Abstract of Dissertation

Title of Dissertation「Design for modular construction of ship hull considering uncertainties」
（不確定要素を考慮した船殻ブロックの設計方法）

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1. Introduction

Design for modular construction of ship hull can be defined as a design to reduce construction costs and time to a minimum, compatible with the requirements of the ship hull to fulfill its operational functions with acceptable safety, reliability and efficiency. It is important that the design for modular construction effort starts early in the design process. The designer has the greatest influence on the cost of the vessel during the early design stages. This influence drops off quite rapidly in the later design stages. But at the early design stages the uncertainties that affect the decision making process of the designer will be high. The management of these uncertainties is very important for the design for modular construction to be effective. In this thesis, a system to help the designer in design for modular construction by the effective management of various uncertainties in the early design stage is proposed.

2. Uncertainties in design for modular construction

Some of the key factors that affect the design for modular ship hull construction considered in this research are module division planning, assembly process planning, weld deformation and rework of each module and modular construction scheduling. These factors are related to each other. The management of these factors for the optimization of design for modular construction at the early design stage is difficult due to the uncertainties at that stage.

The factors affecting module division planning are many and uncertain at the early design stage. The weight and size of modules depend on the facility constraints, which are uncertain at the early design stages. Also, the accurate estimation of weight and size of modules, generated from module division planning at the early design stage, is difficult. Since the structure of the modules itself is uncertain at the early design stage, the amount of welding between modules at the erection stage is also uncertain. Similar is the case of work content of each module. Also there are uncertainties in the amount of modular outfitting done and the locations of outfit components. In order to develop a more flexible and optimum design for module division, the consideration and management of uncertainty at the early design stage is very important.

At the early design stages, the choice of assembly sequence from a range of options available is also difficult. Also the selection and allocation of the production resources is also difficult and uncertain. This makes the estimation of the assembly process time and cost for a module at the early design stage difficult. Also there are limitations in the tools available to the designer in analyzing and evaluating assembly strategies, assembly sequences and estimating assembly time and cost. Predictions of module inaccuracies like weld deformations and associated rework time and cost and its management are also difficult at the early design stage, due to the uncertainties in the weld parameters affecting weld deformations. The uncertainties in the intermediate tasks like the module division planning, assembly sequence, module assembly time and rework may affect the overall construction time and cost schedule.

The uncertainty factors that affect design for modular construction can be broadly classified as shown in Fig.1. These are uncertainties related to information, decision-making, estimation, analysis tools, physical processes, performance of worker or equipment and engineering change orders. These are related to each other and cannot be considered independently. This makes the management of uncertainties more difficult.

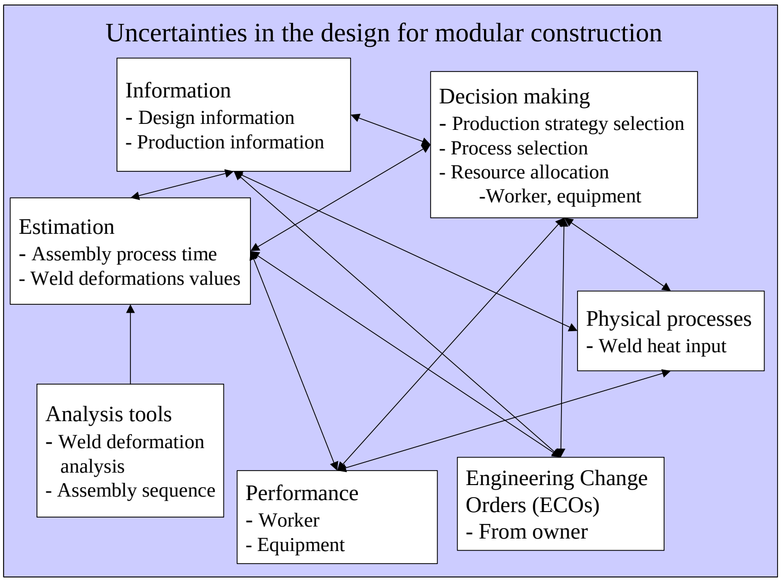

Fig.1 Uncertainties in design for modular construction

3. Aim of the research

As mentioned in the previous section, the design for modular construction should start at the early design stage because the designer will be able to control the overall cost and time of production more effectively at this stage than the later stages. But the uncertainty factors are high at this stage. As shown in Fig.2, as the design progresses to more advanced stages and as the production starts, the uncertainties reduces, but at the same time the cost reduction opportunities will also be reduced.

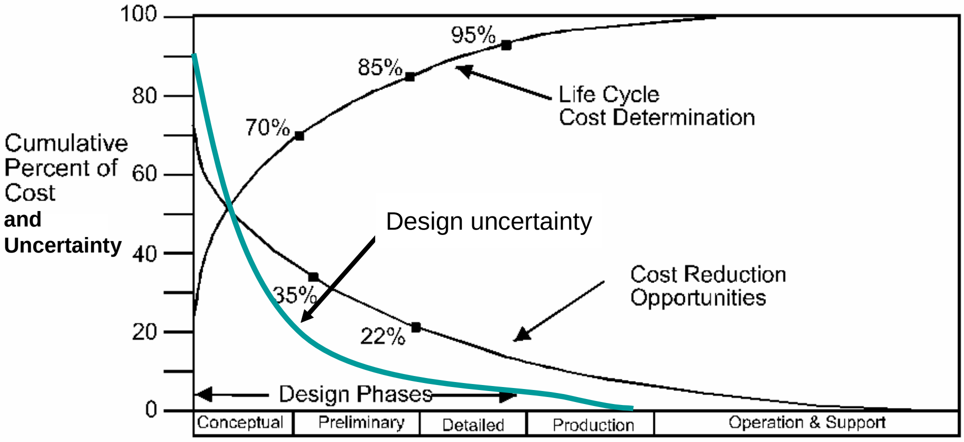

Fig.2 Uncertainty and cost determination variation along design stages

The aim of the research is to develop a system to help the designer involved in the design for modular construction in the process of decision-making at the early design stage by effective management of the uncertainties. The major factors addressed are module division planning, assembly planning of each module, accuracy management (mainly weld deformations and associated rework) of modules and the associated uncertainties, and the effect of uncertainty at the intermediate stages on the overall modular construction time schedule (Fig.3).

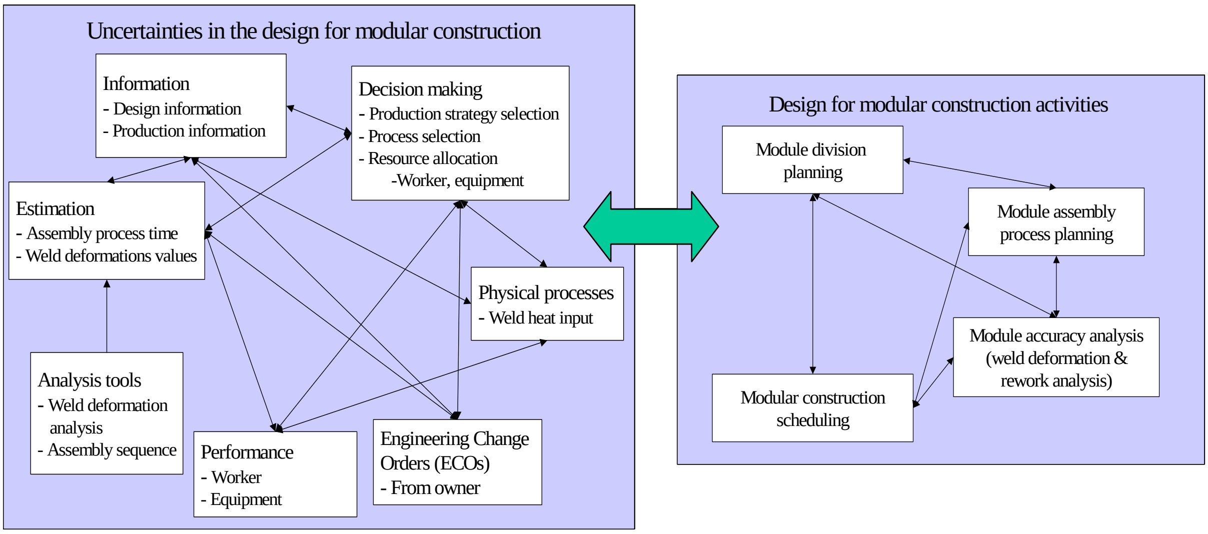

Fig.3 Design for modular construction considering uncertainties

4. Overview of the proposed system

Fig.4 shows the overview of the system proposed in this research. The system consists of four main parts: - Fuzzy logic based module division planning, module assembly analysis, module weld deformation variation and rework variation analysis and modular construction scheduling risk management systems. The details of each of the components are explained briefly in the following sections.

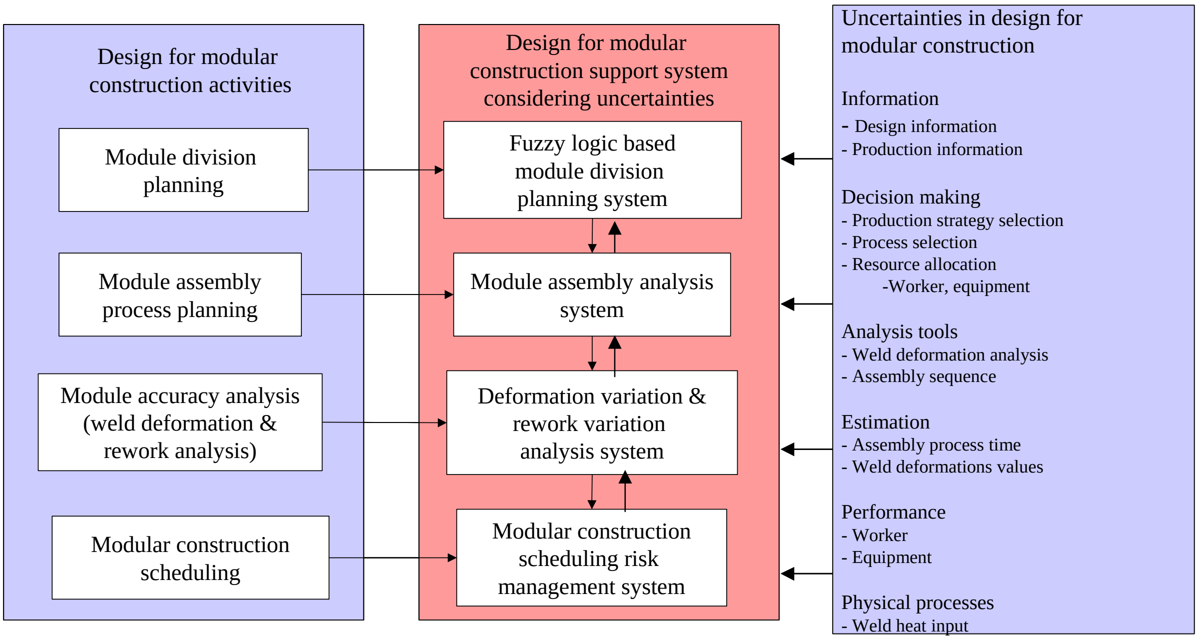

Fig.4 An overview of the proposed system

5. Module division planning system

The aim of the module division planning system is to help the designer in module division planning by generating various module division patterns considering the designer's built strategy or design intentions and evaluating each pattern considering various design and manufacturing constraints and associated uncertainties. The system is developed based on the concept of module division using candidate seams, graph theory and fuzzy logic as shown in Fig.5. At first, the designer will input 'candidate seams' in locations that are considered suitable for module division. The ship hull structure is divided to 'modules' based on the candidate seams. A liaison graph of modules is generated. In the liaison graph, a node represents a module and a link between nodes represents the connection between two modules. Module division patterns are generated by 'cutting' the module liaison graph using cut-set method. In the next step, module division patterns are evaluated and ranked using fuzzy logic. The uncertainties in the various evaluation factors are expressed as fuzzy sets. The candidate seams used to generate each pattern and the modules in each pattern are evaluated. Other evaluation criteria defined by the designer can also be considered. Module division patterns can be ranked based on this evaluation. The designer can carry out further analysis on the selected module division patterns.

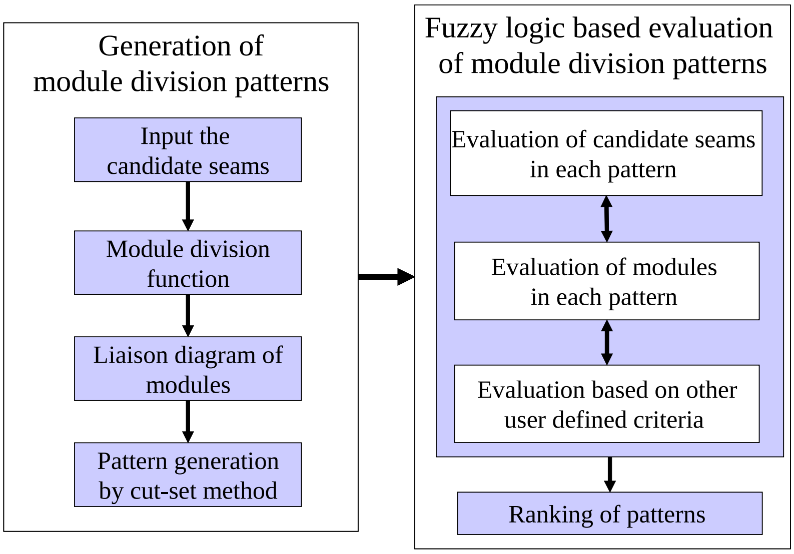

Fig.5 Outline of module division planning system

6. Module assembly analysis system

The module assembly analysis system helps the designer in evaluating various assembly sequences of modules, generated from module division planning, by analyzing each assembly stage from individual parts to the final assembly considering designer's assembly strategy. The uncertainly in the assembly time at each stage is considered and final assembly time uncertainty is calculated. As shown in Fig.6, the system is based on graph model or liaison diagram of the module structure, assembly sequence generation from the liaison diagram considering the assembly preferences defined by the designer in the liaison diagram, analysis of each assembly stage from the assembly sequences, generation of assembly PERT chart from selected assembly sequence and Monte-Carlo simulation of assembly PERT chart for the estimation of risk of variations in assembly.

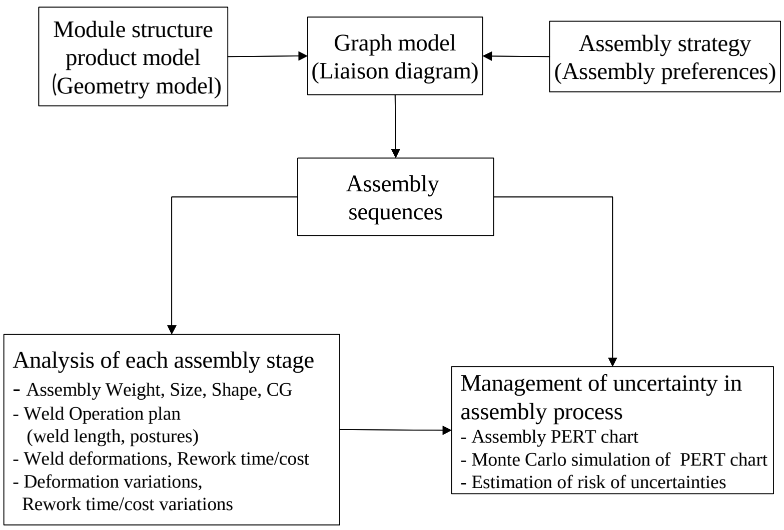

Fig.6 Outline of the assembly process planning system

7. Module weld deformation analysis system

The module weld deformation analysis system helps the designer in calculating the weld deformation values of each modules as well as variations in deformation values considering the variations in weld parameters, mainly heat input variation. Considering a selected assembly sequence of the module and the weld postures, weld heat input and its variations at each weld line are identified. The force/moment equivalent of the hear input is calculated based on experimental values and defined on the FEM model generated from the module structure model. The weld deformation values of the module and its variations are calculated using FEM analysis of the model and Monte-Carlo simulations. Fig.7 shows an outline of the proposed weld deformation analysis system.

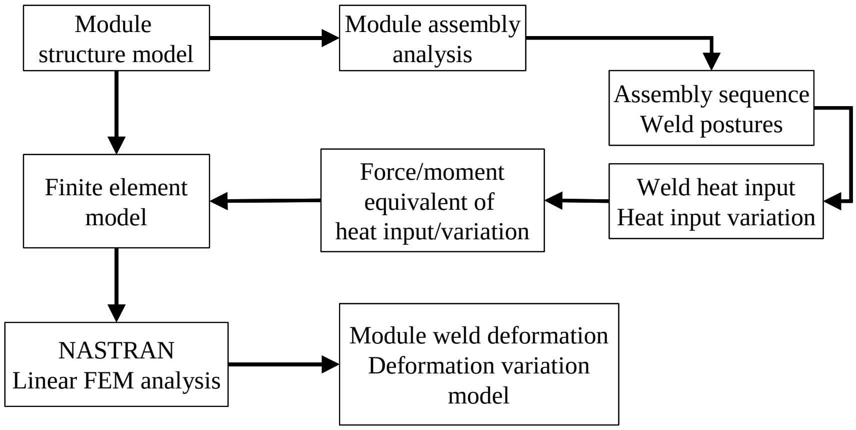

Fig.7 An outline of the proposed weld deformation analysis

8. Module rework analysis system

The rework time associated with the weld deformations and its variations are calculated using the module rework analysis system. As shown in Fig.8, the calculation is done considering the deformation values at the module interface and its variations. The root gap and misalignment values at the module interface and the associated rework activities are identified. From the accuracy-labor functions defined by the designer, total rework time and its variations are calculated using Monte Carlo simulations. The optimization of the module positioning in order to reduce the rework can also be done using the system.

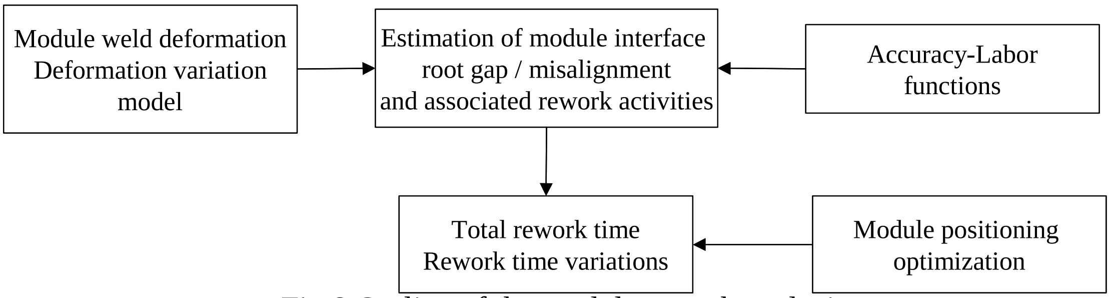

Fig.8 Outline of the module rework analysis system

9. Modular construction schedule risk management system

The aim of the modular construction time scheduling risk management system is to help the designer in effectively managing the risk in modular construction time scheduling due to uncertainty in each intermediate activities, especially the risk due to the uncertainty in module assembly time and module rework time due to weld deformations. First, a module division plan is selected and analyses of the modules are done based on the systems explained in the previous sections and activity times at each stage are estimated. Then a modular construction schedule network is generated for the selected plan. Using the Monte-Carlo simulation of modular construction schedule network, total construction time and its variation are estimated. The risk is identified as the probability of the total estimated time exceeding the planned time. For the management of this risk by reducing the total modular construction time variation, alternate module division plan, alternate construction plan for each module and alternate selection of weld resources can be considered. Using the system, for given module division plan and construction plan for each module, risk management can be done by the optimization of the resources, by minimizing the total resource management cost and also considering the constraints in resources. Outline of the proposed system is as shown in Fig.9.

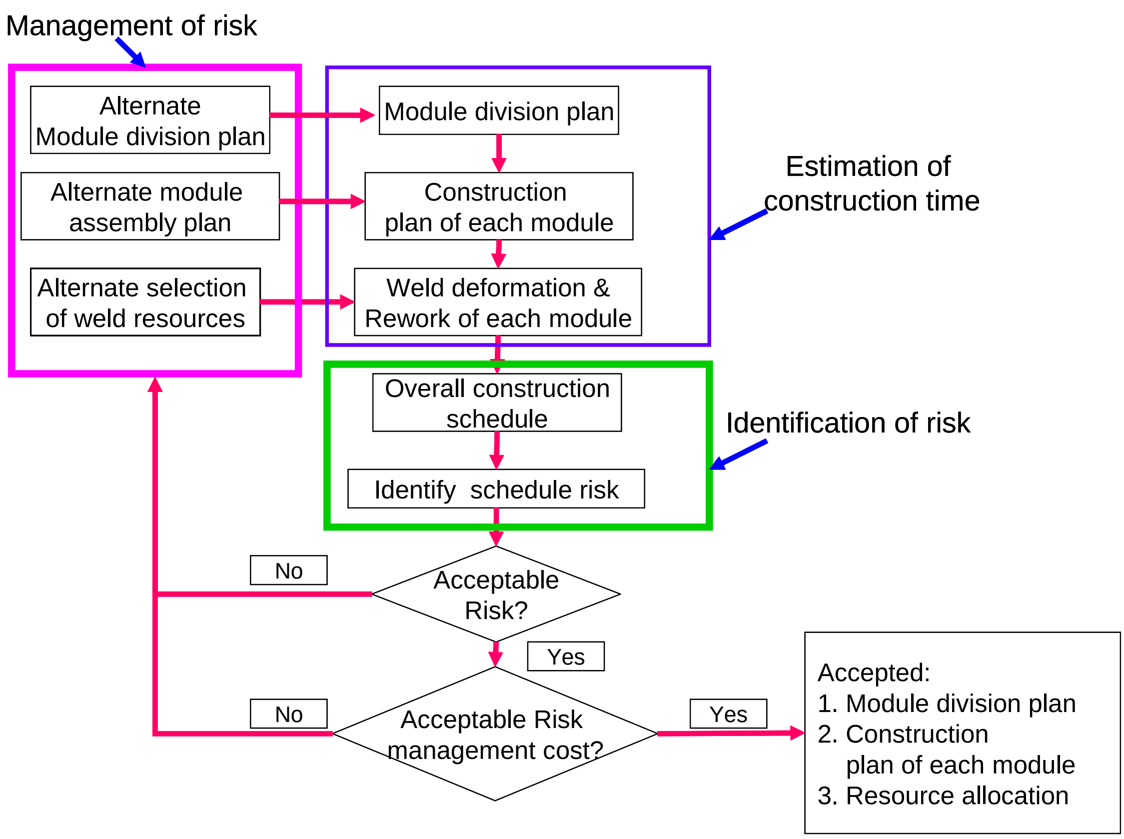

Fig.9 Outline of the proposed risk management

The system, proposed in this research, is implemented using VisualWorks Smalltalk Release 2.5.2J and based on SODAS (System Of Design and Assembly in Shipbuilding), a CIM system developed by Manufacturing System Engineering Laboratory of Department of Environmental and Ocean Engineering, University of Tokyo.

10. Conclusion

The major contribution made by the research outlined in this thesis is the development of the system for the integration of some of the critical design for modular construction activities and the management of uncertainties in these activities at the initial design stages, considering the overall design for modular construction. The important design for modular construction activities considered are module division planning, assembly process planning of each module, module weld deformation and associated rework and modular construction time scheduling. Using the proposed system, designer will be able to make decisions in the design process aimed at modular construction by considering all the design activities and the associated uncertainties, both simultaneously.