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Finite Element Analysis and Structure Optimum Design of Lifting Padeye

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Abstract. The lifting padeyes are widely used in the offshore and shipbuilding industry. The design of lifting padeye requires extremely high safe reliability and economic rationality. Based on finite element analysis (FEA), the variations of stress and deformation with external force and hoist angle are analyzed. For minimizing cost of steel, optimum design models of lifting padeye were built and the reliability of the optimum design scheme was proved. The results show that the optimum design accords with structure design principle and the cost of padeye steel reduce notably.

Introduction

Lifting operation is an integral part of any construction, ship-building, ship-repairing or manufacturing process. With the development of modern shipbuilding industry, the construction blocks of offshore structures and ships are now in the region of hundreds to thousands of tons. Normally these heavy blocks can be constructed only by cranes with the aid of slings and shackles which are attached to a number of padeyes built on the structures. As many countries enhance the importance of Workplace Safety and Health, lifting activities has been identified as a “high risk” operation. Lifting padeyes play a very important role in Lifting operation. Therefore, high safe reliability of padeyes is required1-5.

Another important aspect to pay attention to is the steel consuming of lifting padeyes. In recent years, most of the new ships in large shipyards are 10,000-300,000 tons. Meanwhile, the size and weight of the hull blocks present the macro-scale development trend. Lifting operations are required in all the stages of the construction of macro-scale blocks, which means the consuming of padeyes increases notably. According an investigation in Dalian Shipyard, there are 3776 different padeyes used for 2 ships of 69,000DWT oil tanker and 115,000DWT bulk carrier. The total weight of these padeye is 137 tons. In order to reduce the shipbuilding cost, optimum design of lifting padeye becomes a very important job.

In this paper, an attempt was made toward developing a new optimum design scheme of lifting padeyes. Numerical simulation of lifting padeyes was performed based on finite element analysis.

Simulation of FEA

FEA is an effective tool and has successful application in a lot of scientific fields. In this study, padeyes are analyzed by the finite element code ANSYS. The forms of structural and specifications of the padeyes D are provided in Fig. 1 and Table 1. In the following study, the type 60～70t of padeyes model D is taken as an example for the strength check. The material of padeye is ASTM A36 steel, Young’s modulus is 2.0e11Pa, poisson’ ratio is 0.3, and yield stress is 250MPa.

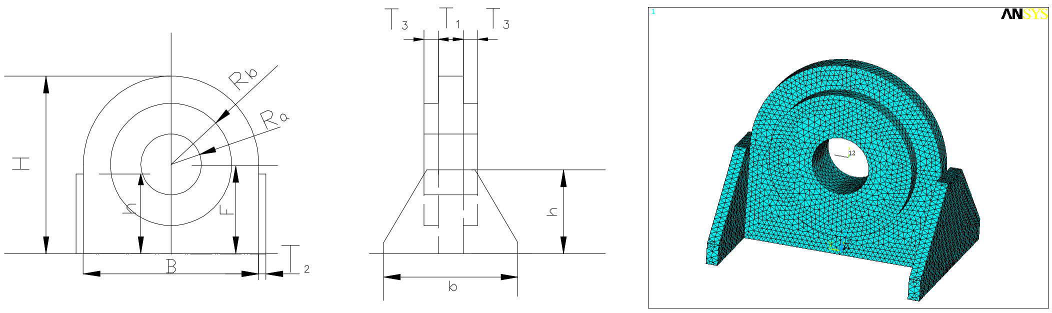
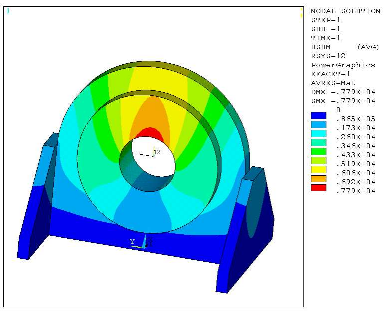


Fig.1 The structural forms and FEM model of D padeye

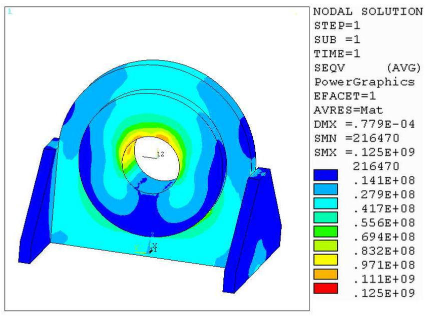
Table 1 The specifications of D padeyes

Sustainable loads /t	Specifications /mm										
	T_1	H	B	R_a	R	F	T_3	R_b	T_2	h	b
30～40	30	280	280	40	140	160(140)	—	—	10	140	260
40～50	30～35	310	310	45	155	175(155)	18-25	110	18	155	290
50～60	30～35	340	340	50	170	190(170)	18-25	120	22	170	320
60～70	30～35	370	370	55	185	205(185)	22-30	138	22	185	350

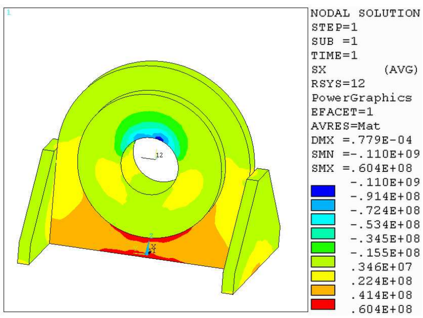
The padeye bottom is constrained. The external force 60t is applied on padeye model. The results are illustrated in Fig.2 and Table 2. All the results are shown in a cylindrical coordinate system, the origin of which is the center of pin hole and the vertical direction is along the thickness of padeye. The maximum stress is in the internal surface of padeye pin hole. The radial stress is compressive stress and the tangential stress is tensile stress.



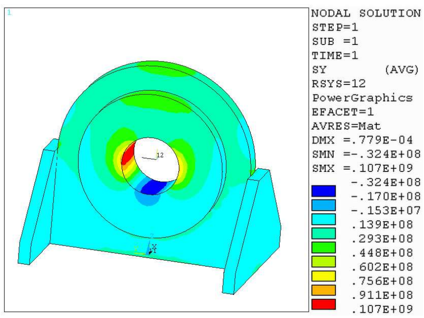
Displacement



Equivalent stress



Radial stress



Tangential stress

Fig.2 Results of FEM

Table.2 Displacement extremes and stress extremes

Displacement /m	Radial stress /MPa		Tangential stress /MPa		Vertical stress /MPa		SEQV stress /MPa
0.779E-04	-110	60	-32	107	-13	36	125

Optimum Design of Lifting Padeye

In modern structural design, optimum methods play an increasingly important role. Structural optimization design is basically a decision procedure based on different design requirements. In the design process, a set of decision criteria, which are then used to evaluate possible design results, is imposed[6-8].

1) Variables of optimum design

Design variables

Design variables form the decision (design) space of an optimum design. Any set of variables which defines the design of a structure represents a point in the decision space. The design variables of this study are the specification of padeyes, as shown in Table 1. The parameters T1, T2, T3, Ra, Rb and B is taken as design variables, where other parameters are set as B=H=2R=2F=2h.

Constraints in optimum structural design

Constraints are the restrictions placed on a design. Each constraint will be influenced by one or more design variables. The Constraints of this study are the allowable stress of padeye. As the stress factor is 0.67, the allowable stress is 168Mpa9.

Objective functions

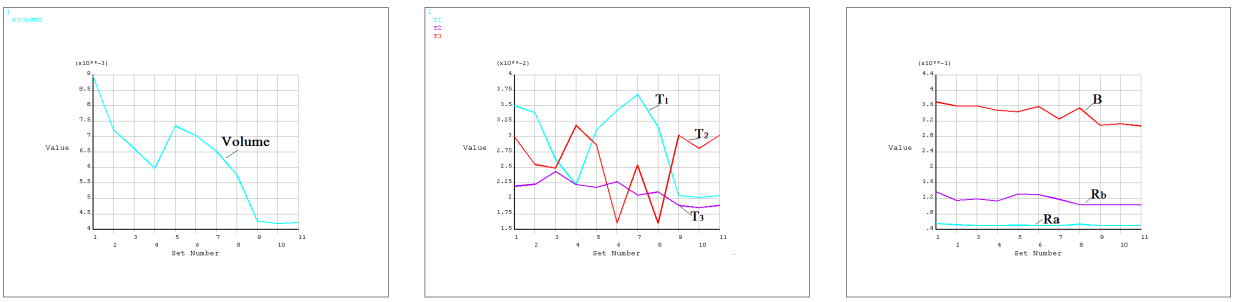
Objective (cost, criterion) function is a function of design variables. It is the merit measurement (criterion) of a design. To better utilize materials and reduce costs of a structure, structural weight can be chosen as the objective function. The objective functions of this study are structural weight.

2) Optimum methods

Two commonly used optimum methods are the Sub-problem Approximation Method (SAM) and the First Order Method (FOM). The SAM can be described as an advanced zero-order method in that it requires only the values of the dependent variables, and not their derivatives. Compared to the SAM, the FOM is seen to be more computationally demanding and more accurate. However, high accuracy does not always guarantee the best solution. Here are some situations to watch out for: It is possible for the FOM to converge with an infeasible design. In this case, it has probably found a local minimum, or there is no feasible design space. If this occurs, it may be useful to run a subproblem approximation analysis, which is a better measure of full design space. Also, you may try generating random designs to locate feasible design space (if any exists), then rerun the FOM using a feasible design set as a starting point.

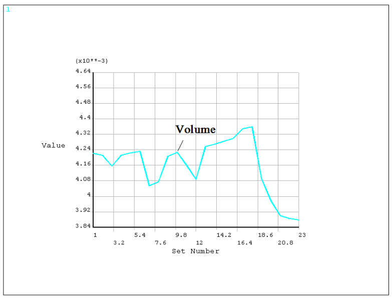
results of optimum design

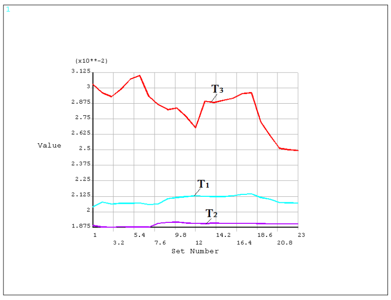
Variables curves of SAM are shown in Fig.3. According to the new variables range of SAM, padeyes are optimally designed with FOM again and variables curves are shown in Fig.4. Among all evaluated configurations, the best designs of different methods are shown in table.3.

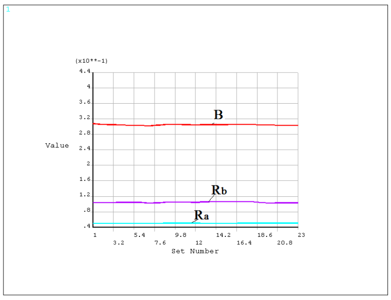


Curves of volume   Curves of T_1,T_2 and T_3 Curves of R_a, R_b and B

Fig.3 Curves of SAM







Curves of volume Curves of T_1,T_2 and T_3 Curves of R_a, R_b and B

Fig.4 Curves of secondary FOM

Table.3 The optimum designs of different methods

Design	B / m	R_a / m	R_b / m	T_1 / m	T_2 / m	T_3 / m	Volume/m^3
Initial design	3.70E-01	5.50E-02	1.38E-01	3.50E-02	2.20E-02	3.00E-02	8.95E-03
SAM	3.08E-01	5.01E-02	1.03E-01	2.04E-02	1.89E-02	3.03E-02	4.22E-03
FOM	3.32E-01	5.50E-02	1.18E-01	2.33E-02	2.07E-02	2.30E-02	5.07E-03
Secondary FOM	3.05E-01	5.08E-02	1.04E-01	2.12E-02	1.90E-02	2.73E-02	4.09E-03

3) The safe reliability of final design

According to the result of optical analysis and real thickness situation of steel plate, the final design is built and shown in table.4. The safe reliability of final design is checked with FEM and result is shown in Table.5. It can be seen that the stresses of final design is less than the allowable stress 168Mpa. The results show that the optimum design scheme accords with structure design principle.

Table.4 The specifications of final design

Design	B / m	R_a / m	R_b / m	T1 / m	T2 / m	T3 / m	Volume/m^3
Optimun design	3.05E-01	5.08E-02	1.04E-01	2.12E-02	1.90E-02	2.73E-02	4.09E-03
Final design	3.00E-01	5.0E-02	1.05E-01	2.2E-02	1.90E-02	2.9E-02	4.22E-02

Table.5 Displacement extremes and stress extremes of final design

Displacement /m	Radial stress /MPa	Tangential stress /MPa	Vertical stress /MPa	SEQV stress /MPa
1.16E-04	-137.1	165.0	60.7	161.2

Conclusions

Based on external force analysis, FEA models of padeyes are set up. The final optimization design saves 50% of the cost of steel and the strength also accords with structure design principle. Based on some conservative assumptions and formulae, most of the traditional padeyes are over-designed and therefore more costly for fabrication. With the development of new methods (such as FEA), the traditional padeyes can be optimally designed. It should be noted that the security and economy for the optimum design of padeyes can be promoted notably. The proposed method presents a valuable reference for the analysis of similar structures.

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