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A Virtual Erection Simulation System for a Steel Structure Based on 3-D Measurement Data

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Abstract: The virtual erection simulation system was explained for a steel structure including ship and ocean plant blocks. The simulation system predicted the erection state to optimize any gap or overlap of blocks based on 3-D measurement data. The blocks were modified (cut) on the basis of the simulation result on the ground before erecting them by crane. The re-cutting process was not required and the blocks were erected into a mother ship speedily. Therefore, the erection time is reduced, increasing the dock turnover.
Keywords: block erection; dimensional accuracy control of ship block; production planning and scheduling; ship construction; virtual simulation system; steel structure
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1 Introduction

In the modular construction of ships, significant productivity losses can occur during the erection stage when the modules or hull blocks are joined together. Frequently, adjacent blocks do not fit together properly, and reworking of one or both of the mating block interfaces is necessary to correct the problem.

The specific cause of reworking is the variation of plate edges at the block interface which is itself a cumulative product of numerous manufacturing variations inherent in hull block construction (Storch and Giesy, 1987).

Table 1 shows the cause of block deformation.

Table 1 The cause of block deformation

Stage	The cause of deformation
Cutting	- Falling-off in the accuracy of marking - Falling-off in the accuracy of cutting machine
Forming	- Falling-off in the accuracy of forming by heating and cooling process
Welding	- Transverse shrinkage - Longitudinal shrinkage - Angular distortion
Etc.	- Deformation caused by self-weight - Deformation caused by crane lifting

In recent years, the size of hull blocks has become larger and larger to reduce the erection time. Some Korean shipyards erect great block using a crane vessel as seen in Fig.1.

Fig.1 The block erection using crane vessel

As the size of block is larger, these misalignment problems of adjacent blocks become more critical.

Fig.2 shows the misalignment problems of adjacent blocks.

Fig.2 The misalignment problems of adjacent blocks in the erection stage

Many pipes and structures were fitted to the blocks and they were modified painted before the erection stage. The modification of a block in the erection stage causes additional work such as modification of pipes and structures as well as re-painting. It also requires additional crane usage and modification of all kinds of equipment for erection. Consequently, the construction cost and term are increased.

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2 Reworking in the erection stage due to misalignment problem

The deformation of blocks cause the misalignment in the erection stage as seen in Fig.2. There are several kinds of misalignment problems. One critical problem is the misalignment of the hull. While the misalignment problem of outfitting can be solved by the adjustable pipe relatively easily, fixing the hull problem is not easy. Once the hull misalignment problem occurs, it can be solved by cutting, built-up welding, and heating. A lot of time and cost is spent. Figs.3, 4 and 5 show the modifying process of a deformed hull.

Fig.3 Line heating for modification of hull to close a gap between adjacent blocks

Fig.4 Cutting the inner parts for closing a gap between upper block and bottom block

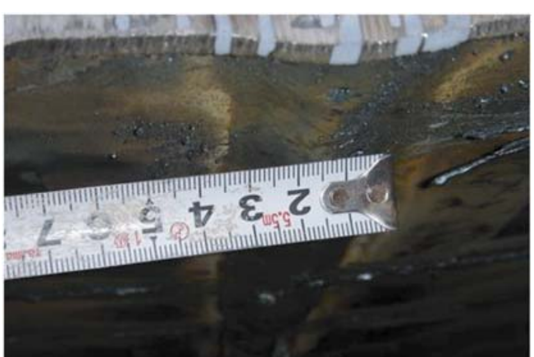

Fig.5 Built-up a gap (30mm) between adjacent blocks

The second problem is the misalignment of outfitting. As mentioned above, this problem can be solved easily compared with a hull problem.

Due to these problems, the procedure of erection is as follows.

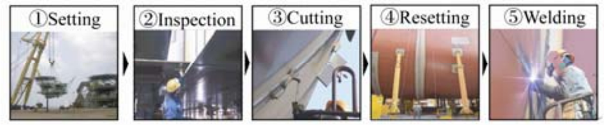

Fig.6 The procedure of erection not applying the virtual erection simulation

Fig.6 shows the procedure of erection which does not apply to virtual erection simulation.

First, a pre-erection block is set by the crane, and the gap or overlap between adjacent blocks is inspected. Next, the hull which will be overlapped is cut with the adjacent hull and re-set. Procedures ②–④ are repeated until the blocks fit. Then, the blocks are welded. In the procedure, the crane is not available to be used in other work and it is hard to cut the hull when the blocks are interlocked. Therefore, much time is spent.

3 The existing study for improving accuracy of block assembly and block erection for shipbuilding

Block erection is the core process for ship construction, and it is closely related with results from pre-stages. Existing research was conducted in various directions concerning the problem occurring in the erection stage caused by errors from steel cutting, fabrication, welding, and block movement. The research is categorized into two groups. One is the active approach and the other is the adaptive approach.

3.1 Active approach

The active approach serves the purpose of preventing the deformation in advance. The research for minimizing the weld deformation was conducted by several scientists. Ueda and Mashaiov studied about the prediction of the weld deformation on simple structures based on numerical methods or test results (Ueda *et al*., 1992; Moshaiov and Song, 1991). Also, Okumoto conducted research on rationalization of the production process through the block assembly accuracy control (Yuuzaki and Okumato, 1992). Nomoto did the basic research on accuracy control systems for block assembly and erection based on the prediction of deformation caused by welding (Nomoto *et al*., 1997).

Also, studies for minimizing the steel cutting and steel forming errors were conducted along with the study of forecasting the welding deformation.

Existing research was concentrated on the active approach such as preventing the block deformation in advance or controlling the block deformation directly. However, it is hard to predict and control the block deformation because the ship blocks are mostly complex structures. Therefore, to control block accuracy, workers' experience and manual techniques are still relied upon in the yard. On the contrary, this can hardly satisfy the requirements of the adaptive approach such as finding the best condition of an erection block which is already deformed.

3.2 Adaptive approach

An adaptive approach is used to modify the block for optimal assembly or erection after the block deformation. The adaptive approach is simpler than the active approach, so it has a high probability of being applied to actual production. The most common way of controlling block deformation is based on measurement information of structures. This way was applied often in shipyards in the past. However, the measurement technique lagged behind, and accuracy also was poor. Recently, a highly accurate 3-D measurement technique has been developed, and though it is on a basic level, the research based on this method has been developed gradually. Steven D. Hand studied 3-D measurement of a hull curve using a coherent laser radar (CLR) scanning system (Hand *et al*., 2004). Michael Goldan did research on applying a photogrammetry system to ship repair as shown in Fig.7 (Goldan and Kroon, 2003).

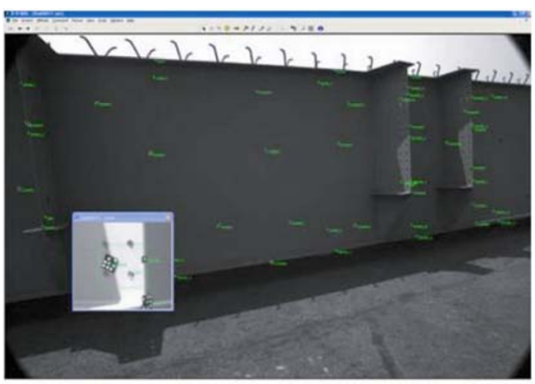

Fig.7 The measurement of steel structure by the photogrammetry

4 The virtual erection simulation method for predicting the erection state to find any gap or overlap of blocks based on 3-D measurement data

4.1 The procedure of erection applied the virtual erection simulation

Fig.8 shows the procedure of erection application to the virtual erection simulation. First, the block and virtual erection simulation are measured using a 3-D design model and 3-D measurement data. The amount of gaps or overlaps between adjacent hulls is computed and the position of erection block is also computed. Next, the hull is cut as the computed data. Finally, the blocks are joined and welded. Procedures ②–④ of Fig.6 are not repeated in this method. The block is erected at a certain time in the dock. The cutting is also carried out on the ground, making it very simple and quick. This method is called the onetime setting method in Korean shipyards.

This paper explains the virtual erection simulation method and system for the onetime setting.

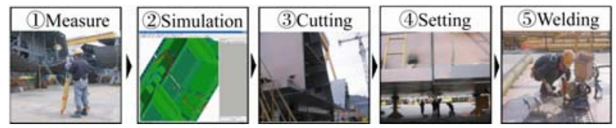

Fig.8 The procedure of erection applying the virtual erection simulation

This method has following effects.

- Eliminates the need for resetting
- Reduces the cutting time
- Reduces the setting time
- Reduces the time of crane usage
- Increases the usage of automatic welding machines

4.2 The 3-D measurement method for measuring a great steel structure

The erection simulation presented in this paper is performed based on 3-D measurement data, so the block measurement technique is very important. The accuracy and time required to measure blocks are the most important factors.

3-D measurement techniques are divided into several types depending on the measurement purpose, measurement range, and measurement methods. Ship blocks are huge and require high accuracy, so it is necessary to pay much attention in choosing the measurement system. The size of the block for the measurement is about 10–80 m, and the required block tolerance is generally ± 5 mm. Since techniques for measuring a large scale structure have been developed in civil engineering fields, the techniques used for civil engineering are often applied to measure large scale blocks for ship construction. Measurement techniques normally used for ship building are a total station, photogrammetry system, and laser scanning system.

A total station has outstanding performance in data processing, and it is more accurate than theodolite which is used for a construction survey, so a total station is widely used for ship building and steel bridge assembly.

A total station shoots a laser beam (Fig.10) to the target (Fig.9) to obtain the values of the horizontal angle, vertical angle, and the distance between the positions of total station standing and measurement targets. Then it calculates 3-D coordinates using that data (horizontal angle, vertical angle, and distance).

Fig.9 Put the sheet target for measurement by total station on the ship block

Fig.10 The measurement of ship block by the total station

Measurement techniques using the total station method have problems in measuring all parts of the block complicatedly welded with many steel plates in limited places within a limited time. However, they cost less than the photogrammetry system and laser scanning system, and represent a proven technique from civil engineering fields. Therefore, shipyards have adopted this technique for measurement.

The photogrammetry system attaches the various types of targets to the structure and takes photos to be overlapped from various angles for 3-D positional measurement. The principle of the photogrammetry system is “Triangulation”. After taking more than 2 photos from different directions, two different 2-D images are composed to calculate 3-D coordinates. The V-STARS System from the Geodetic System in U.S.A and the AICON 3-D Studio from AICON in Germany are the commonly used photogrammetry systems.

The following is the example to explain features of the photogrammetry system using the V-STARS system.

It takes 20–30 minutes from the time for attaching targets to the time for measuring blocks when measuring a 10 m object. The accuracy is 0.055 m. It takes 10 minutes to get 3-D coordinates through 2-D images. Measurement can be done in a short time. However, the photogrammetry system is limited to use in a sunny spot, and it is not possible to know the analysis measurement result right away. Therefore, it applies to few parts of ship construction such as special ships like submarines, and it is not possible to use it generally in most ship yards.

Fig.11 The measurement by photogrammetry system

The laser scanning system does not need targets for the measurement unlike other existing measurement techniques. It shoots about 1000 laser points per second at the intervals of 0.5 mm to the structure, and calculates 3-D coordinates through this reflective wave. In other words, this creates a point cloud of the structure.

Fig.12 shows the measurement of a ship block by the laser scanner.

Fig.12 The measurement of ship block by the laser scanner

The existing measurement techniques are affected by worker’s skill and decisions, whereas the laser scanning system is able to measure a wide range of area accurately without any human intervention.

The typically used laser scanning system is the FARO LS series from FARO Technologies in Germany and Leica Geosystems' HDS Series. The accuracy of the HDS system is 1–15 mm when measuring the object within an area 25–50 m.

The laser scanning system is very fast for measuring structures compared with any other measurement system, and users can also obtain a large volume of data. However, it is generally less accurate than other measurement techniques. However, considering the fact that laser scanning systems have been commercialized since the late 1990s, better accuracy is expected in the future. This system has a high probability for application in shipyards and a lot of work need to be done in a short time.

4.3 Develop the virtual erection simulation software

The simulation software was developed for performing the virtual erection simulation as seen in Fig.18 in this study. The simulation software requires the following functions:

- Interface with 3-D measurement equipment
- Interface with the 3-D CAD system
- Visualize the 3-D CAD and measurement data
- Fitting the 3-D CAD data and measurement data
- Move and rotate the data in the 3-D virtual space
- Analyze the gaps and overlap of adjacent blocks
- Analyze the position of the erection block
- Draw and plot the resulting report

4.3.1 Interface with 3-D measurement equipment

The measurement software was developed in this research separately. It runs on a PDA (Personal Digital Assistant) and is able to interface with the total station (SOKKIA SET series, SOKKIA NET series). The measurement software communicates with the total station through RS-232C or Bluetooth. The software sends the command to the total station and receives the measured data.

The measurement software stores the measured data into the PDA storage as text file. The analysis software obtains the measurement data from the PDA storage. Fig.13 shows the format of measured data. The data consists of the index and *x*, *y*, *z* coordinates.

```
1,19255.000000,1032.979614,-5.001293
2,19272.000000,1881.182373,0.117515
3,19265.000000,4239.911133,622.473389
4,19275.000000,5331.891602,1921.995239
5,19264.000000,11.998397,-8.001293
6,19285.000000,-1061.017822,-0.001293
7,19272.000000,-1918.093872,0.271590
```

Fig.13 The sample of measurement data

4.3.2 Interface with 3-D CAD system

The 3-D CAD data is not used for analysis. It is only reference data. If the measurement data is only visualized without the 3-D CAD data as seen in Fig.14, the workers cannot know which part the measurement point on. Therefore, the 3-D measurement data must be visualized with 3-D CAD data as seen in Fig.15.

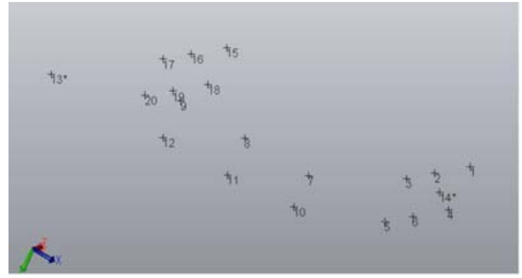

Fig.14 Measurement data was visualized without 3-D CAD data

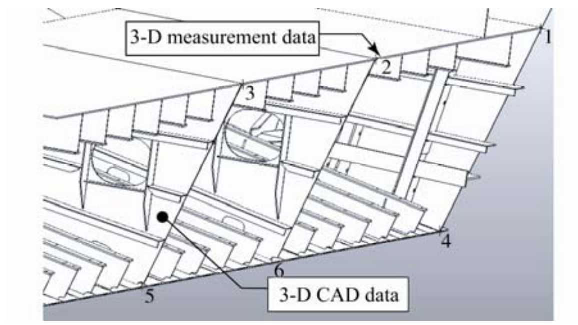

Fig.15 Measurement data was visualized with 3-D CAD data

Several CAD systems are used for ship design. For example, Tribon, Aveva-Marine, Smart-Marine, Ship-Constructor, and Foran. The virtual erection software was developed to import DXF, IGES, and SAT files for compatibility with the 3-D CAD system.

4.3.3 Visualize the 3-D CAD and measurement data

The virtual erection software visualizes the CAD, measurement, and analysis data as 3-D. The workers can easily rotate, zoom, and pan the 3-D data on the screen using a mouse. This allows for improvement in the analysis efficiency. The erection block consists of 2–10 unit blocks. In case of Korean shipyards, the mega-blocks or tera-blocks are made for erection. Those blocks can consist of about 8–12 unit blocks. The 3-D CAD model of those blocks is very heavy. The simulation software must visualize rapidly.

4.3.4 Move and rotate the data in the 3-D virtual space

Generally, the block is moved nearby a mother ship by crane and the position of the block is accurately adjusted by a hydraulic jockey.

Fig.16 shows the block is adjusted by hydraulic jockey.

Fig.16 The hydraulic jockey was installed on the block to adjust the position of block in detail

The simulation software can adjust the block accurately. The developed software has some functions for adjusting the block.

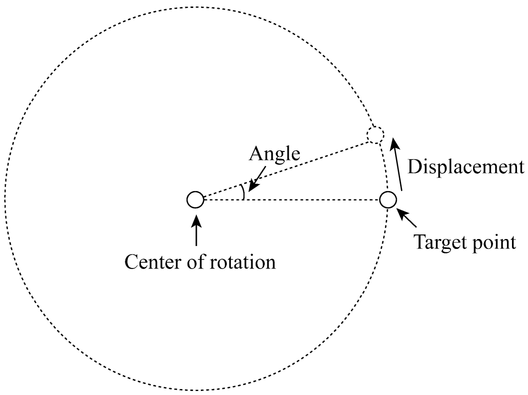

Fig.17 The simulation software to rotate a block by the center of rotation and the displacement of target point

In particular, the simulation software can rotate the block by the rotation center and the displacement of the target point as seen in Fig.17. General CAD systems rotate the object by the rotation center and angle. The blocks must be adjusted accurately because the block should be moved or rotated to keep the gap at about 0–10 mm.

4.3.5 Analysis of the gaps and overlap of adjacent blocks
The amount of gaps or overlaps is computed as the difference between the coordinates of adjacent measurement points. The software finds the adjacent pair measurement point automatically by the distance of measurement points. A pair measurement point has a relationship. Also, the relationship can be set manually. The relationship has several properties, including the direction of connection and calculation method. The software computes the amount with reference to the relationship as in Fig.18.

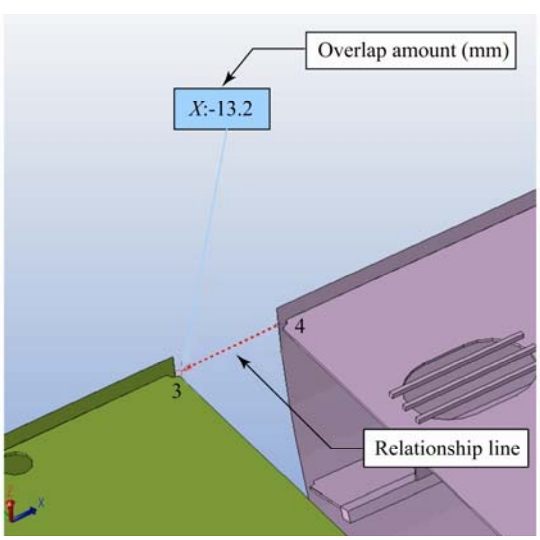

Fig.18 The relationship line and the overlap amount

4.3.6 Draw and plot the result report
When the analysis is finished, the workers make the result report. It is called the final sheet in Korean shipyards. The number of gaps and overlaps are presented on the final sheet. The workers cut and modify the hull by the final sheet. The developed software has the ability to construct the final report easily.

5 Full-scale experiments

Full-scale experiments were carried out to verify the suggested method and system. The two side blocks of a bulker carrier were used for these experiments.

Table 2 shows the condition of blocks for the experiments.

Table 2 The condition of blocks for experiment

Item	Value
Ship type	Bulker carrier
Ship DWT	30000
Block type	Side block
Block length/m	20
Block breadth/m	4
Block height/m	14

A 110-point block was measured by total station. Table 3 shows the measurement time. Fig.19 shows the block used for the experiment.

Table 3 The measurement time

Block name	Prepare time for measurement	Measurement time
S13P	20 min×1 person (0.3 Man-hour)	35 min×2 person (1.16 Man-hour)
S14P	15 min×1 person (0.25 Man-hour)	30 min×2 person (1Man-hour)

Fig.19 The block used for the experiment

Fig.20 shows the image of virtual erection simulation in the developed software. The number of gaps or overlaps was presented on the screen.

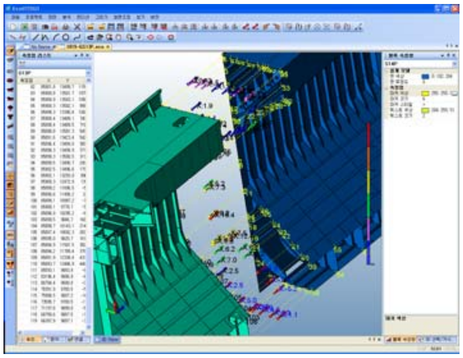

Fig.20 The virtual erection simulation using developed software

Fig.21 The blocks were erected at a time after simulation and cutting the blocks

The blocks were modified (cut) on the basis of the simulation result. Then, the blocks were joined as seen in Fig.21.

The gaps of all parts were kept to 2–3 mm. The blocks were welded by the automatic welding equipment rapidly. The virtual simulation and welding process were carried out successfully and rapidly.

Table 4 shows the result of this experiment. The erection time (setting time and re-cutting time) was reduced compared to previous method. Setting time was reduced and re-cutting time was not required.

Table 4 The result of the experiment

Whether the simulation was applied	Setting time/h	Re-cutting time/h
Not applied	2	1.5
Applied	1.8	0

6 Conclusions

The following conclusions were obtained with this study.

• The 3-D virtual erection simulation method suggested in this paper can be the method to solve the problems which were caused by the block deformation in the assembly and erection stage.

• For the development of virtual erection simulation software, 3-D measurement techniques, interface techniques with the 3-D CAD system, 3-D visualization techniques, and 3-D geometric techniques were required.

• The method suggested in this paper can be applied to constructing steel bridges, buildings, and plants.

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