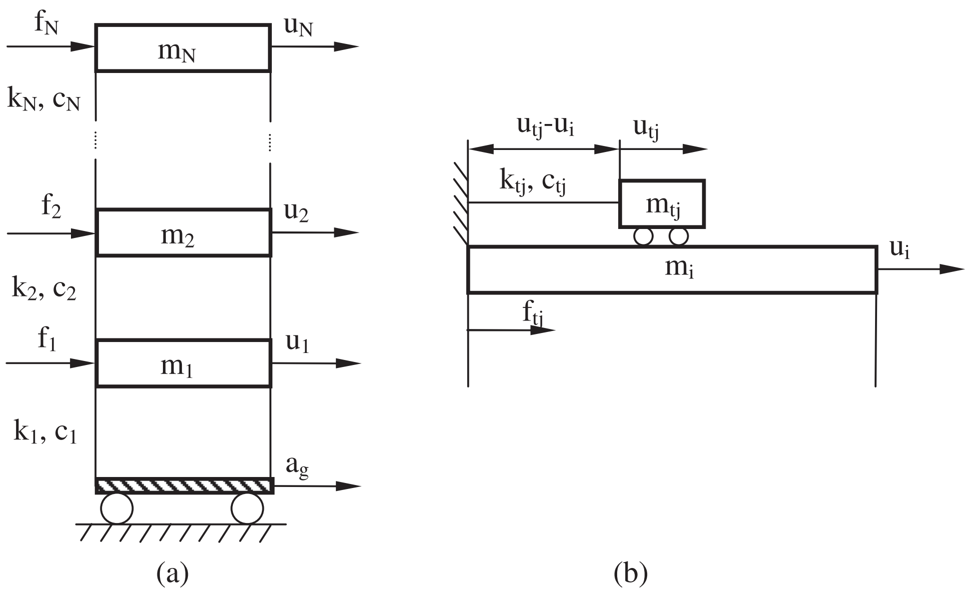

Fig. 1. (a) N storey building and (b) TMD models.

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