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Estimation of welding material quantity for shipbuilding at early design stage based on three-dimensional geometric information

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Estimation of welding material quantity for shipbuilding at early design stage based on three-dimensional geometric information

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Abstract

These days, shipbuilding companies are making an effort to adopt the IT technology in order to improve the production efficiency. One such effort is to utilize a planning and scheduling system to predict the production cost in advance. In this system, assessing the welding material quantity is an important factor. Unfortunately, obtaining the welding material quantity in the early design stage is extremely difficult because the detailed production information, which is essential in deriving the cost associated with welding, is normally available at a later stage. This paper aims at developing a computerized program that produces an index to estimate the welding material quantity in the early design stage. By using only three-dimensional geometric information, the program analyzes the production process and estimates the welding material quantity at any design or production stage when no production information is available. The results can be used for the planning and scheduling system.

KEY WORDS: Welding quantity amount 용접물량, Geometric information 형상정보, Assembly simulation 조립시뮬레이션, Production information 생산정보

Chapter 1. Introduction

Recently, shipbuilding companies are making huge efforts in applying IT to shipbuilding industry to secure competitiveness and reduce cost by increasing production efficiency. In line with these efforts, various studies have been conducted on integrated manufacturing execution system and simulation-based management system for efficient production management. Integrated manufacturing execution system refers to a system that prepares shipbuilding plans, middle level planning after erection, and middle level planning before erection on the basis of the planning information needed for shipbuilding in a shipyard. Shipbuilding companies may used the system to prepare specific and precise production plans to improve the production efficiency. In preparing a reliable production plan by using the manufacturing execution system, it is important to calculate the accurate man hour for each required activity.

Prediction of man hour and estimation of production quantity have been studied in various ways. Cho et al. (1998) conducted a study on the determination of assembly units and assembly order in a block assembly stage. In the year, the information required to calculate welding material quantity was identified on the basis of shipyard database, and a relevant software program was developed and validated (Lee, et al., 1998). Afterward, Roh et al. (2006) developed a method of automatically generating a three-dimensional hull structure CAD model and acquiring production amount information from each block by estimating the block weight, center of gravity, painting area, and mount length on the basis of the three-dimensional model. Ruy et al. (2013) proposed a method of establishing a substantial computerization and automation system by interconnecting most of the procedures required for the calculation of welding length and welding material quantity with the shipbuilding exclusive CAD system.

In previous studies, the production quantity was calculated by using the shape information and the production information obtained from the conventional CAD system for ship design. This method may enable to calculate the production quantity based on accurate information. However, this method has an unavoidable disadvantage that the timing of calculating the production quantity should be late because the production information required to calculate the production quantity becomes available late. In particular, from the perspective of manufacturing execution planning, the production quantity information needed for manufacturing execution planning may not be obtained early, because the timing when the shipyard production quantity information is calculated is after the manufacturing execution planning, while the manufacturing execution planning must be performed in an early stage of the entire design process. Such a disadvantage is a critical obstacle to the early production quantity estimation for manufacturing execution planning.

In addition to the previous studies mentioned above, contentional commercial software programs have made efforts to estimate welding material quantity. Since most of the software programs calculate simple welding material quantity data, such as the welding length and leg length, it is difficult to early estimate the welding man hour by considering production information. Hence, there is the need for developing a method of acquiring approximate production quantity information at the timing when detailed production information is not generated yet.

The subject of the present study is the material quantity in welding, which is the activity requiring the most man hours among the various activities included in an assembly process. The aim of the present study is to estimate the welding material quantity by performing Common Structure Rule (CSR) with the shape information, including thickness information, at the time point after the completion of basic design and before the start of detailed design when only the shape information is available but the production information is unavailable. An algorithm for estimating the welding material quantity by using the shape information was developed, and a welding material quantity estimation program was developed by connecting Graphic User Interface (GUI) with graphic functions. A double bottom structure shape model was used to verify the validity of the algorithm.

Chapter 2. Integrated Manufacturing Execution System

2.1 Overview

Manufacturing Execution System (MES) refers to a system that manages manufacturing plans, work directions, material consumption, production follow-up, facility management, and production accomplishment analysis to increase the efficiency of production management. MES has been upgraded as integrated MES for manufacturing enterprises, providing various approaches and solutions to improve availability, efficiency, and stability of core parts of manufacturing enterprises. The integrated MES has been developed as a system that can remove the uncertainty in distribution and logistics industries by performing business analysis and big data analysis and share the methods of predicting the future situations.

The MES is basically for manufacturing scheduling as well as preparation of manufacturing and materials supply plans. The functions of the MES include search and control of process information, search and control of facilities, search and control of quality information, summary of accomplishment information, management of warehouse operation, management of products, management of materials input, management of human resources, and management of official affairs. Therefore, the MES may be used to integrate and manage all types of information that may be generated at a manufacturing site. The MES is an online system that prevents waste of expenses in all manufacturing processes and helps stock management. The collected data are used to reduce the percentage of defective products and to check the problems generated from the processes.

2.2 Functions

Resources Allocation and Condition Management

Resources available to workers are managed, including equipment, tools, worker skill, materials, and documents. The function of resources allocation and condition management provides detailed history of resources and real-time equipment condition and verifies installation of equipment appropriate for work. Resources management also includes reservation and distribution of resources in accordance with work schedule.

Work and Detailed Schedule Management

The function of work and detailed schedule management provides prescription related to specific production units, priorities, and order based on properties and characteristics in the process of minimizing installation workload when appropriate work order is determined. Schedule management has limitations. Duplicated and parallel works as well as alternative schedules should be investigated to perform detailed calculation of precise time, equipment mounting, and shift types.

Production Unit Distribution

The distribution information to manage the flow of production units in different work types is provided by the works that should be performed due to an event occurring at a factory site and the order of real-time changes.

Document Control

The function of document control is used to control the documentations that should be managed along with production units. The document control function delivers work directions to actual work sites by providing data to workers or by providing prescriptions about equipment control. The document control function also embraces process management information including the control and integration of environment as well as sound and safe regulations and right behavioral procedures.

Data Collection and Acquisition

The function of data collection and acquisition provides connection of the data popularizing the records and formats relevant to production units with the information to acquire internal work production.

Labor Management

The labor management function provides the information about the state of individual workers in minutely time structure. The labor management includes indirect behavior follow-up capability such as preparation of materials and tools as the cost standards based on presence report, validation follow-up, and behavior per time. The labor management function may interact with the resources allocation function to determine the optimal allocation.

Quality Management

The quality management function provides real-time analysis of measurement values collected from manufacturing sites to verify quality control with reference to quality control index or to identify problems. The quality management function provides behavioral pattern to correct the problems, including the signs, behavior, and interaction with results to determine causes.

Process Management

The process management function provides workers with support for decision-making or automatically corrects the decisions to monitor production and improve undergoing works. These conducts may work internally or follow up the process from one work to another, particularly focusing on internally operation instrument and equipment. The function may include alert management to make individual workers recognize the change of processes within an externally acceptable error range.

Maintenance Management

The maintenance management function directs and follows up the behavior for the maintenance of equipment and tools to verify the production and schedule management capabilities. The maintenance management function conserves past events and history of problems to help the diagnosis of a new problem.

Production Follow-up and History-Taking

This function shows work locations and the site of regular works. The condition information includes the identity of workers, supplier element materials, lot or serial numbers, current production conditions, alert status, re-work, and other exceptional items relevant to production.

Execution Analysis

The execution analysis function provides minutely reports with regard to actual work operation results through the comparison of past records and predicted results.

2.3 Reference Information System

Establishing a reference information system needed for production is critical to more accurate manufacturing execution scheduling. Reference information menas standardization of lead time serving as reference for scheduling (node, drawing schedule, steel materials, production, procurement, etc.) and establishment of a work classification system that may be applied as a node for production, design, materials, and cost.

From the perspective of shipyards, the reference information system includes work system classification, Work Breakdown Structure (WBS), job analysis, member numbering system, and establishment of building standards. It is important to connect the reference information system with Block Division, W.S.D, D.A.P, member specification information, and production information-based BOM to establish production database.

2.3.1 Work Breakdown Structure (WBS)

2.3.1.1 Introduction

WBS is a family tree structure of works performed to obtain a final product and it defines the entire scope of a project. The WBS theory was developed in the US in 1960's. The theory presents a method of efficiently managing a project, because the viewpoint of the theory suggests a method of observing a project. Therefore, WBS is defined as a method of comprehensively defining work and decomposing the work into manageable smaller components. Thus, WBS refers to the framework of individual work items. Generally, it is desirable to construct a WBS that makes the planning and the execution easy for each work item.

2.3.1.2 Composition

Physical Breakdown Structure (PBS), which is the reference for work classification and management for a project, systematically classifies final products, which are the business substances. Functional Breakdown Structure (FBS) is a systematic classification of all functional works that are implemented to produce the final products as well as the accomplishments of the functional works.

2.3.1.3 Purposes

WBS has two purposes. The first is activity definition where activities needed for a project are defined to the lowest level and the relationship between unit activity and the entire project is investigated at each level. The second is summarizing and reporting where subsequent schedule is prepared, cost information is collected and summarized, and the reporting system is established.

2.3.1.4 Application and Utilization

WBS may be applied and utilized in various areas, as shown in Table 1. (http://m.blog.naver.com/alchlch/60092085694)

Table 1 Scope and contents of WBS applications.

Scope	content subject
Planning and budget formulation	Tools for efficient planning are provided by supplying a basic framework representing project activities and products. Basic data for resource input plans and budget formulation are provided in unit activity plans.
Process planning	All the unit activities needed for a project are easily defined. The classification of each activity may be immediately noticed. The standards for cost and resource allocation for each activity are provided in the formulation of basic plans.
Estimation of project cost	Estimation of project cost is performed with reference to the WBS system, because WBS serves as a common reference for process and project planning. The enterprise database (EDB) of enterprises having a similar WBS system may be accumulated and reused.
Analysis of accomplishment	The project accomplishment analysis function is provided by applying the Enterprise Volume Management System (EVMS). Equal process and project cost management standards are provided to the ordering body and the contractor.

Chapter 3. Development Tools

3.1 Introduction

The graphic user interface (GUI) used as a development tool for a welding material quantity estimation program was the Microsoft Foundation Class (MFC) library. The open source graphic library, OPEN CASCADE, was used as a graphic library for three dimensional shape input and processing.

All the development tools used in the present study were based on the C++ language. The Microsoft Visual Studio was used as the integrated development environment.

3.2 OPEN CASCADE

Open Cascade Technology (OCCT), developed by Open Cascade SAS in France, is an open source graphic library for 3D CAD, CAM, and CAE. High-level graphic libraries that are now used extensively include Parasolid (Simens) and ACIS (Spatial), and the most representative low-level graphic library is Open GL.

Open GL is a basic graphic library that is most appropriate for the visualization of a 3D model on a screen. However, since it is a low-level graphic library, Open GL requires much time for visualization and geometry calculation. On the other hand, high-level graphic libraries, such as Parasolid, ACIS, and Open CASCADE, provide users with such functions as rendering, geometry calculation, and model input and output, on the basis of Open GL, to reduce the time and effort required for a user to write a program. As shown in Table 2, high-level graphic libraries are used as kernel in many applications.

Table 2 Utilization of high-level graphic libraries as program kernel.

Application	Developed by	Kernel
4MCAD IntelliCAD	4M S.A.	Open CASCADE
KeyCreator	Kubotek USA, Inc.	ACIS
KOMPAS-3D	ASCON Group	ACIS
KOMPAS-Builder	ASCON Group	C3D
K3-Furniture	Center GeoS	C3D + K3 kernel
Renga Architecture	ASCON Group	C3D
KOMPAS:24	ASCON Group	C3D
nanoCAD	NanoSoft	C3D kernel
T-FLEX	Top Systems	Parasolid
APM Studio	APM	APM Engine
TECHTRAN	NIP-Informatic	C3D
PASSAT	NTP Truboprovod	C3D
Rhinoceros 3D	Robert McNeel and Associates	Own Kernel
ESPRIT Extra CAD	LO CNITI, Rubius	C3D
BAZIS System	BAZIS Center	C3D
Adams	MSC Software	Parasolid
ADEM	ADEM Group	ACIS
ADINA Modeler	ADINA R&D Inc.	Parasolid
AutoCAD	Autodesk	ShapeManager
Autodesk Inventor	Autodesk	ShapeManager
BricsCAD	Bricsys	ACIS
Siemens NX	Siemens PLM Software	Parasolid
SolidFace	SolidFace	Parasolid
Solid Edge	Siemens PLM Software	Parasolid
SolidWorks	Dassault Systèmes	Parasolid
MicroStation	Bentley Systems	Parasolid
CATIA	Dassault Systèmes	CGM
PTC Creo Elements/Pro	Parametric Technology Corporation	GRANITE
PTC Creo Parametric	Parametric Technology Corporation	GRANITE

Parasolid and ACIS are paid kernels and thus license should be purchased for program development. In contrast to the paid kernels, Open CASCAD is an open source library that may be freely used in program development for research purposes.

3.2.1 Structure

Figure 1 shows the library structure of Open CASCADE. Table 3 shows the content included in individual libraries.

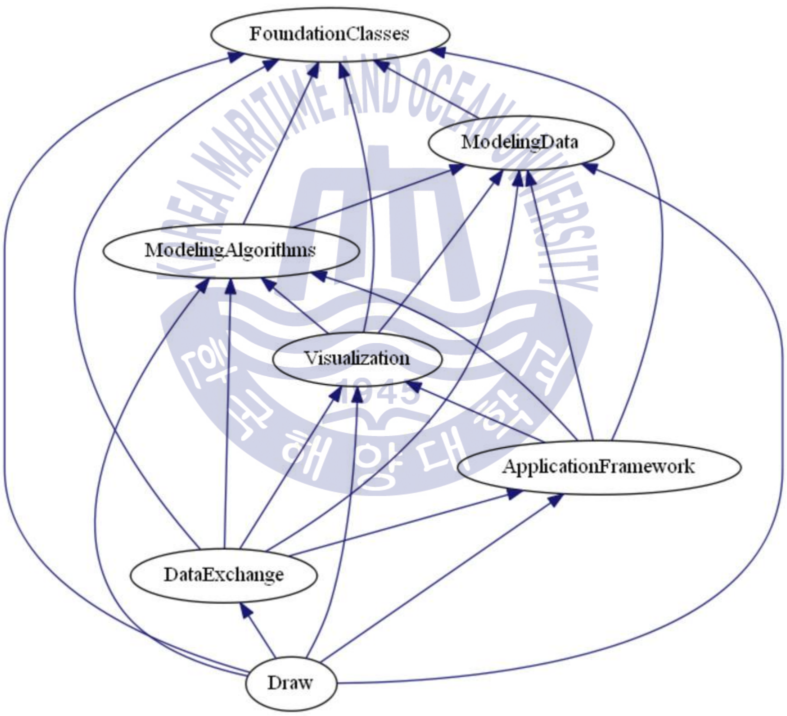

Fig. 1 OCCT libraries structure

Table 3 Content included in OCCT Libraries

Library	Content
Foundation Classes	Kernel Classes Math Utilities
Modeling Data	2D Geometry 3D Geometry Geometry Utilities Topology
Modeling Algorithms	Construction of Primitives Boolean Operations Fillets and Chamfers Offsets, Drafts Sewing and Sweeps Hidden Line Removal Geometric Tools Topological Tools
Visualization	Services Common to 2D and 3D 2D Visualization 3D Visualization
Data Exchange	IGES STEP AP 203 STEP AP 214 Extended data exchange(XDE)

3.2.1.1 Foundation Classes

The Foundation Classes library includes basic classes related to a kernel as well as libraries related to mathematic calculations.

3.2.1.2 Modeling Data

The Modeling Data library includes libraries relevant to data for geometric shapes and provides geometry and topology libraries as the format for expressing modeling data.

3.2.1.3 Modeling Algorithms

The Modeling Algorithms library provides the TKMesh, TKBO, TKBool, and TKFillet libraries for modeling data calculation as well as the TKHLR library for hidden line processing.

3.2.1.4 Visualization

The Visualization library provides a collection of visualization libraries, including TKOpenGl, TKIVtk, and TKV3d, to visually display topology modeling data.

3.2.1.5 Data Exchange

The Data Exchange library includes the libraries supporting data exchange formats. The file formats currently supported by Open CASCADE includeIGES, STEP AP 203, STEP AP 214, XDE, STL, VRML, Brep, and others.

Chapter 4. Overall Program Structure

4.1 Introduction

The operation of the welding material quantity calculation program starts with the input of a model file in a neutral file format, as shown in Figure 2. The program consists of an input section where properties of each shape are automatically generated and the shape connection relations are investigated, a processing section where the welding material quantity is estimated on the basis of the generated shape information and connection relations, and an output section where the estimated welding material quantity is displayed in a 3D graphic.

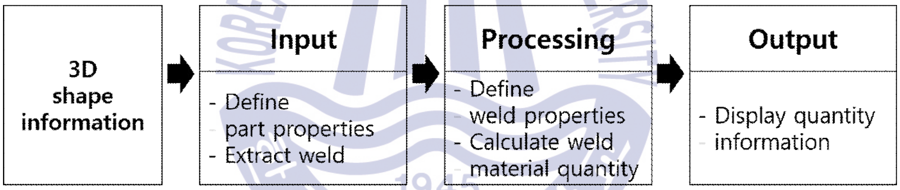

Fig. 2 Structure of entire system.

Fig. 3 shows the flowchart of the entire program structure.

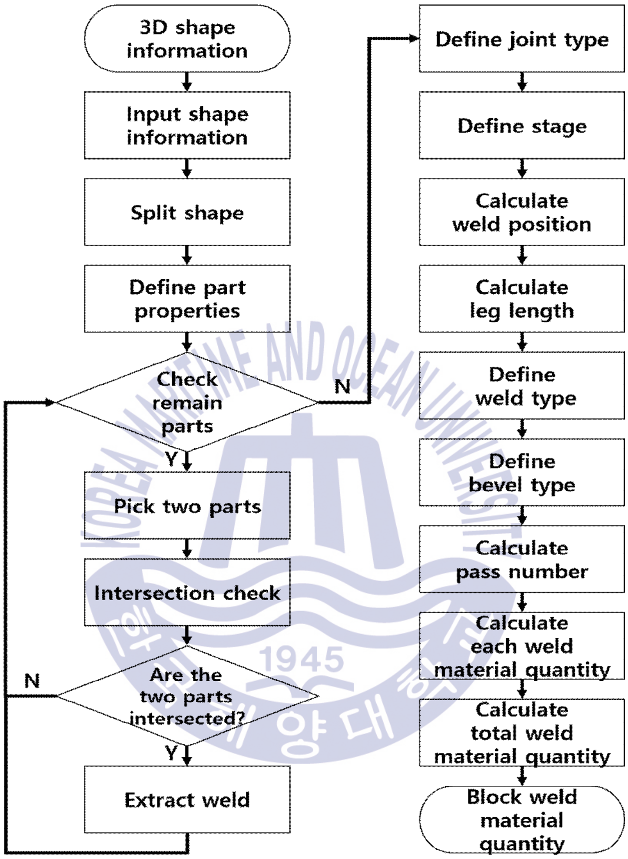

Fig. 3 Flowchart of welding material quantity estimation system.

4.2 Class Structure

Figure 4 shows the main class structure needed for the welding material quantity estimation process. First, basic classes representing members and welding, the member class and the welding class, were generated to define the common properties of the member and welding objects. Then, the classes having different properties, such as plates, panel members, and sub-assembly members, inherited the member class so that the individual classes may have an organic relationship with each other.

An algorithm class was created to perform various types of calculation and determination. The algorithm class includes an algorithm that decompose an input 3D shape into individual member units, an algorithm that extracts welding seams from cross-checking of members, and an algorithm that determines activity unit, welding posture, and welding type.

Each class includes member variables and member functions. The key member variables of the member class include location, volume, weight, activity unit, and shape information representing the unique properties of each class. The member variables of the welding class are welding length, leg length, shape information, improved shape, joint type, activity unit, and welding posture. Individual member variables must be appropriately defined for various types of geometry calculation and material quantity estimation. In addition, member functions should be also defined to perform calculation by using these variables or to input the variables. With regard to members, various assembly member classes inherit the basic member class. Member variables and functions should be additionally defined for each class, because different member classes may require different functions.

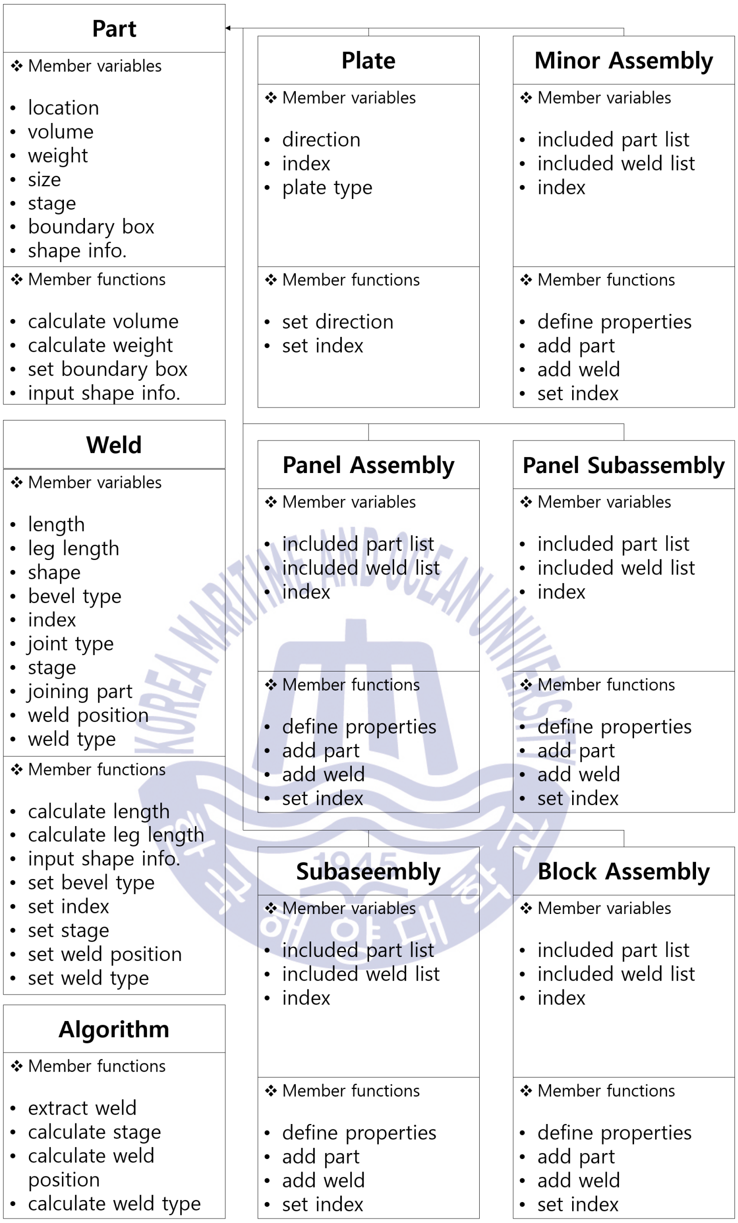

Fig. 4 Main classes

4.3 Output Screen

The estimated welding properties and material quantity should be displayed in a way that users may conveniently view and correct. Displaying the block shape for each activity unit in a 3D shape is also an important function. Thus, various numerical values and welding properties are displayed in an interactive mode as shown in Figure 6 so that users may correct the information. In addition to the visualization of a 3D shape of an entire block, the activity unit and welding seam selected by a user is highlighted in a different color so that the user may easily recognize, as illustrated in Figure 6.

The material quantity properties displayed on the output screen include the list of an entire member for the current material quantity, the list of individual welding units, and the list of all welding activities, which are displayed on the left side of the screen, as well as the properties of individual members and welding activities and the list of sub-members included in the current member, which are displayed on the right side of the screen.

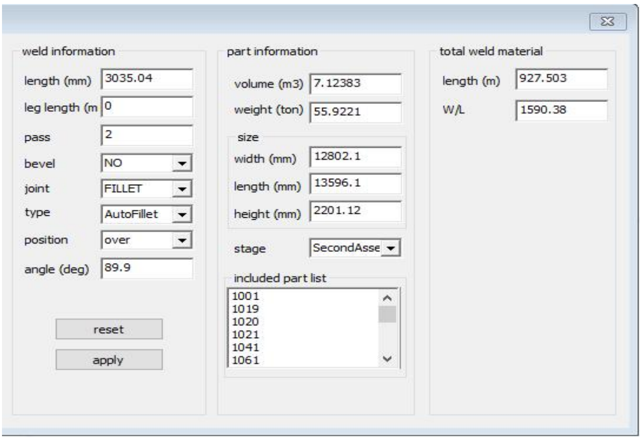

Fig. 5 Output screen

Fig. 6 3D shape of double bottom structure

Chapter 5. Main Functions of welding material quantity Estimation

5.1 Shape Information Input and Additional Information Estimation

Commercial design programs generally used by shipyards includes unique file formats for 3D shape processing. However, the program developed in the present study that is operated independently from a specific design program employed a neutral file format instead of file formats for specific commercial software.

A neutral file format may be extensively used in various areas. The program developed in the present study employed the Initial Graphics Exchange Specification (IGES) format and STEP (ISO 10303-21) format that may be used for the output of shape information in commercially available design software. Therefore, the output is not limited by conventional commercial design software, and the shape information produced from small and medium-sized shipyards that do not use expensive commercial software may also be input.

Since the input shapes of individual members are merged and returned as a single shape, the input shapes should be decomposed into individual plate units. This decomposition process was processed by using the OnCompoundExplode function as shown below.

```
for (TopoDS_Iterator ext(_shape); ext.More(); ext.Next())
{
        TopoDS_Shape _tempShape = ext.Value();
        TopAbs_ShapeEnum _type = _tempShape.ShapeType();
        Handle(AIS_Shape) _AISshape = new AIS_Shape(_tempShape);
        if (_type == ShapeEnum){
```

```
                Plate* _plate = new Plate();
                _plate->SetShape(_AISshape);
        }
}
```

Since a 3D model in a neutral file format is basically assumed to have no other information except the shape information, the size, volume, weight, and direction of a member should be estimated on the basis of the input member shape information. For this, the program developed in the present study extracts all the vertexes of individual shapes to acquire the bounding box information of the shapes, as shown below.

```
for (TopExp_Explorer exp(_tempShape, TopAbs_VERTEX); exp.More(); exp.Next())
{
        TopoDS_Vertex _tempVertex = TopoDS::Vertex(exp.Current());
        gp_Pnt _tempPoint = BRep_Tool::Pnt(_tempVertex);
        _plate->AddPoint(_tempPoint);
}
```

The length, width, and height values of a member are determined from the extracted bounding box information to calculate the volume and estimate the weight. In addition, to obtain the direction information, the shape is decomposed to unit planes. The most wide plane among the unit planes is determined as a representative plane of a member, as shown in Figure 7, and the inertia axis of the representative plane is determined as a representative direction of the member.

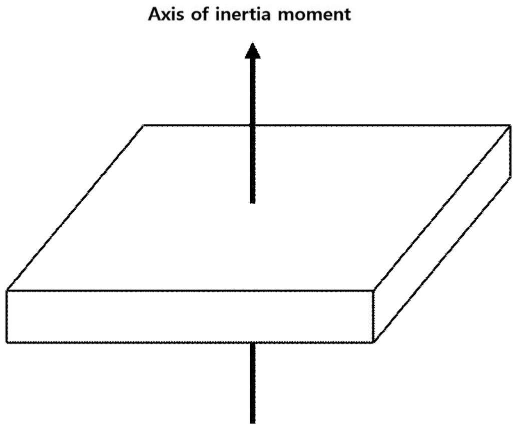

Fig. 7 Determination of representative direction of a member.

5.2 Extraction of Welding Seam

The entire welding material quantity is calculated by summing the material quantity for individual welding objects. Since the input shape model does not include welding information, welding objects should be extracted from the shape information. Welding is usually performed at a point where two members meet together. Therefore, a cross-line between geometric shapes is assumed as a welding object connecting two members, as shown in Figure 8.

```
BRepAlgoAPI_Section _section(_plate1->Shape(), _plate2->Shape());
_section.Approximation(Standard_True);
Weld* _weld = new Weld();
_section.Build();
if (_section.IsDone() && !_section.Shape().IsNull()){
            _weld->SetShape(new AIS_Shape(_section.Shape()));
}
```

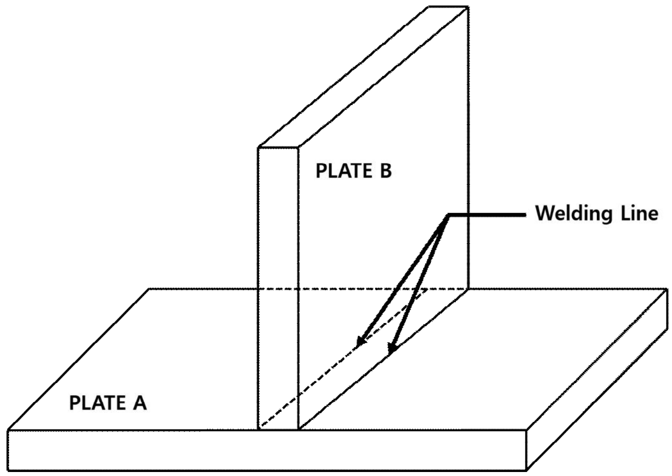

Fig. 8 Estimation of welding seam from geometric shape

A single welding seam is generally formed from a cross-line of two adjoining members, as shown in Figure 8. However, in cases where a single welding seam is form over two continued members, the seam should be recognized as a single seam by an additional processing.

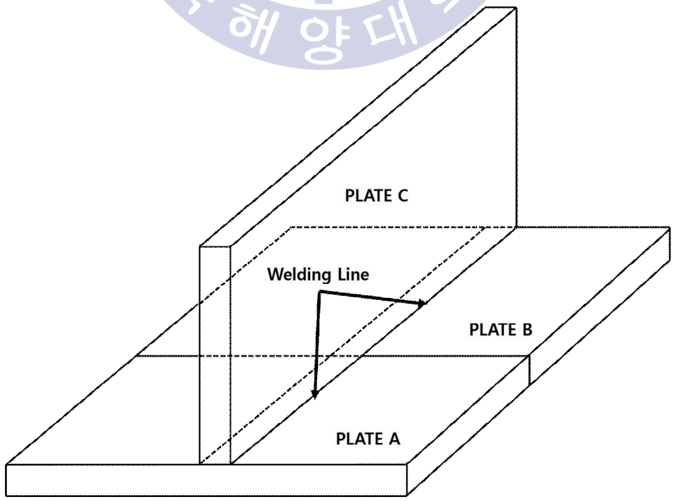

Fig. 9 Estimation of welding seam from geometric shape

The generated cross-line is highlighted on the screen in a predetermined color. Figure 10 shows an example of a welding shape generated from the cross-calculation between shapes.

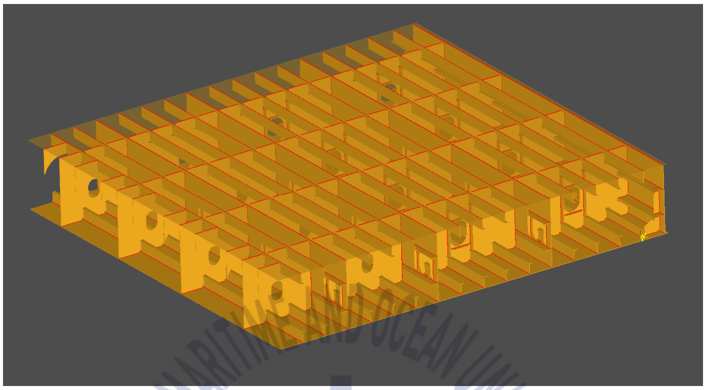

Fig. 10 Extraction of welding object through cross-calculation

Generated welding objects are separately saved and managed. Individual welding objects include the information about the connected members for the convenience of management. In addition, the vertex information of individual welding objects were used to calculate the welding length and welding thickness.

5.3 Determination of Joint Type

Joint type refers to the type of connecting two member in performing welding of two different members. A welding line may be basically divided into the following two joints according to the adjoint angle and direction of two members, as shown in Figure 11.

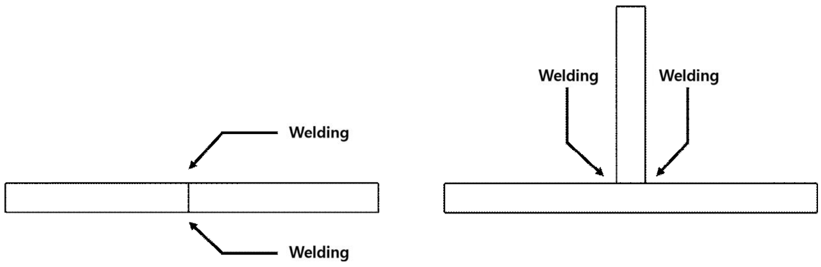

Fig. 11 BUTT / FILLET joint types

The first type is a butt joint where two members meet horizontally. Welding is performed at the front and the back of the member depending on the member thickness and welding type. The second type is a fillet joint where two members meet vertically. Welding is performed at both sides of the vertical shape.

In addition to joints of the simple shapes shown in Figure 11, there are many types of joints, as shown in Figure 12. The joint type should be accurately identified according to the adjoining shape of the members.

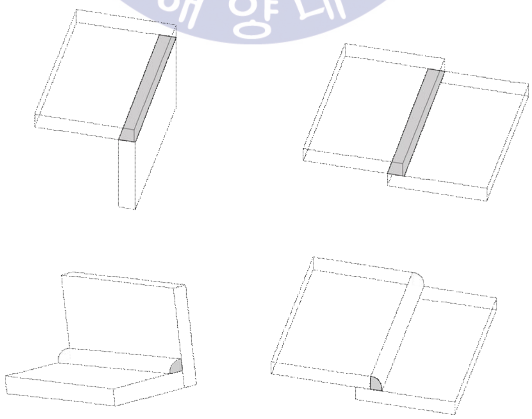

Fig. 12 Various joint types

The joint type is determined by the angle and position of two adjoining members. Since the joint type information is extensively used in the determination of welding type, welding posture, and assembly stages, it should be determined earlier than other information in the estimation of welding material quantity.

In the present study, the joint type is automatically determined by calculating the adjoining angle and position of two members from the geometric information.

5.4 Establishment of Assembly Stages

Assembly stages are classified by skilled shipbuilding workers according to the shipyard regulations. However, the assembly stages are automatically classified in the program developed in the present study, because the material quantity is estimated at a time point when the production information is not available yet. The constraint is that the classification should be performed according to the general regulations applied in shipyards.

It is critical to understand the assembly stages where individual members undergo welding. For example, a welding object may require different welding postures depending on the standard base plate for each assembly stage. In addition, the welding difficulty level may be changed by the block complexity depending on the assembly stage. Hence, it is very important to automatically classify the assembly stages according to the shipyard regulations.

The assembly stages are generally classified into the following six stages, as shown in Figure 13.

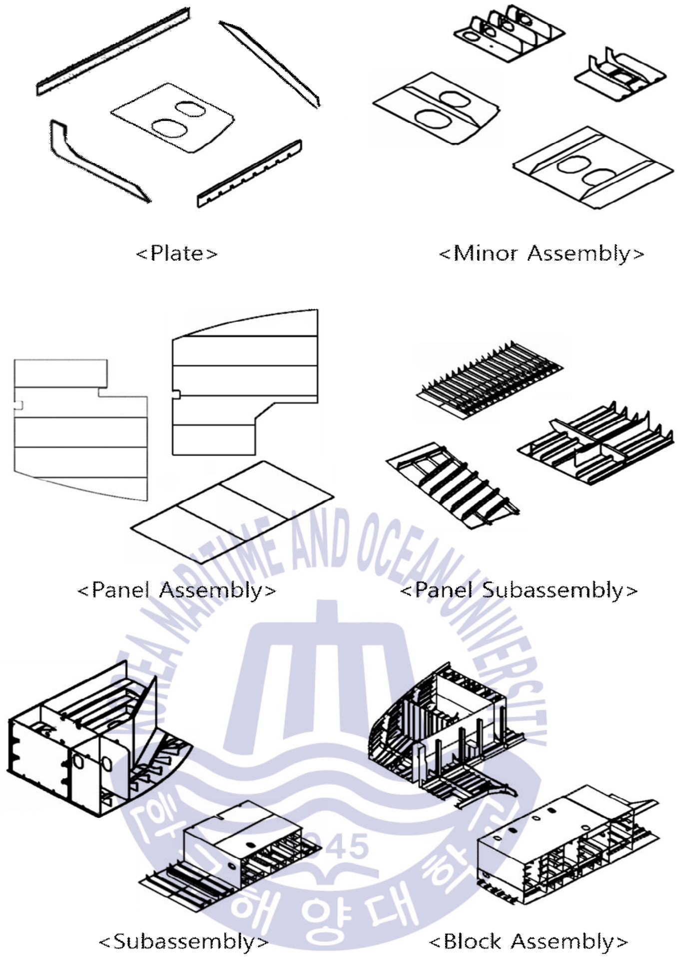

Fig. 13 Shape of structure for each assembly stage

For more accurate classification, assembly stages that may be easily determined and clarified are firstly classified. Firstly, the members for panel assembly are classified. The members for panel assembly have a welding seam of a specific length or longer and require a butt joint to connect the members. Then, members for intermediate assembly are classified. The members for intermediate assembly, which are the members connected with the panel assembly members, satisfy the welding seam length condition, require a fillet type joint, and have a height over a specific level. Subsequently, members satisfying specific size and weight conditions are classified as sub-assembly members. The intermediate assembly members are classified by considering the size and weight conditions as well as other conditions of individual members, panel members, panel intermediate assembly members, and sub-assembly members. All the finally classified members are included in the large-scale assembly members.

The important factors and constraints were established by referring to the design criteria of specific shipyards. The important factors and constraints may be adjusted according to the design criteria of each shipyard.

5.5 Determination of Welding Posture

Welding posture is a critical factor to the estimation of welding material quantity. Welding objects having the same welding length may have significantly different difficulty levels depending on the welding posture. A welding posture of a high work difficulty requires a skilled worker and longer welding time, affecting the final welding material quantity.

The welding posture is determined according to the welding posture determination criteria of the American Society of Mechanical Engineers (ASME), as shown in Figures 14 and 15 and Table 4. The welding posture is automatically determined on the basis of the base plate, welding seam axis angle, and welding plane angle of the assembly stage block to which a welding seam belong. For the geometric calculation of the angle between a base plate and a welding object, the information about the representative plane of a base plate and the representative line of a welding seam is extracted, and the angle between the plane and the line is automatically measured. The plate having the largest area among all the plates belonging to an activity unit is determined as the base plate, but a user may change the base plate manually.

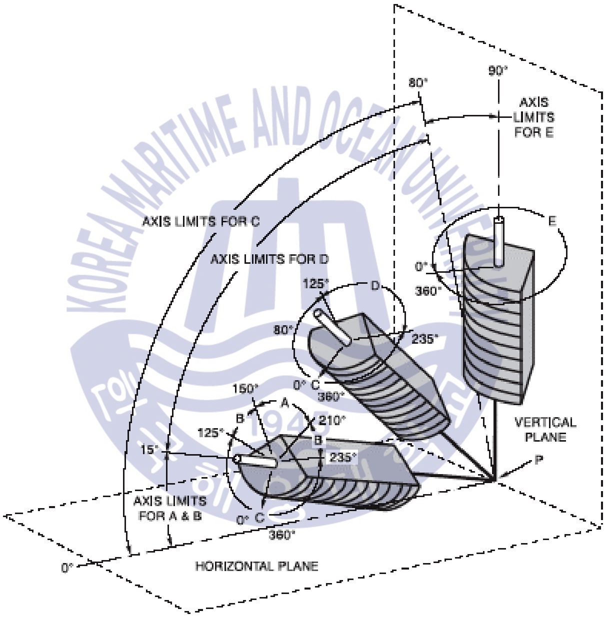

Fig. 14 Criteria for fillet joint welding posture

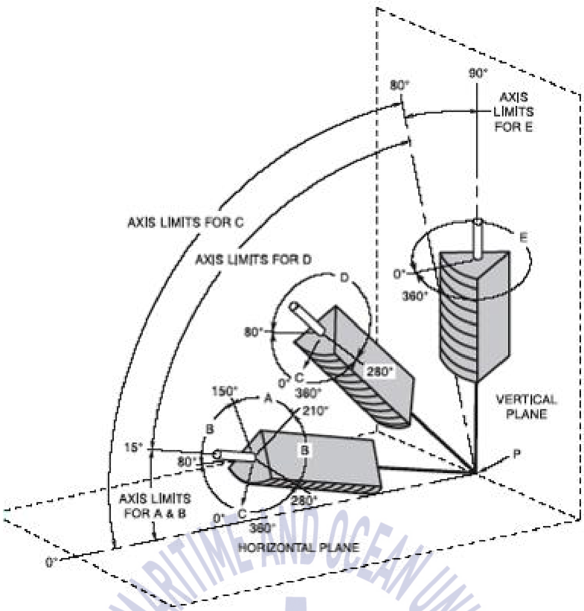

Fig. 15 Criteria for butt joint welding posture

Table 4 Criteria for welding posture classification

	Position	Inclination of Axis (degree)	Rotation of Face (degree)
Butt	Flat	0-15	150-210
	Horizontal	0-15	125-150 / 210-235
	Overhead	0-80	0-125 / 235-360
	Vertical	15-80 / 80-90	125-235 / 0-360
Fillet	Flat	0-15	150-210
	Horizontal	0-15	80-150 / 210-280
	Overhead	0-80	0-80 / 280-360
	Vertical	15-80 / 80-90	80-280 / 0-360

5.6 Calculation of Leg Length

As illustrated in Figure 16, a leg length refers to the length from the root of a fillet welding region to a horizontal or vertical end. The leg length is necessary to calculate the quantity of welding deposition. The leg length is calculated by considering the thickness and angle of two members included in a welding object.

```
if (_weld->GetJoint() == Joint::FILLET){
std::vector<Plate*> _connectedPlateList = _weld->GetConnectedPlateList();
float _legLength = 0;
if(_PlateList.at(0)->GetThickness() <= _PlateList.at(1)->GetThickness())
        _legLength = _connectedPlateList.at(0)->GetThickness() / 2;
else
        _legLength = _connectedPlateList.at(1)->GetThickness() / 2;
_weld->SetLegLength(_legLength);
}
```

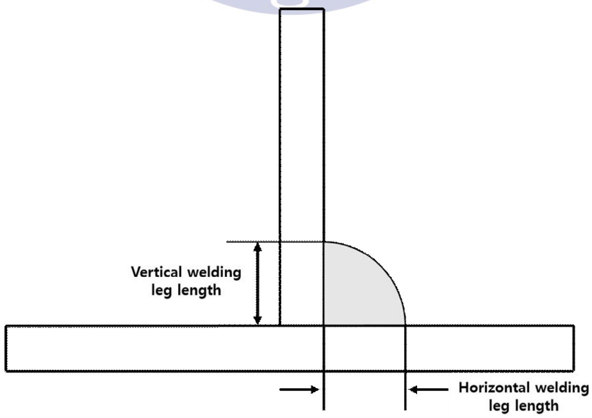

Fig. 16 Leg length

5.7 Determination of Welding Methods

Different shipyards may employ different welding methods depending on the properties of each welding method. Various welding methods are available as shown in Figure 17, but the welding methods currently used in shipyards may be generally classified into automatic welding and manual welding. Automatic welding is divided into submerged arc welding (SAW), flux asbestos backing (FAB), gravity welding, electrogas welding (EGW), manual welding.

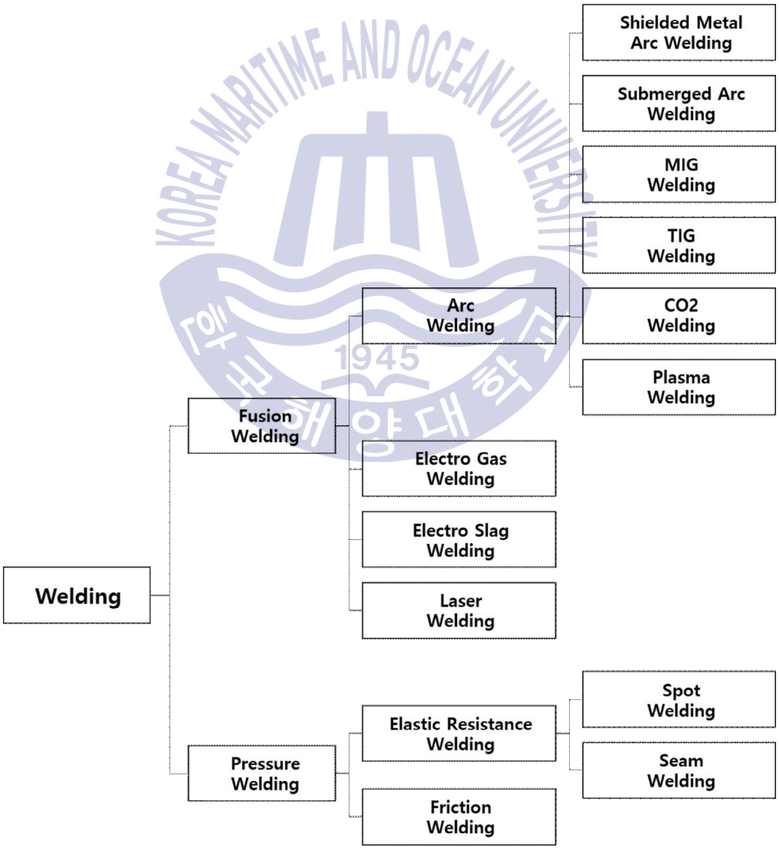

Fig. 17 Welding methods

In the present study, welding methods are determined with reference to joint type, welding length, assembly stage, and welding posture. For example, a welding work for the panel assembly with consecutive butt joints over a certain length is classified as automatic SAW. In other assembly stages, the welding work is classified as either FAB welding or gravity welding depending on the thickness and member size. If an automatic welding method is difficult to apply, the welding work is classified as manual welding.

5.8 Determination of bevel shape

Since an bevel shape of a butt joint is correlated with the quantity of welding deposition, an improve shape is important in the estimation of welding material quantity. Generally, an bevel shape is given according to the member thickness and welding type. In the present study, the I, V, Y, and X shapes shown in Figure 18 are given as an bevel shape on the basis of the member thickness and the applied welding method according to the work standards for shipyards.

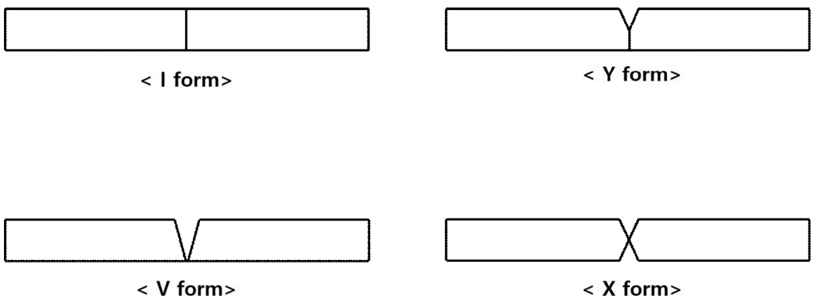

Fig. 18 Various bevel types

5.9 Calculation of Pass Number

A pass refers to one welding activity along a welding line or its trajectory. A single welding line may have significantly different welding material quantity depending on the pass number. The pass number is determined in the present study by considering either the thickness in the case of a butt joint or the leg length in the case of a fillet joint.

5.10 Estimation of Material Quantity

Final welding material quantity is calculated by multiplying the welding seam length by various numerical welding properties. The assembly stage, welding posture, welding method, and pass number were considered as the factors to work difficulty level and material quantity. The welding properties were quantified by considering the effect of each property on welding material quantity, and different weight factors were given to individual properties. Therefore, Q is considered as an index representing the welding material quantity.

$$Q = \sum_{k=1}^{N} L_k * P_k * (w_s)_k * (w_p)_k * (w_m)_k$$

N : *Number of welding*
Q : *Welding material quantity*
L : *Welding length*
P : *Number of pass*
w_s : *Stage of block*
w_p : *Welding position*
w_m : *Welding method*

Fig. 19 Equation for welding material quantity estimation

Chapter 6. Example

The welding material quantity for different blocks included in a same arc line were calculated and compared by using the program realized in the present study. The blocks were double bottom blocks of the central and the stern, and a fore section block of a 80,000 CBM LPG carrier (229.5 m length, 36.6 m breadth, 22.4 m depth).

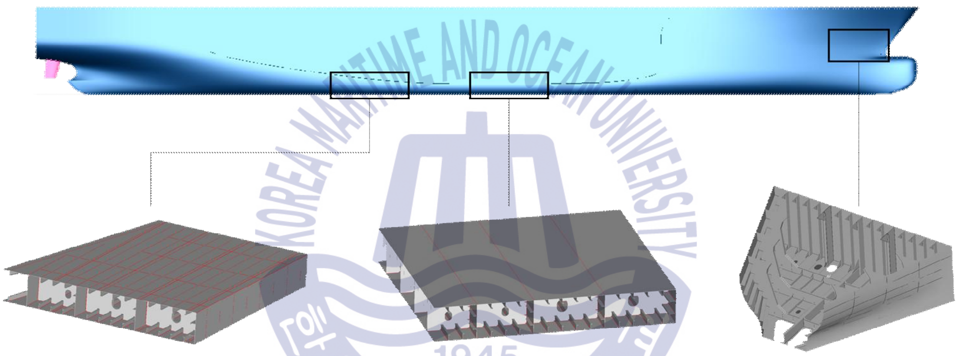

Fig. 20 Example blocks used for comparison

Table 5 compares the calculated major welding material quantity of the three blocks.

Table 5 Comparison of blocks of example

	Fore section	Midship section (port only)	Near-stern section (port only)
Number of Plates (ea)	162	158	122
Length (m)	9.515	13,600	13,252
Width (m)	13.404	12,805	12,805
Height (m)	5.011	2,215	2,215
Weight (ton)	39.33	82.33	69.44
Welding length (m)	469.662	927.447	728.694
Welding quantity index	1487.95	1590.29	1232.62

The size of the stern block was not significantly different from that of the mid-ship block, but the total number of member of the stern block was 122, which was smaller than that of the mid-ship block by 36, because the hull width was decreased in the direction of the stern. The welding length was also decreased in proportion to the number of members. The estimated welding material quantity was also less in the stern block than in the mid-ship block.

The number of members constituting the fore section block was 162, which was similar to the member number of the mid-ship block. However, the weight and the welding length of the bow stern block were smaller due to the structural properties. As a result, the welding material quantity of the bow block was slightly less than that of the mid-ship block and significantly more than that of the stern block. The welding material quantity of the bow block was greater because the welding difficulty level was higher due to the complex curve shape of the bow block in comparison with the two double bottom blocks.

Chapter 7. Conclusions

In the present study, the welding material quantity estimation process using 3D shape information was investigated for the early estimation of welding material quantity in the absence of production information. Since pure shape information does not include production information, the member properties and the welding seam information should be estimated on the basis of the input shape information. The program developed in the present study may be used to estimate the welding man hour for specific blocks for the early estimation of welding material quantity in scheduling and simulation.

The results from the program developed in the present study are useful to provide a relative index in comparison with the unit cost of other members or blocks, rather than calculating accurate welding material quantity. For more accurate estimation of welding material quantity information, accurate shape information is necessary, and various determinations should be made according to the conditions of individual shipyards.

The welding material quantity was estimated in the present study with respect to a single block. Further studies will be conducted for simultaneous welding material quantity estimation of many blocks and the consideration of workload variation due to pending of welding work.

Acknowledgement

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