Study on strength evaluation and structural analysis for spherical pressure shells subjected to external pressure

学位名	博士(工学)
学位授与機関	東京海洋大学
学位授与年度	2021
学位授与番号	12614博甲第603号
URL	http://id.nii.ac.jp/1342/00002217/

［課程博士・論文博士共通］

博士学位論文内容要旨
Abstract

専　攻 Major	応用環境システム学	氏　名 Name	黄　詠芯
論文題目 Title	外圧を受ける耐圧球殻の座屈強度評価と構造解析に関する研究 Study on strength evaluation and structural analysis for spherical pressure shells subjected to external pressure		

With the improvement of ocean exploration and technological advances, the deep submergence vehicle (DSV) has played a crucial role in underwater survey activities. The DSVs are divided into three types: autonomous underwater vehicles, remotely operated vehicles, and human occupied vehicle (HOVs). Among them, the HOV has the most complex design and manufacturing processes. The spherical pressure shell is the main structure of the HOV, and it provides safe living space for scientists and investigators. This pressure shell plays a crucial role in human occupied vehicles; therefore, it should be designed precisely and its ultimate strength should be analyzed.

Nowadays, each classification society has its own evaluation criteria for determining the minimum scantling requirements of spherical pressure shells. At the initial design phase of the spherical pressure shell, the structural dimensions are mainly chosen based on the use of specifications and formulas published by various classification societies. Then, finite element (FE) analyses are used to evaluate the designed results. If the outcomes fail to meet the rules or requirements, they must be modified by the correction formula to account for reinforcements in the design.

All current design rules are based on the classic yield load formula and theoretical elastic buckling formula, but there are subtle differences between different rules. ABS rules are based on these two formulae for pressure shell strength evaluation of a pressure shell. RS, BV, and CCS consider both yield load and elastic buckling load and use the minimum values of these loads as the ultimate strength. The safety factor is considered in the calculation of the yield load, and the structural imperfection factor is considered in the calculation of the elastic buckling load. The DNV rules are mainly based on the classic yield load formula for strength evaluation, and the strength loss caused by structural imperfections is also considered.

LR and DNVGL rules divide the design method based on two collapse problems. In the first stage, when thickness/radius ratio is small, the pressure hull mainly collapses due to buckling. Generally thin spherical shells belong to the first stage. In the second stage, as thickness/radius ratio increases, the pressure hull mainly collapses due to yielding, which means that the stresses in the spherical shell reach the yield strength of the material. In the LR rules, material coefficients are considered when evaluating structural stability. Moreover, among all the rules, only ABS and RS rules clearly stipulates that its formula can be used for the calculation of titanium structures; other rules should only be applied to steel structures, and titanium structures should be considered as a special case.

This study uses five pressure shells as design targets and recalculates them using seven classification rules. However, according to the results obtained herein and based on the consideration of various classification rules, the maximum deviation between the calculated and actual thickness values is approximately 30%.

According to the design results of this study, there are significant differences in the design results of various

classification rules; however, in fact, the design methods of classification rules have not been discussed and unified. This study mainly focuses on the design results obtained based on the various classification rules and proposes a design method to estimate the scantling of spherical pressure shells. This method can reduce the waste of design time and reduce estimation errors. Since the actual pressure shells are assembled by bending and welding, it is inevitable that initial imperfections and residual stresses will inevitably occur during the production process, and the actual strength of pressure shells will be reduced from the theoretical value. The design method proposed by this study institute also discussed this initial imperfections, and brought the design results closer to the actual situation.

Each classification rule provides an evaluation method for the ultimate strength of the spherical pressure shell to ensure that structural scantling can meet the requirements. However, the validity of the design results cannot be easily confirmed without numerical analyses and model experiments. This study used ABAQUS, a simulation software, to verify the design results of each classification rule. In numerical simulation, the Riks method (hereinafter referred to as the "ABAQUS / Riks method") in ABAQUS was used to perform elastic–plastic buckling analysis to calculate the ultimate strength and eigenvalue mode of a non-ideal spherical pressure shell. The analytical methods used have been fully validated. In addition, we confirmed the effectiveness of the proposed design method and verified that the estimation method in this study is more accurate than those employed in the previous studies.

This study proposed that LR rules should be used to evaluate the structural collapse trend and that the correction curve of the BSI specifications should be used for the design correction of the yield load. The usability of the design method was confirmed with FE analyses. According to the proposed design method, the thicknesses of the five pressure shells were recalculated, and the structural strengths were verified based on FEA.The difference between this result and the required thickness calculated based on the LR rule is approximately 5–8%. This also proves that the design result of LR is relatively conservative. According to the comparison results, the thickness of the pressure shell calculated using the proposed design method was significantly lower than that calculated based on the original design rules and is close to the actual thickness. Although the thickness was reduced, the structural strength was maintained within a safe range and satisfied the design requirements.

This study uses five pressure shells as design targets and recalculates them using seven classification rules. Additionally, elastic–plastic buckling analysis was performed with the Riks method in ABAQUS to confirm the ultimate strength. It is demonstrated that the results calculated by LR rules are more stable and smaller deviations than other rules. Using the design correction curve of the British Standards Institution for the correction of the yield load shows that the thickness of the pressure shell is significantly lower than that of the original design. Despite the fact that the thickness is reduced, the structural strength can be maintained within a safe range that meets the design requirements. Although this method has yielded good design results in the five pressure shells tested herein, there are several openings in the spherical pressure shell that weaken its critical strength. In future research, an in-depth study of the opening reinforcement method based on the design method proposed by this study.