論 文 の 内 容 の 要 旨
Abstract

論文題目　Development of Reliability Based Assessment Method for Piping Containing Local Metal Loss Existing at Structure Discontinuity
（不連続部に局部減肉を有する配管の信頼性基準評価手法の開発）

氏　名　曲 強

In chemical plants, inner pressed pipes, vessels and storage tanks are the most important structures. The safety of the pipe must be ensured in all processes of design, construction, and maintenance. In Japan, most of equipment and structures in chemical plant have been severing for over 40 year. The aging of structures becomes serious maintenance issue, the awareness of importance of accident prevention increases fast recently. The explosion of aged high-pressure structures might causes miserable accident, so the evaluation of pressed structures becomes more and more important. The most typical aging problem of the pressed pipe is metal loss which caused by corrosion or abrasion, Metal loss reduces the pipe's wall thickness and resistance to internal pressure. In Japan, the recent methods of maintenance of pipe and vessels doesn't allow the defected structures to continue operating. Once the flaw is inspected, the structure must be replaced or repaired regardless the size of the flaws. This is a too conservative method leads to unnecessary maintenance cost because of the frequently repair or replacement.

Fitness-For-Service (FFS) assessment is quantitative assessment of the structure integrity. It is widely applied to maintenance of chemical plant and generation plant in US and European countries. To improve the maintenance method in Japan, the introduction of FFS assessment method and oversea FFS standard is necessary. In API579-1/ASME FFS-1, a most noticeable oversea standard, the assessment methods for the pipe containing local metal loss is provided. The studies on the applicability of API579 assessment have been started since 1990s. However, most of the previous studies are on the case of straight pipe containing local metal loss. As a result, the applicability of API579 assessment method to the pipe with discontinuities are not clear recently.

In API579 assessment method, the safety of defect pipe with discontinuity is examined by a value of maximum allowable working pressure (MAWP). This method is based on deterministic

approaches, therefore, it is impossible to evaluate the safety margin of piping quantitatively. In addition, the value of MAWP is generally calculated form a conservative approaches so that it might cause a too much underestimation of remain safety margin of the defect pipe.

In this paper, a reliability based FFS assessment method for the piping containing local metal loss at discontinuity is developed and proposed. In this developed method, probabilistic reliability approach is imported. Therefore, it is possible to evaluate the safety margin and risk caused by the uncertainties quantitatively. The response surface method is also introduced in the assessment method to explorer the limit state function for the reliability analysis. Furthermore, the probabilistic sensitivity analysis is also included in the assessment method, so the evaluation can be simplified and optimized by neglecting unimportant factors.

In this paper, a model of tee pipe containing a circumferential local metal around the nozzle discontinuity is used to test the applicability of the proposed method. This test tee pipe is composed by a main pipe (STPG370 200A Sch30) and branch pipe (STPG370 100A Sch40). The Finite Element Analysis (FEA) is performed to calculate the burst internal pressure (P_{bc}) of the test tee pipe for 60 sample cases of different tensile strength of material and geometries regarding width and depth of metal loss. The results of P_{bc} are compared to the MAWP calculated by API579 process. It is shown that, the P_{bc} calculated by FEA is at least 7 times greater than the MAWP by API579 process. It is indicated that API579 process might produce too much underestimation of remain safety margin, and lead to too conservative evaluation results.

Response surface method is applied to explore the functional relation between burst pressures and input variables of tensile strength and metal loss width, depth. The sample points are obtained from the FEA. Second order polynomial regression surrogate model is used for test tee pipe case. The burst pressures predicted by explored function are compared to the values calculated from FEM. It is showed that, the predicted values are nearly agreeing with the calculated values. The accuracy of the explored function is verified. The limit state function for following reliability analysis is defined based on the explored function.

Reliability analysis is applied to develop the safety check expression and partial safety factors by which the safety margin can be evaluated quantitatively in the FFS assessment. The partial safety factors are calculated for 3 level of reliability demands. In addition, the reliability level of MAWP by API579 is also investigated. It is shown that the reliability level of MAWP by API579 is much higher than the highest level adopted in FFS assessment standard. From both the results from FEA and reliability analysis, an unreasonable high safety margin produced by MAWP is observed.

Sensitivity analysis is performed to influence of the probabilistic properties of variables. The variable which has a very low level of sensitivity can be treated as constant, as a result, the number of variables in evaluation can be reduced, and the evaluation is simplified. In this test pipe case, the working pressure has a low sensitivity, and the partial safety factor of working pressure is deleted

from the safety check expression. The relative error of reliability caused this simplification is also investigated. The results show that, the relative errors are acceptable and this simplification is proved to be reasonable.

Finally, the applicability of proposed assessment process is also investigated by applying to another case of tee pipe of which the main pipe is STPG370 300A Sch30. The FEA, response surface method, reliability analysis and sensitivity analysis are applied successively on this case of tee pipe. The limit state function, safety check expressions and partial safety factors are developed for this case of tee pipe. Compared to the case of test pipe 1 (main pipe STPG 200 A), it is found that the products are different. It indicates that, it is impossible to evaluate all size of tee pipe by 1 set of limit state function, safety check expression and partial safety factors.

To sum up, in this paper, a reliability based assessment method for piping containing local metal loss at discontinuity is proposed. This method produces precise evaluation of the safety margin and treatment of the uncertainties. In this process, FEA, response surface method, reliability analysis and sensitivity analysis are included. By applying this method to 2 case of tee pipe containing circumferential local metal loss at nozzle, the applicability and reasonability of this proposed method is proved. By comparing the products of 2 cases of tee pipe, it is proposed that, for different size of tee pipe, the assessment should be performed individually in accordance with the proposed process.