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Thermal and integral lifting analysis of a lattice shell lighting roof based on genetic algorithm and probabilistic design

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ABSTRACT

The optimum analysis for Railway Station Building of Yujiapu (a shell-shaped single-layer reticulated shell structure) was conducted based on genetic algorithm. An elitist genetic algorithm was used by combining Matlab and a general finite element software ANSYS. Analysis was firstly conducted to study the influence of temperature load on support reaction force, then the optimal combination of support stiffness to minimize the effects of temperature load was derived by using GA. Subsequently, probabilistic design analysis was conducted for the integral lifting process and the key lifting points which influence the stress of lifting zone significantly was derived, at the same time the probability distribution model of lifting height difference was established and validated. Finally, the same genetic algorithm was adopted to optimize the combination of lifting height difference, the maximum stress of lifting zone will be reduced obviously by using the computed results. The efficiency and applicability of GA in optimization of complex structures were demonstrated in this paper.

1. Introduction

In the past twenty years, genetic algorithms (GAs) have emerged as a powerful tool for optimum design of structures. A genetic algorithm is a search/optimization technique based on the survival of the fittest theory and natural section proposed by Darwin. The genetic algorithm has the advantages that it is able to deal with discrete optimum design problems, does not need derivatives of objective functions and has the capability of identifying global optimal values of the objective function. Due to these advantages, the GA method has found numerous applications in the optimized design of structures [1–4]. Goldberg and Samtani examine the application of the GA method to the optimum design of structures [5]. Genetic algorithms (GAs) are efficient and robust searching and optimization methods that are used in data mining [6]. Venugopal seeks to generate large item sets in a dynamic transaction database using the principles of genetic algorithms [7]. Tormos use a genetic algorithm to solve the train timetabling problem [8]. Thermal optimization was conducted for external light concrete multi-holed brick walls by the finite element method [9,10]. Elitist genetic algorithm was adopted to optimize the design of a 3D steel structures [11]. It was validated that the elitist genetic algorithm is appropriated for the optimization of 3D structures.

Although many researchers have performed optimum design using the GA, the GA has not been applied to the optimization of combination of support stiffness and the integral lifting process of complex steel structures. The objective of this paper is to apply GA to solve the combination of support stiffness and optimization of lifting height difference of integral lifting for complex steel structures. It was validated that GA could be conveniently and efficiently applied to solve the optimal combination of multiple factors.

2. Analyzed structures

Yujiapu Railway Station Building locate in Tianjin, China, has complex roof shapes. It is a three-story building with two stories underground and the first story of the underground is station hall, which includes waiting hall, entrance hall, device rooms and office occupancy, etc. The second story of the underground is platform which possesses 3 island platforms and 6 arrival-departure tracks. The above-ground part is a shell-shaped single-layer lattice shell lighting roof. The main members of the entire structure are 72 curved steel box-girders which intercross with each other, as shown in Fig. 1. It is 142 m in length direction, 80 m in width direction and 24 m in height, as shown in Fig. 2. A ring beam was set on top and bottom of the shell to connect and constrain steel box-girders.

The bottom ring beam (BRB) is connected to base by 36 supports, as shown in Fig. 3, among which there are 5 single supports and 31 double supports, as shown in Fig. 3, and the supports are constrained by concrete corbels. There is a spherical bearing between top and bottom plate and the center of the spherical are set to the same for double supports to ensure that they can rotate freely.

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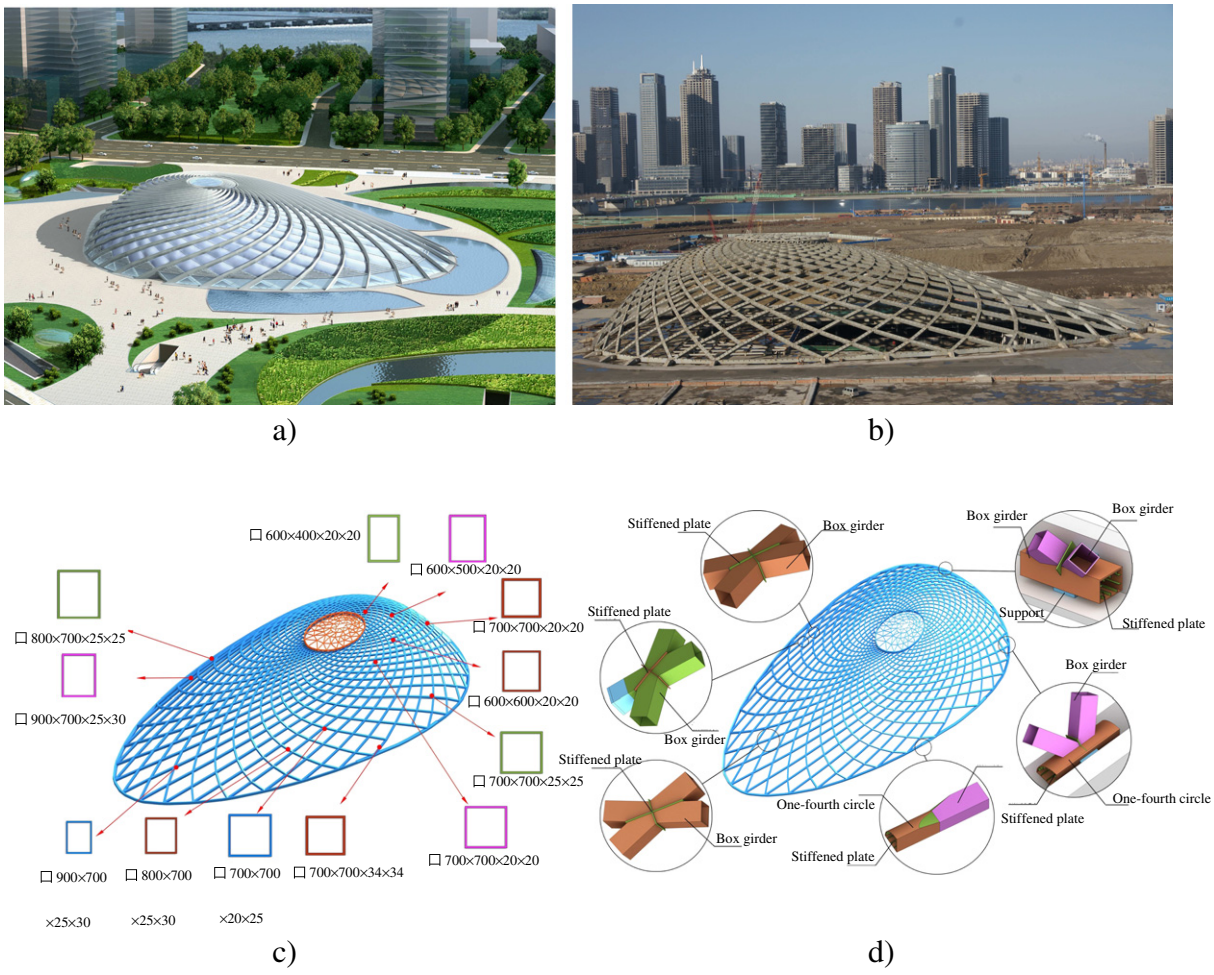

Fig. 1. Schematic of railway station building of Yujiapu. a) Effect picture, b) actual picture after unloading process, c) section of box girder (unit: mm) and d) nodal style.

3. Optimization of support stiffness

3.1. Optimization process

The genetic algorithms (GA) are search and optimization algorithms that are based on the Darwinian theory of evolution. The underlying concept is that reproduction is based on the rule of "survival of the fittest" [12]. This algorithm is self-organization, self-adaption, self-learning and group evolution function. With the strong ability of solving kinds of problems, it has been applied in many areas.

GA is started with a set of solutions called the population. These solutions are represented by chromosomes that are strings of genes. Solutions from one population are taken and used to form a new population, with expectations of having a better new population than the old one. Solutions are selected to form new solutions, so-called offspring, which are selected according to their fitness. The one with more fitness value has a better chance of selection in the reproduction procedure. This is repeated until some condition is satisfied. Some of these termination criteria, as taken in this investigation, are the number of generations and the maximum fitness value.

A GA does not require an explicit relationship between the objective function and the constraints whereas this relationship should be defined when mathematical programming are employed. Another privilege of GA is that there is no need to use the derivative of objective function and constraints. In general, GA has three main operators: reproduction, crossover, and mutation.

The procedure of the selection method [13] is:

1. Calculate the value of the penalty function of every individual of the population.
2. Select the better individuals into the matching pool. Select two individuals randomly. When comparing two individuals, we can have three possible situations:
   ① Both are feasible. In this situation, the individual with a better fitness value wins.

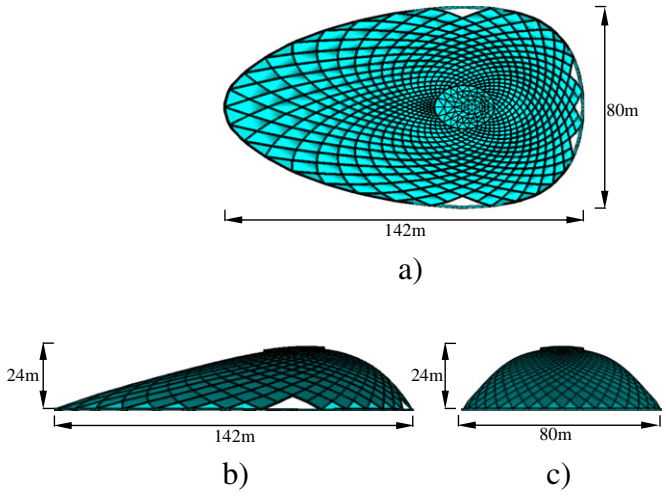

Fig. 2. Details of analyzed structure. a) Plant view, b) lateral view and c) front view.