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Optimum Design of Timber Roof Structural Members in the Case of Fire

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ABSTRACT

One of the most important tasks of structural engineers is the design of structural elements with appropriate cross-sections to ensure the balance of economy and safety in structural design. In this context, different numerical algorithms are developed for the optimum design of structural systems. In this study, the optimum design of the roof structural model made of wood is done using teaching-learning based optimization (TLBO) in case of fire-free and fire according to Eurocode 5. The sections of the existing timber roof structure in the literature are calculated in case of fire-free and fire (30 and 60 minutes of fire). The necessity of the proposed method is emphasized by comparing the obtained optimum cross-sections in the case of fire-free with the values available in the literature. As a result, the optimum cross-section of timber roof structural elements and the wood type is determined in a short time for the different fire situations where the cross-section and characteristic features change with time.

KEYWORDS

Eurocode 5, Metaheuristic Algorithms, Optimization, Roof Structures, Structural Fire Safety, Structural Timber, Teaching-Learning-Based Optimization

INTRODUCTION

For simple structural problems, traditional mathematical methods are usually enough to keep balance between building safety and cost but for solving complex problems, these methods have been replaced with some applications and simplifications to achieve the optimum results. One of the important representative of these applications and simplifications is metaheuristic algorithms which express real-life approaches with matematical equations to obtain the minimum or maximum value of the objective function effectively in short time using computer science. Although the mathematical equations that make up the structure of each metaheuristic algorithm differ, the feature of choosing the most successful result as a solution is present in the structure of all algorithms.

Countless metaheuristic algorithms are available in litarature. However, they are mainly separeted into three groups: evolutionary algorithms, swarm intelligence, and other metaheuristic algorithms. Anty colony optimization (ACO) inspired by the behavior of ants was proposed by Dorigo (1996).

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Particle swarm optimization (PSO) formulated the behavior of swarm was initialy mentioned by Kennedy and Eberhart (1995). Flower Pollination algortihm (FPA), Bat algorithm (BA) and Firefly algorithm (FA) inspried by the polination process of flowers, echolocation behaviour of micro bats and the flashing behavior of fireflies were evolved (Yang, 2012; Yang, 2010; Yang, 2010). Artificial Bee Colony (ABC) Algorithm inspried by the behavior of honey bees was defined by Karaboga (2008). Genetic Algoritm (GA) based on the features of biological evolution was develop by Holland (1975). Harmony search algortihm (HSA) was formulated by Gee,Kim and Loganathan (2001) by observing music performances. Teaching- Learnig based Optimization (TLBO) and Jaya Algorithm (JA) were proposed formulating teaching–learning event of a class (Rao et al. 2010; Rao, 2016).

Metaheuristic algorithms or newly developed metaheuristic algorithms or modified existing metaheuristic algorithms are used to solve engineering problems.For instance,carbon dioxide and construction costs are minimized with harmony search algorithm when designing reinforced concrete retaining walls and reinforced concrete piles (Kayabekir et al. 2020; Arama et al. 2020). Jaya, flower pollination and learning teaching-based algorithm are used to determine the PID controller parameters of the active tendon controlled structures including soil structure interaction (Ulusoy et al. 2020). The PID controller parameters of structures with the same algorithms are determined considering different time delays and control limits (Ulusoy et. al 2020). PID controller parameters of structures with active mass damper are calculated using modified harmony search algorithm (Kayabekir et al 2020). Passive mass damper parameters are optimized via bat algorithm (Bekdas et al. 2018) and flower pollination algorithm (Yucel et al. 2019). The post-tensioned axial cylindrical wall with different wall heights are optimally designed under different loads with the help of harmony search and hybrid metaheuristic algorithms (Bekdas, 2015; Bekdas, 2019). Optimum steel I profile cross-sections (Cakıroglu et al. 2020) and optimum laminated composite plates (Cakıroglu et al. 2020) are computed taking into account the local buckling and the maximum buckling load with harmony search algorithm. Reinforced concrete structural members (Nigdeli et al. 2018; Nigdeli et al. 2015; Nigdeli and Bekdas, 2017; Ulusoy et. al 2018; Ulusoy et. al 2020) and steel structural members (Artar and Daloglu, 2018; Camp et al. 2005; Bekdas et al. 2019) are dimensioned with different algorithms.

In this study, the optimum design of the timber roof structural members, which are genarally used on the top floor of the structures to protect from snow and rain, is done according to Eurocode 5—Design of timber structures, Part 1–2: General—Structural fire design (CEN, 2004). As a result, the use of metaheuristic algorithms is an appropriate method to determine safe and economical structural sections in fire and non-fire conditions.

GENERAL FIRE DESIGN OF TIMBER STRUCTURES

Although there are flammable materials in timber structural members, they have very high fire resistance if their cross sections are sufficient. The most important reason for this positive behavior is the formation of a protective coal layer with very low thermal conductivity on the outer surface of the wood (Werner et al. 2008). The low thermal conductivity coal layer formed on the outer surface of the wood section exposed to fire is shown in Figure 1. In the event of a fire, structural members are classified according to their fire resistance times such as F30-B (fire resistance time more than 30 minutes), F60-B (fire resistance time more than 60 minutes) and F90-B (fire resistance time more than 90 minutes) (Nebgen and Peterson, 2015). In addition, the load combination specified in EN 1990: 2002 (Eurocode–Basis of structural design) (BS EN, 2002) and Eurocode 5: (Eurocode 5—Design of timber structures, Part 1–2: General—Structural fire design) are used for safe design in case of fire. This load combination is given in Equation 1. $E_{d,fi}$ is the design load in case of fire, γ_{GA} is the permanent load coefficient in case of fire (equal to 1.0), G_k is the permanent load, $\psi_{1,1}$ and $\psi_{2,i}$ are the combination factor, $Q_{k,1}$ and $Q_{k,i}$ are live loads and A_d (t) is the design value of the indirect loads. If indirect loads have a minor influence on the load-bearing behavior, they can be neglected (Dietmer, 2012):

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