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Pressure limit evaluation codes for Spent Nuclear Fuel cask submerged in deep Sea

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1. Introduction

It is important to investigate the critical depth at which the integrity of the Spent Nuclear Fuel transport cask is maintained to prevent radioactive materials release in the event of a maritime loss of transport cask. The spent nuclear fuel transport cask is a type B cask and its safety must be guaranteed under normal transportation conditions and under hypothetical accident conditions. Among the hypothetical accident conditions, the integrity of the containment boundary must be maintained under water of depth up to 200 m to prevent in leakage of water and the release of radioactive materials. However, if the transport cask is lost at a depth exceeding 200 meters, damage to the containment boundary may occur due to the high hydrostatic pressure in the deep sea, and the damage to the containment boundary can be predicted by evaluating the pressure limit of the cask. In this study, we developed a code that can evaluate the pressure limit of the cask by inputting the loading conditions and design specifications of the cask. A simplified computational model was developed based on the detailed cask model and computational experiments were conducted to obtain training data for the construction of a code for evaluating the pressure limit of transport casks. The simplified model was constructed by removing and simplifying the complex structure of the detailed model to reduce computational analysis time and to facilitate parametric design update. The computational experiments were conducted using the Design of Experiments process. As a result of the computational experiments, a meta model was created and utilized as code.

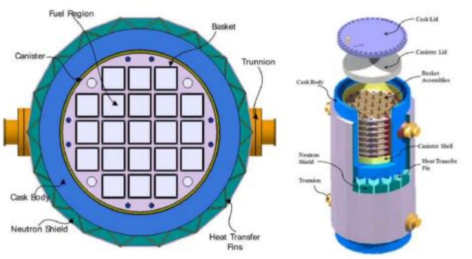


Fig. 1. Spent fuel transport cask components

2. Methods and Results

2.1 Development of simplified cask model

The spent nuclear fuel transport cask was simplified to consist of the lid, bolts, and body by removing the internal canister, radioactive materials, and basket to ease of modeling and reduced analysis time. The components and properties of the simplified transport cask model are summarized in Table 1.

Table 1: Properties of the simplified cask model

Components	Lid & Body	Bolt
Material	SA518 GR70	SA193 B7
Yield Strength (MPa)	334.9	835.7
Density (ton/mm^3)	7.85E-09	7.85E-09
Young's Modulus (MPa)	210,000	206,000
Poisson's Ratio	0.3	0.3

The simplified model of the transport cask was developed by considering the dimensions and properties from the detailed model, and parametric modeling technique was utilized to enable automatic update of analysis model from the inputs on the design parameters of cask and loading conditions.

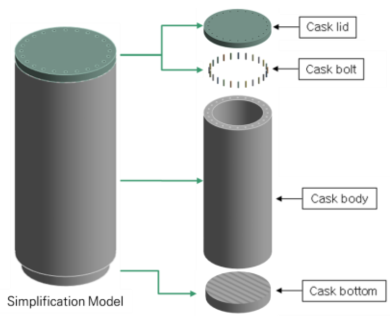
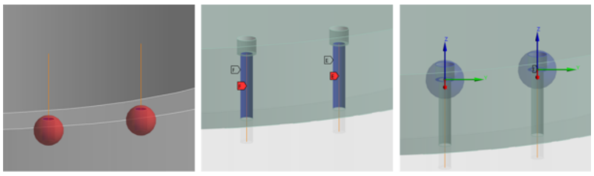


Fig. 2. Simplified cask model components

The three-dimensional solid bolts were simplified into beams for smooth shape change of the transport cask, and the complex shape was removed to construct a simplified model. For the static analysis, the constraints of the simplified model were given a Fixed Support in the center of the Bottom. As a boundary condition, Frictional Support was applied to the lid and body of the container, with a friction coefficient of 0.2. The load condition for the analysis consists of external and internal pressures and a bolt pretention to simulate the clamping force of the bolt as in the detailed model. The size of the bolt pretension was set to 704139.0N by applying the same force as 50% of the bolt's yield strength multiplied by the bolt's cross-sectional area.



(a) Bonded-Bolt & Body (b) Frictional-Bolt & Lid (c) Joint_Fix-Bolt & Lid

Fig. 3. Constraints for simulating bolting

For the bolt simplified to a beam, we need boundary and constraint conditions to simulate the behavior of actual bolts. A boundary condition was given to simulate the bolt coupling by the thread of the bolt and the body, and a Frictional condition was given to simulate the behavior bold stud without the thread. In addition, a Fixed condition in the Joint function is given to simulate the behavior of the bolt head.

2.2. Computational Experiments for Developing Pressure Limit Evaluation Codes

The computational experiment using the simplified model for the development of a code to evaluate the pressure limits of transport cask was carried out using the Design of Experiment.[1] As the first step of the Design of Experiment technique, it is necessary to determine the objective variables and input variables. In this study, the objective variables are set to the von-mises stress and stress intensity in the cask, so that the pressure limit can be evaluated by the Von-misses yield theory and the Tresca yield theory.

Table 2: Range of input variables

Input Variables	Maximum	Minimum
Cask Diameter (mm)	3,000	1,500
Lid Thickness (mm)	300	150
Bottom Thickness (mm)	400	200
Body Thickness (mm)	300	150
Pressure_out (MPa)	20	0
Pressure_in (MPa)	0.5	0

The input variables are the main dimensions that determine the shape of the cask and the external and internal pressures acting on the cask surface. The next step was to set the range of input variables to determine the design space for the computational experiment. The range of input variables were determined considering the conventional design of cask, and the depth of the sea around the expected transport path of the cask. The final step is to determine the design of experiments. Representative techniques of Experimental Design include Conventional Sampling and DACE(Design and Analysis Computer Experiment) Sampling techniques. In this study, the Optimal Space filling technique of DACE Sampling was used to enable to achieve uniform prediction accuracy across the design space.

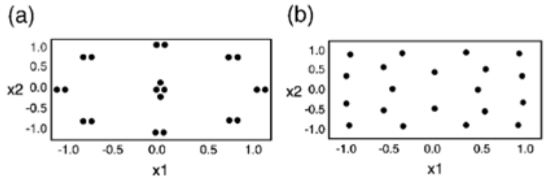


Fig. 4. (a) Conventional Sampling, (b) DACE Sampling

2.3 Development of Meta-model

The purpose of this study is to construct a code that can evaluate the integrity of transport casks, which should be produced as a mathematical model rather than a computational analysis model. In this study, a meta-model that can be generated as a result of Design of Experiment was used to produce a mathematical model. A meta-model is a mathematical model that simulates the relationship between input and objective variables using statistical techniques as an approximate model that can replace the actual model. There are many techniques for generating the meta-model. In this study, neural networks of the regression model, which is advantageous for learning complex data with high nonlinearity was used.

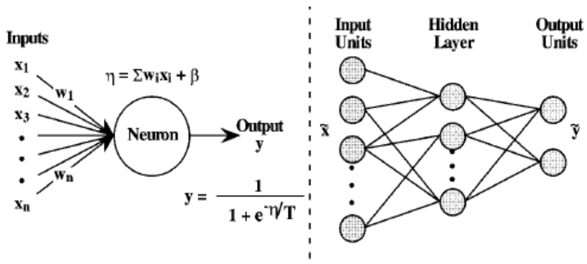


Fig. 5. Neural Networks

3. Conclusions

In this study, a simplified computational model was constructed using the parametric modeling technique to develop a code for evaluating the pressure limit of the spent nuclear fuel transport cask. The computational experiment was conducted through the procedure of the Design of Experiment technique. As a result of the experiment, a meta-model was developed so that the output variable can be calculated according to the input variable entered by the user. The developed meta-model can be used as a code for evaluating the pressure limit of a transport cask.

REFERENCES [1] Metamodels for Computer-based Engineering Design: Survey and recommendations, T. W. Simpson1, J. D. Peplinski2, P. N. Koch3 and J. K. Allen