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Structural Optimization of Jacket Platform Based on Genetic Algorithm

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Structural Optimization of Jacket Platform Based on Genetic Algorithm

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Abstract: The jacket platform is a basic facility for offshore oil and gas resources and wind energy resources, the structure of which is often redundant. In order to get better investment benefits, the structure of the jacket platform is needed to be optimized and the structure redundancy is reduced while meets the strength, the stiffness, and the stability. The genetic algorithm has excellent performance in structural optimization, and MATLAB and ANSYS are used to optimize the jacket platform based on genetic algorithm. Penalty function is applied in fitness function of genetic algorithm that transforms the constrained condition into unconstrained condition. After calculation and verification, the jacket platform still meets the constrained condition, approaching the optimization limit. The overall volume of the jacket platform is reduced by 38.8% after optimization and the genetic algorithm is feasible in optimizing the jacket platform while it has high accuracy.

1. Introduction

The ocean is rich in oil and gas resources and wind energy resources[1]. The jacket platform is the most common type of structure in offshore oil platforms, and it is also the main type of offshore wind power platform[2], that has big market. The platform structure is complex, the cost is expensive, and there always exists structural redundancy. It is necessary to optimize the structure of the jacket offshore platform[3].

The optimal design of the structure is based on the mathematical theory[4]. With rapid development of the computer, the objective function can be established according to the performance goal pursued by the design, and the optimal design scheme can be obtained by satisfying various constraints[5]. Genetic algorithm is a random search algorithm that simulates the natural competition of living beings. The genetic algorithm has strong global search ability, which can be used in structural section size optimization[6-7], and can also be applied to topology optimization design of discrete structure[8-9]. The genetic algorithm toolbox of MATLAB is good at dealing with the optimization problem. This paper will use MATLAB as the main control program, call ANSYS for finite element calculation, and optimize the structure of the jacket platform in genetic algorithm.

2. Realization of genetic algorithm optimization by calling ANSYS in MATLAB

MATLAB has its own genetic algorithm toolbox, which can be directly used by command functions or GUI interface, making genetic algorithm simple and intuitive. The main format of genetic algorithm invoked by MATLAB[10]:

[x,fval,exitflag,output]=ga(fun,nvars,A,b,Aeq,beq,lb,ub,nonlcon,options)

Users can adjust the format according to their needs (refer to the help file in MATLAB), or they can use GUI interface to set the above parameters.

In order to ensure the high accuracy of the calculation results, it is necessary to set the parameters of the genetic toolbox, as shown in Table 1 below.

Table 1. Options parameter setting

Population size	100
Initial range	*0~2*
Function tolerance	1e-6

The jacket platform is numerically simulated by finite element software ANSYS. As the main control program, MATLAB calls ANSYS for calculation and transfers data between the two software.

MATLAB generates the population, namely chromosome, and imports the data into ANSYS for calculation, and then returns the results to MATLAB for evaluation by the fitness function. The genetic algorithm selects the next generation population according to the fitness value and carries on the cycle calculation. The flow chart is shown below：
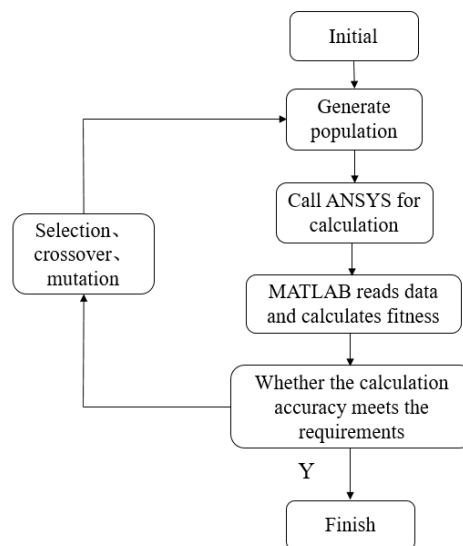

Figure 1. MATLAB calls ANSYS for genetic algorithm optimization

3. Establishment of finite element model

3.1 The finite element model is established by ANSYS command stream and GUI interface.
The geometric parameters of the platform structure are as follows

Table 2. Jacket platform model parameters

Number	Element	Diameter	Thickness
1	Main pipe above mud line	1.2 m	0.050 m
2	Main pipe below mud line	1.2 m	0.050 m
3	Main pipe of deck Partial	0.78 m	0.0381 m
4	Transverse brace	0.78 m	0.0381 m

5	Sway brace	0.508 m		0.0254 m	
6	Beam of deck Partial	Sectional Area	Section Length		Section Width
		0.16 m^2	0.4 m		0.4 m
7	Deck	Sickness	Length*width		
		0.025 m	30*20 m^2		

The finite element model is established by ANSYS (Figure 2). Pipe16 element is used to mesh the pipes below the mud line of jacket platform, pipe59 element is used for the pipe above the mud line, beam4 element is used for the beam of deck and shell 43 element is used for the deck.
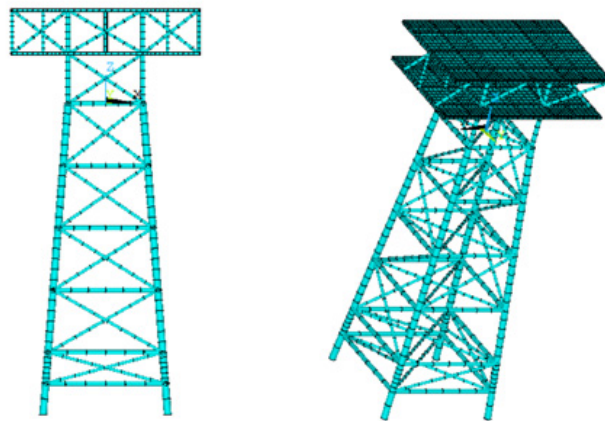

Figure 2. Finite element model of jacket platform

3.2 Environment and parameter setting

The jacket platform is located in Bohai Sea, China. The model is made of D36 steel with a density of 7850 kg/m^3, Poisson's ratio of 0.3, elastic modulus of 2.0E11 Pa and yield strength of 360 MPa. The environmental loads on offshore jacket platforms are complex. This paper only considers the effects of wind, wave and current on jackets, as shown in Table 3 below.

Table 3. Marine environmental parameters

Depth	45 m
Effective wave height	14.8 m
Effective wave period	10.8 m
Surface velocity	2.35 m/s
Middle velocity	1.96 m/s
Bottom velocity	1.60 m/s

The Mises stress nephogram of the jacket platform element is shown in figure 3. The maximum displacement of the element is 0.03 m and the maximum stress of the element is 81.5 Mpa at the bottom of the main pipe which are all within the safe limit and have a large optimization space.
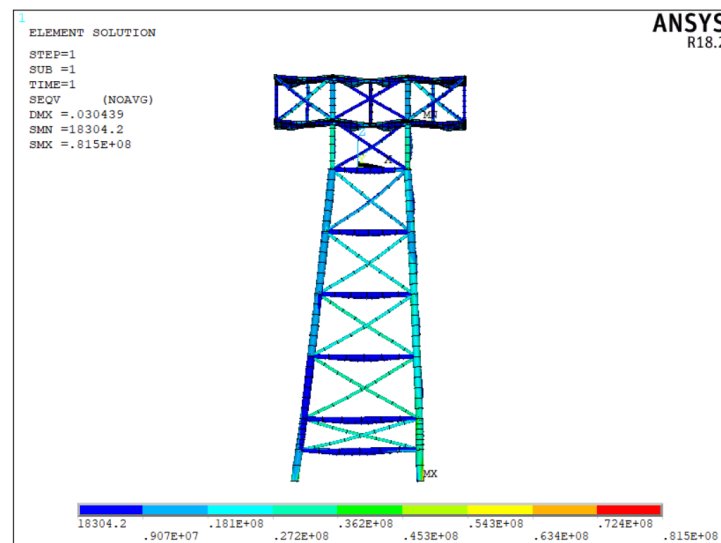
Figure 3. Stress nephogram of jacket platform element

4. Mathematical model of optimization of the jacket platform

The mathematical model of optimization is established as follows:

4.1 The design variables

Outer cross-sectional diameter and wall thickness t of the jacket platform tubular members are used as design variables. There are three groups of tubular members and six variables in this paper.

4.2 Objective function

The design is most economical when the total structure volume is smallest. The total volume of the element is directly calculated by the ANSYS command stream, and the total volume is specified as the objective function. The MATLAB genetic algorithm toolbox needs to write code of the objective function which is fitness function. For the convenience of calculation, the constrained condition is added to the fitness function by penalty function, and the constrained condition is transformed into unconstrained condition.

4.3 Constrained condition

The optimization of the jacket platform structure is based on a certain stiffness, strength and stability. The stiffness constraint is achieved by the displacement constraint of the apex side of the jacket platform. Reference to technical specification for steel structure of tall building and "The interlayer displacement limit of the steel structure in the elastic stage is 1/200 of the layer height" that is one of Japanese architectural law. In this paper, only the elastic phase is considered. Since the jacket platform is 60 m high, the maximum displacement of the jacket deck is 0.3 m[11]. According to "specification for the Construction and Classification of Offshore Fixed Platforms" that is one specification of China Classification Society[12], the allowable tensile, bending and compressive stresses of platform members are $0.6\sigma_s$, the allowable shear stresses are $0.4\sigma_s$, and the yield strength of D36 steel is 360 Mpa. Because the jacket platform is mainly subjected to tension and compression, $0.6\sigma_s$ is adopted as the allowable stress, i.e. 216 Mpa, which is verified by the fourth strength theory of material mechanics.

5. Genetic algorithm optimization by combing ANSYS with MATLAB

The results of ANSYS calculation can be extracted by MATLAB as highly non-linear constraints. The genetic algorithm toolbox of MATLAB deals with highly non-linear constraints slowly, has small search space, and is easy to converge in advance, so it can't obtain the optimal solution. By

using fitness function and penalty function, the non-linear constrained optimization is transformed into unconstrained optimization.

The jacket platform structure optimization calculation is carried out, as shown in figs. 4 and 5 below.
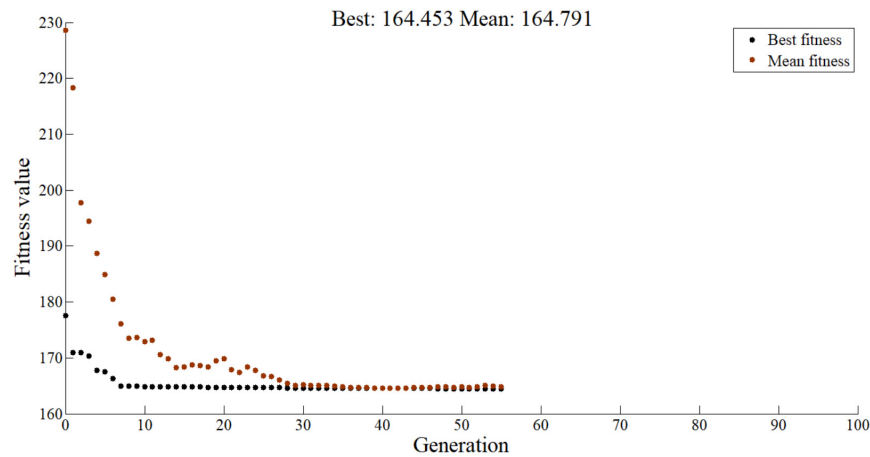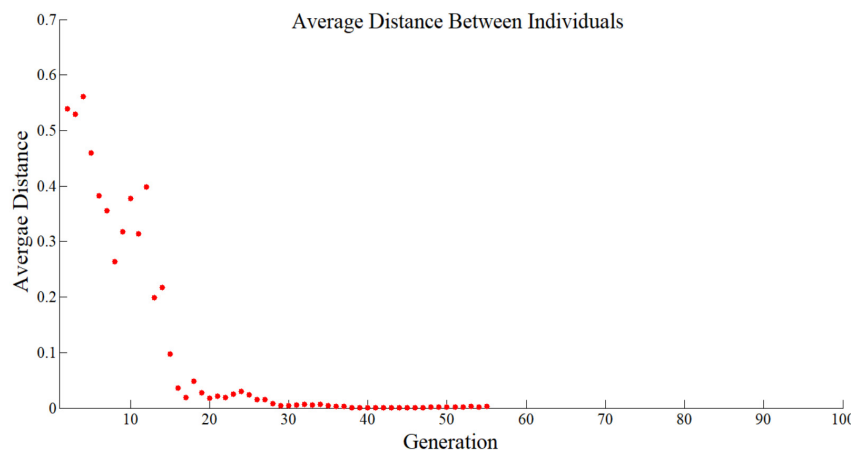

Figure 4. Fitness of each generation

Figure 5. Average Distance between Generations

The genetic algorithm converges at the step 55. As the iteration progresses, the fitness value gradually decreases, changes rapidly within 10 generations, and then gradually slows down. At the 30th generation, the fitness value tends to be stable. The population evolution is obvious. In the process of iteration, the average distance of each generation shows a decreasing trend. Within 20 generations, the population distance changes obviously, then the change gets slower and the difference of population gets smaller. The average fitness value is 164.791, and the best fitness value is 164.453, subtracting the influence of penalty function, the actual total volume of jacket structure optimization is 145.462, the total volume is reduced by 38.8%.

The design variables before and after optimization are shown in Table 4:

Table 4. Design variables before and after the optimization

design variable	Upper limit	lower limit	initial value	Optimization value	Amplitude of increase /%
D_1	1.50 m	0.10 m	1.2000 m	0.2260 m	101.2
t_1	0.01 m	0.06 m	0.0500 m	0.0351 m	29.8

D_2	0.10 m	1.00 m	0.7800 m	0.3478 m	55.4
t_2	0.01 m	0.06 m	0.0381 m	0.0157 m	58.8
D_3	0.10 m	0.80 m	0.5080 m	0.2508 m	50.6
t_3	0.01 m	0.06 m	0.0250 m	0.0103 m	58.8

After optimization, the diameter and wall thickness of circular pipe are reduced by 50%-110% and 25%-60%, respectively. The optimization effect is obvious. After the optimization, the constraints change as shown in Table 5：

Table 5. Constraints before and after optimization

Constraint	initial value	Optimization value	Limit value	Amplitude of increase /%
Maximum horizontal displacement /m	0.030	0.118	0.3	293.3
Maximum Mises stress /Mpa	81.5	205.6	216.0	152.2

The result of the genetic algorithm has high accuracy and satisfies the constraints. From Table 5, it can be seen that the maximum stress, as a constrained condition, plays a more important role than the maximum horizontal displacement in structural optimization. There is still much space for the maximum horizontal displacement distance limit value, and the maximum stress is close to the optimization limit. The combination of MATLAB and ANSYS has a good optimization effect.

6. Conclusion
(1) MATLAB calls batch mode of ANSYS for cyclic calculation, data transmission between them is smooth, and the optimization design of jacket platform based on genetic algorithm can effectively reduce the structural redundancy. The overall volume of jacket platform is reduced by 38.8% after optimization.

(2) The self-programmed penalty function has strong constrained ability, result of the optimization satisfies the constrained condition, and it is close to the constrained condition limit. The optimization has high accuracy and feasibility.

(3) The optimization method adopted has certain guiding significance for other structure design, and genetic algorithm can be further studied for topology optimization.

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