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C. G. Corlu, S. R. Hunter, H. Lam, B. S. Onggo, J. Shortle, and B. Biller, eds.

SIMULATION-BASED OPTIMIZATION FOR ENHANCED CCS SCHEMATIC ARRANGEMENT DESIGN

SookYoung Son

Dept. of Naval Architecture and Ocean Engineering
Seoul National University
1, Gwanak-ro, Gwanak-gu
Seoul, REPUBLIC OF KOREA

HyeonGoo Pyeon

HD Korea Shipbuilding and
Ocean Engineering Co.,
477, Bundangsuseo-ro, Seongnam-si,
Gyeonggi-do, REPUBLIC OF KOREA

JiHee Kim

HD Hyundai Heavy Industries Co.,
477, Bundangsuseo-ro, Seongnam-si,
Gyeonggi-do, REPUBLIC OF KOREA

JongHun Woo

Dept. of Naval Architecture and Ocean Engineering
Research Institute of Marine Systems Engineering
Seoul National University
1, Gwanak-ro, Gwanak-gu
Seoul, REPUBLIC OF KOREA

ABSTRACT

An LNG cargo tank, referred to as the Cargo Containment System (CCS), encompasses several barriers intended for the storage of LNG at extremely low temperatures. In the case of the membrane-type CCS, each barrier is composed of insulation panels and membrane sheets. The CCS schematic arrangement endeavors to minimize the number of panels and sheets to enhance the manufacturing productivity. In this study, a combinatorial optimization approach is adopted to obtain the optimal CCS schematic arrangement. Then, a simulation environment is established to assess the arrangement results under diverse design conditions. By comparing the actual CCS design with the results of the proposed arrangement, the effectiveness of the proposed approach is valiated.

1 INTRODUCTION

The cargo containment system (CCS) is composed of multiple layers of barriers to store LNG in an extremely low temperature of $-163\,^{\circ}$C. In particular, the membrane-type CCS has the barrier with a structure where membrane sheets are placed on top of insulation panels. When designing the CCS schematic arrangement, the designer needs to minimize the number and types of insulation panels and the welding lines of the membrane sheets to optimize the productivity of the tank. However, in practical CCS design environments, the properties of design condition change frequently depending on production conditions, requiring designers to repeatedly modify the arrangement of panels and sheets. This process can cause human errors and lack the ability to quickly derive the optimal design. We propose a simulation-based approach to address this issue and further explore the optimal design of the CCS schematic arrangement, presenting experimental results.

2 METHODOLOGY AND RESULT

To overcome the challenge, we propose a simulation-based approach for generating the optimal combination of CCS schematic arrangement, which is consists of three main parts.

First, we define design variables, constrains, and objective functions to explore optimal design. The design variables include the sizes of each wall (W_h, W_w) and the sizes of elements (E_h, E_w) that can be placed. And we explore the optimal solution, minimizing the number of panels and the welding line length of membrane sheets ($\min \sum IP(N_k) + MS(N_k)$), within design constraints such as left-right symmetrical alignment configuration and prohibition of panel placement in the special area ($P_{specialarea} \notin P_{N_k}$).

Next, we proceed to the initial arrangement phase, where we determine the backbones ($b_n = \{E_h^a, E_h^b, ..., E_h^z\}$), which are wall components formed by combinations of available element heights. Subsequently, we establish leaf combinations ($l_n = \{E_w^a, E_w^b, ..., E_w^z\}$) based on the width of elements, resulting in each wall combinations. We create a tree graph model with nodes (N_k), representing various wall arrangements, and use it to search for the optimal solution that satisfies the objective function within the design conditions.The figure 1 shows the results of exploration. According to the result, We can demonstrate that our proposed model can not only replicate the designer's drawings but also find solutions with even fewer panel elements, more efficiently.

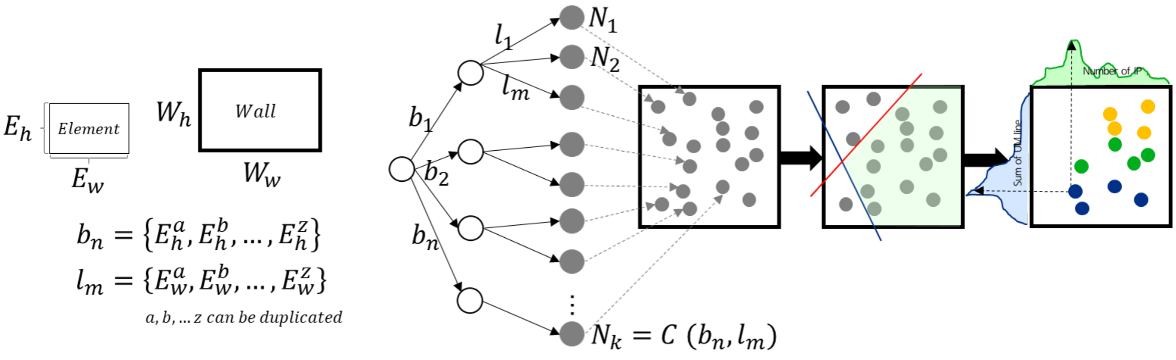

Figure 1: Methodology.

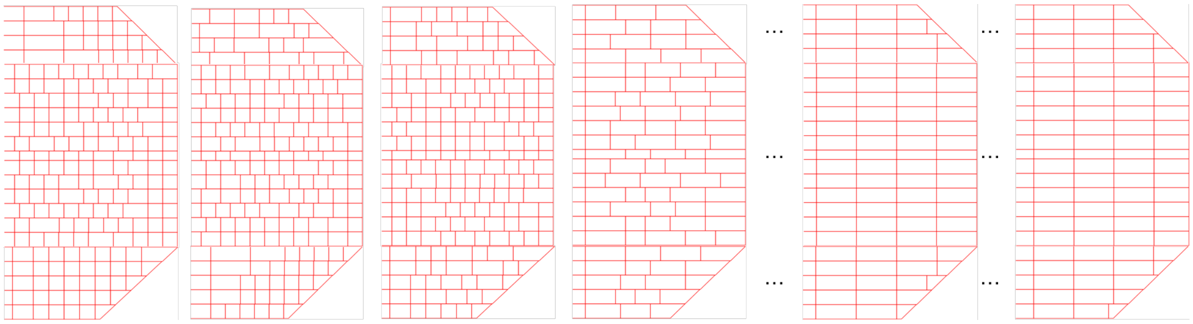

Figure 2: Case study results of LNGDF fuel tank.

Finally, in the simulation phase, we compare and analyze the differences in the arrangement results based on design variable changes, such as the position of special areas, wall sizes, and element types. The experimental results of our simulation-based approach showcase its ability to rapidly generate CCS schematic arrangements that match or surpass manually created designs. The approach significantly reduces human errors, saves time, and leads to higher satisfaction with objective function values, demonstrating its potential to revolutionize CCS design processes and improve tank productivity.