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HYDRAULIC SYSTEM DESIGN AND STRUCTURAL ANALYSIS OF A BOP GANTRY CRANE

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Key words: offshore structure, drillship, gantry crane, blow-out preventer (BOP).

ABSTRACT

A blowout preventer (BOP) gantry crane is an offshore plant that moves a BOP stack located on a drilling platform to a BOP trolley. However, such a plant has yet to be developed in Korea. Because BOP gantry cranes produced overseas are expensive, developing such cranes domestically is imperative. In this study, ANSYS was used to conduct a structural analysis on a BOP gantry crane model to simulate the roll and pitch motions of a drillship that were induced by waves and wind load as well as the weight of the crane. Moreover, Simulation X was used for implementing control-system and subsystem designs and to analyze a hydraulic system.

I. INTRODUCTION

Oil and natural gas, the most convenient and high-quality natural resources, have been used extensively. Drilling for oil in the United States began in 1859, and it is now possible to drill an underwater well to a depth of more than 3000 m; in addition, underwater wells can be drilled at extremely low temperatures and in other harsh environments (Hong, 2007).

Structures used for mining crude oil, natural gas, or other energy sources in deep-sea areas are considerablyinfluenced by environmental conditions such as wind, tide, temperature, and waves. Offshore plants are divided into floating and fixed types depending on the environmental conditions (Kim and Kang, 2011; Hwang et al., 2013).

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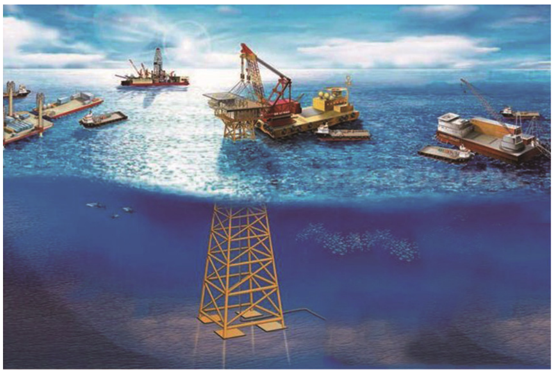


Fig. 1. Floating type offshore plant.

Fig. 1 shows a floating-type offshore plant (Subsea world news, 2014) comprising a tension-leg platform, floating production storage and offloading unit, drillship, spar platform, and drilling rig. Crude oil obtained by an offshore plant is transported to land through a subsea pipeline or tanker and is supplied to consumers after its refinement (Uueoka and Sato, 2000; Zueck, 2000).

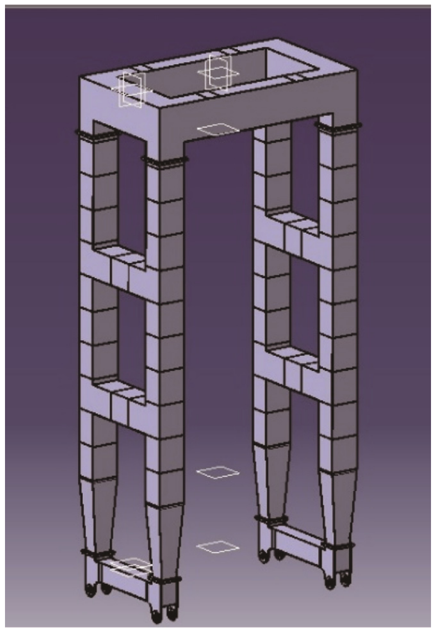
Thus far, the global market for subsea offshore equipment has been dominated by a small number of major international corporations such as Chevron (United States); Total (France); and British Petroleum and Shell (United Kingdom).

In Korea, shipbuilding equipment vendors have attempted to develop the offshore industry; however, because of a lack of basic design skills and the passive attitude of shipowners in the marine sector, only a few equipment vendors have succeeded. In addition, the localization of offshore equipment for shipbuilding trails by 30%, and the skills required for product development are insufficient (Lee, 2013).

Currently, up to 55-ton level blowout preventer (BOP) gantry cranes (main hoist: 275 mT × 2) are being commercialized by overseas professional manufacturers such as Protea in Poland. Moreover, such offshore plant equipment has yet to be developed in Korea. The overseas production of a BOP gantry crane is expensive; therefore, its domestic production is necessary (Jung et al., 2011).

Fig. 2. Drilling system package.

(a) Photograph of crane made in Protia



(b) Computer Aided Three-dimensional Interactive Application (CATIA) model

Fig. 3. Model of BOP gantry crane.

Because of the development of the offshore plant market, the market for offshore equipment is expected to expand. However, only a few Korean companies manufacture a portion of products. Therefore, improving Korean technology by manufacturing domestic offshore plant equipment is imperative.

BOP gantry cranes are essential equipment in the drilling system package of a drillship/rig. A BOP gantry crane is a crane used for moving a BOP stack located on a drilling platform to a BOP trolley. The BOP stack is a safety device that controls mining by the drillship to prevent oil, gas, or water from gushing out of the ocean oil well (Bliyard, 1987).

Fig. 2 shows the structure of drillship equipment. The BOP gantry crane is installed at the end of the drill floor on the upper side of the moon pool of a drillship. It alternates on a rail in the port-starboard direction.

In the current study, ANSYS was used to analyze the roll and pitch motions of a drillship that are induced by waves, wind, and crane weight, and a structural analysis was executed. Moreover, Simulation X was used for control-system and subsystem designs and for hydraulic system analysis. To design a domestic BOP gantry crane, Simulation X was used for conducting a pressure system analysis, and Sand ANSYS was used for deriving the optimal crane design and for executing the structural analysis.

II. STRUCTURE AND ANALYSIS CONDITION

1. Hydraulic System and Structure Analysis Boundary Condition

Marine-system design and problem analysis are based on the complexity of marine systems. Therefore, complex analysis problems can be solved by developing a system including only essential elements.

When the target is excessively large and has several related factors in the environment to be considered, creating a simulation system similar to the actual system is required. Therefore, simulations must be performed according to an identified phenomenon by analyzing marine environment and model data.

Fig. 3(b) shows a CATIA model of a BOP gantry crane. A BOP gantry crane resembles a door or a bridge, and it comprises a jib, trolley, and hoist. The bottom of the crane is equipped with a rail on which the crane moves (Shin et al., 2011).

Extreme desing motions (single amplitude)			
Roll (Degrees)		Pitch (Degrees)	
13		8	
Extreme accelerations at process deck (process deck, 35.4 m above base line)			
	ax	ay	az
	Hor. Longitudinal [m/s^2]	Hor. Transverse [m/s^2]	Vertical [m/s^2]
Ap (x = 0)	1.2	3.1	3.6
COG (x = 137.0)	1.2	3.1	1.5
FP (x = 277.6)	1.2	3.1	4.5
Extreme accelerations at specified points at Centre line			
FlareL (EL = 35.4)	1.0	3.0	3.0
FlareM (EL = 100.4)	2.8	4.7	3.3
FlareT (EL = 165.4)	4.5	6.4	3.6

Fig. 4. Roll and pitch degrees of a drillship.

Table 1. Onboard lift dynamic coefficient.

Crane Mount on	Dynamic Coefficient C_v
Fixed Structure	1.33
Spar	1.33 + 0.003 × *Hsig* ≥ 1.4
Semisubmersible	1.33 + 0.0007 × *Hsig* × *Hsig* ≥ 1.4
Drillship, FPSO	1.33 + 0.0012 × *Hsig* × *Hsig* ≥ 1.4
Hsig : sea significant wave height for the load chart in question (ft)	

The crane used in this study weighs 300 ton, is 25 m high, and has a plate thickness of 16-20 mm. Because this crane may buckle because of the small plate area structure compared with the overall length, a stiffener was designed. Unnecessary parts were eliminated to observe the structural change when subjected to a load, and the model was simplified. A crash test was conducted to confirm whether a conflict or gap existed in the CATIA model among the stiffener, crane plate, and various design parts.

2. Application Condition of Dynamic Figures

Because a BOP gantry crane operates on a drillship/rig, a dynamic coefficient should be applied to the operating weight to reflect the continuous movement of the drillship (Lee et al., 2011).

$$C_v = 1 + V_r \times \sqrt{\frac{K}{g \times \mathrm{SWL}}} \tag{1}$$

Eq. (1) is a general equation used to derive a dynamic coefficient when no other dynamic coefficient is assigned (Son and kim, 2012). Here, C_v is the dynamic coefficient and V_r is the hoisting speed (Lee et al., 2000). The equation for deriving other dynamic coefficients depends on the offshore plant structure (Table 1) on which the crane is mounted. A dynamic coefficient of 1.6 is applied according to the drillship in Table 1.

3. Application Scheme for BOP Gantry Crane Rolling and Pitching

Because a BOP gantry crane operates on a drillship/rig, the drillship motion, such as roll and pitch motions, should be included in the analysis (Hwang et al., 2013). Fig. 4 illustrates the roll and pitch values of the drillship derived according to its height. A FlareL (EL = 35.4) value is used to the analyze roll and pitch motions.

4. Wind Load Application Scheme of a BOP Gantry Crane

Wind load directly exerts a force on the offshore topside. First, when the wind load was applied from the front, the structural analysis was conducted for investigating the effect of this load on the structure (Randel, 2007).

Eq. (2) can be used to calculate wind load. Wind load refers to the load exerted on a structure when hit by wind. Because BOP gantry cranes are used at sea, a maximum wind speed of 72 km/h was applied (Andrzej et al., 2010).

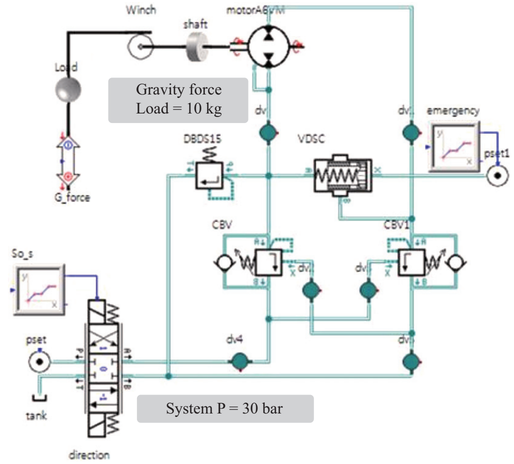
$$F = 0.0473 * Vz^2 * Cs * A \tag{2}$$

According to (2), if the load on a BOP gantry crane is F, the wind load can be calculated as shown in (3).

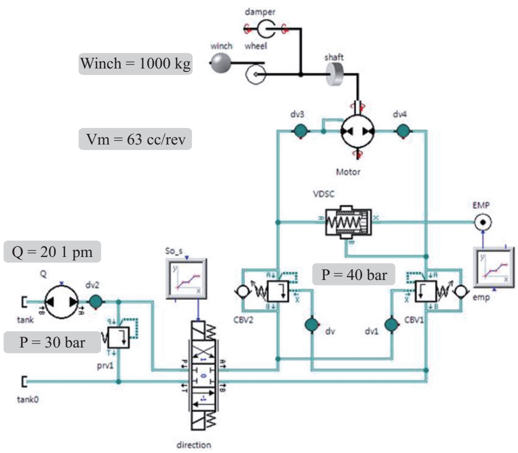
$$F = 0.0473 * (72\ \mathrm{km/h})^2 * 1 * (69.725 * 10^{-6})\mathrm{km}^2 = 17.1\ \mathrm{N} \tag{3}$$

5. Outline of BOP Gantry Crane Hydraulic System

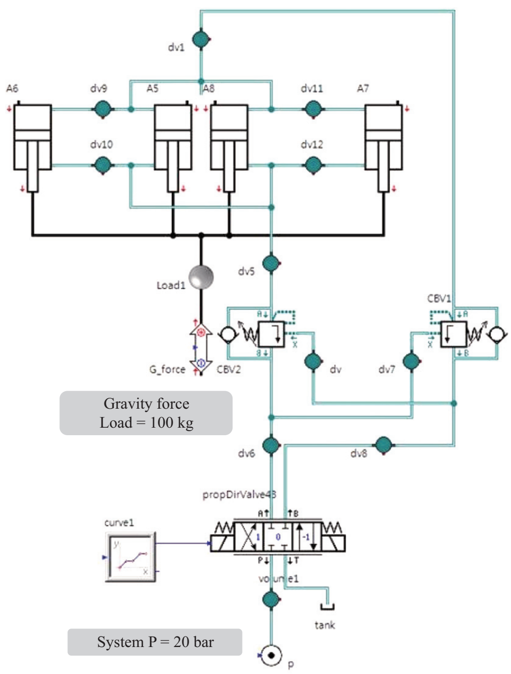
The hydraulic system of a BOP gantry crane involves a main winch, aux winch, winch trolley, and stack device (Yoon and Jang, 2012). In the current study, a submodel was implemented; such a model is generally developed for reviewing the appropriateness of circuit logic before modeling the overall circuit. In the implemented submodel, the aux winch, winch trolley, and stack device are structured as a circuit. Fig. 5 illustrates a subcircuit model.



(a) Aux winch



(b) Winch trolly



(c) Stack device

Fig. 5. Subcircuit model of a BOP gantry crane.

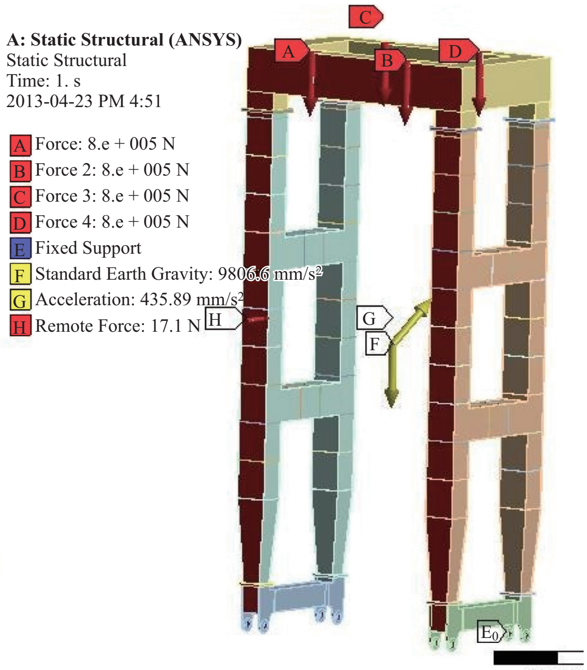


Fig. 6. Boundary condition of a BOP gantry crane.

Fig. 5(a) shows an aux winch comprising a hydraulic motor, winch, brake valve, counterbalance valve, shuttle valve, puppet valve, and brake valve. The external brake was removed from the model.

The ratio of the counterbalance valve to the external pilot valve was set to 4:1, and the pressure was set to 50 bar.

Fig. 5(b) illustrates a winch trolley containing a hydraulic motor, puppet valve, counterbalance valve, shuttle valve, and external brake. Damping of the rotating axis was considered. A 100-kg winch, 30-bar circuit supply pressure, 40-bar counterbalance, and 63-cc/rev motor were used. Fig. 5(c) shows a stack device comprising four hydraulic cylinders and a counterbalance valve. It was set to a maximum supply pressure of 20 bar and load of 100 kg. Moreover, the cylinder was installed vertically considering the gravity of the stack device.

6. Boundary Condition of Structure Analysis

Simulations must be conducted according to an environmental condition by analyzing marine environment and model data. Severe economic losses and casualties occur if the environmental effect is insufficient (Lee, 2013).

Fig. 6 shows the boundary conditions applied to the crane. A hex-dominant mesh was applied, and 119,408 elements and approximately 451,839 nodes were produced. A total of 84 contact regions were created when connection parts of each structure and supplementary material bonded. To apply a 200-ton operating load, a load of 320 ton (with a dynamic factor of 1.6) was applied, with 80 ton applied for each of the A, B, C, and D parts in the main winch. To apply a crane-weight F, standard earth gravity was applied in the −Z direction.

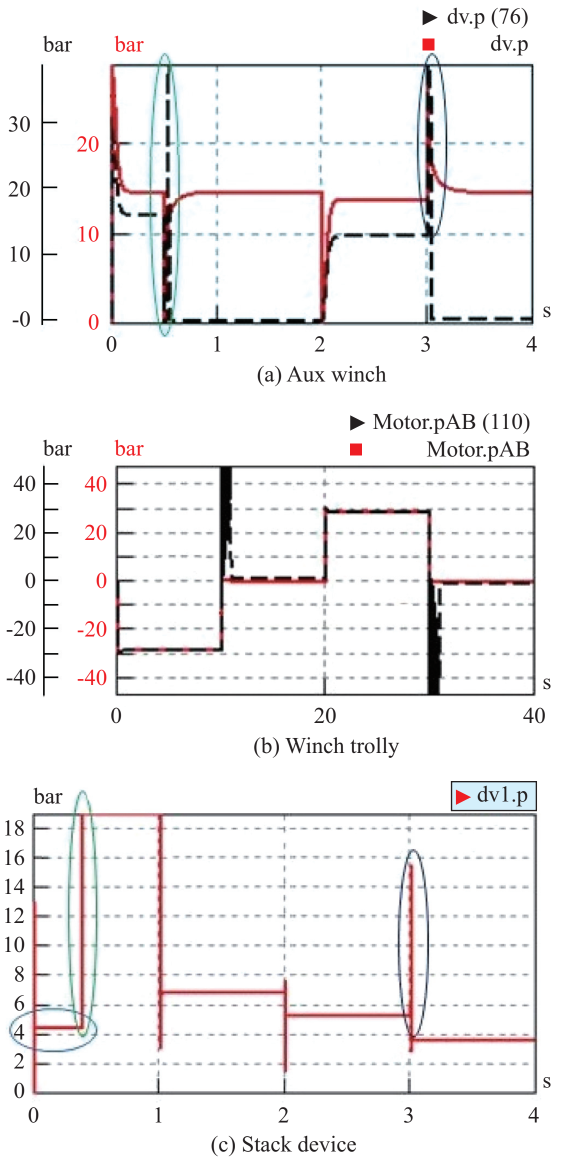


Fig. 7. Analysis results of a hydraulic circuit submodel.

To apply a maximum load on the structure according to the roll or pitch motion of the drillship, an acceleration of 435.89 mm/s^2 was applied to G in ax, ay, and –az (opposite gravity direction) directions. The wind load H exerted on the drillship in the Y direction was 17.1 N, and this value was calculated based on the wind load formula. A pin hole part at the bottom of the crane and E were connected with a traveling device that moved with the rail; therefore, a fixed support was applied.

III. ANALYSIS RESULTS

1. Analysis Condition and Results of a Hydraulic Circuit System Submodel

Fig. 7 illustrates the analysis results of a hydraulic circuit submodel.

A crane hydraulic system was used to develop a BOP gantry crane analysis model and the movements of the stack device, aux winch, and winch trolley system were realized.

Fig. 7(a) indicates that considerable time is required to stop the load on the aux winch if the safety valve is used; however, the difference can be neglected. The black dotted line represents the analysis results when the safety valve was not used, and the red line represents the graph produced when the safety valve was used. Countertorque prevention and soft speed reduction were feasible through the hydraulic motor inertia.

Fig. 7(b) shows that simultaneously using the safety valve when stopping the winch reduces the surge pressure on the hydraulic motor. The black dotted line represents the analysis results when the safety valve was not used, and the red line represents the graph when the safety valve was used. Therefore, the hydraulic motor can enhance motor longevity and overall system stability.

Fig. 7(c) illustrates the stack device; the red line denotes the graph produced when the safety valve was used. The load stops at a certain location because of the closing of the counterbalance valve. Because the counterbalance valve is used as a safety valve in the neutral mode, the stack device cylinder is fixed at a certain location.

2. Static Structural Analysis Results

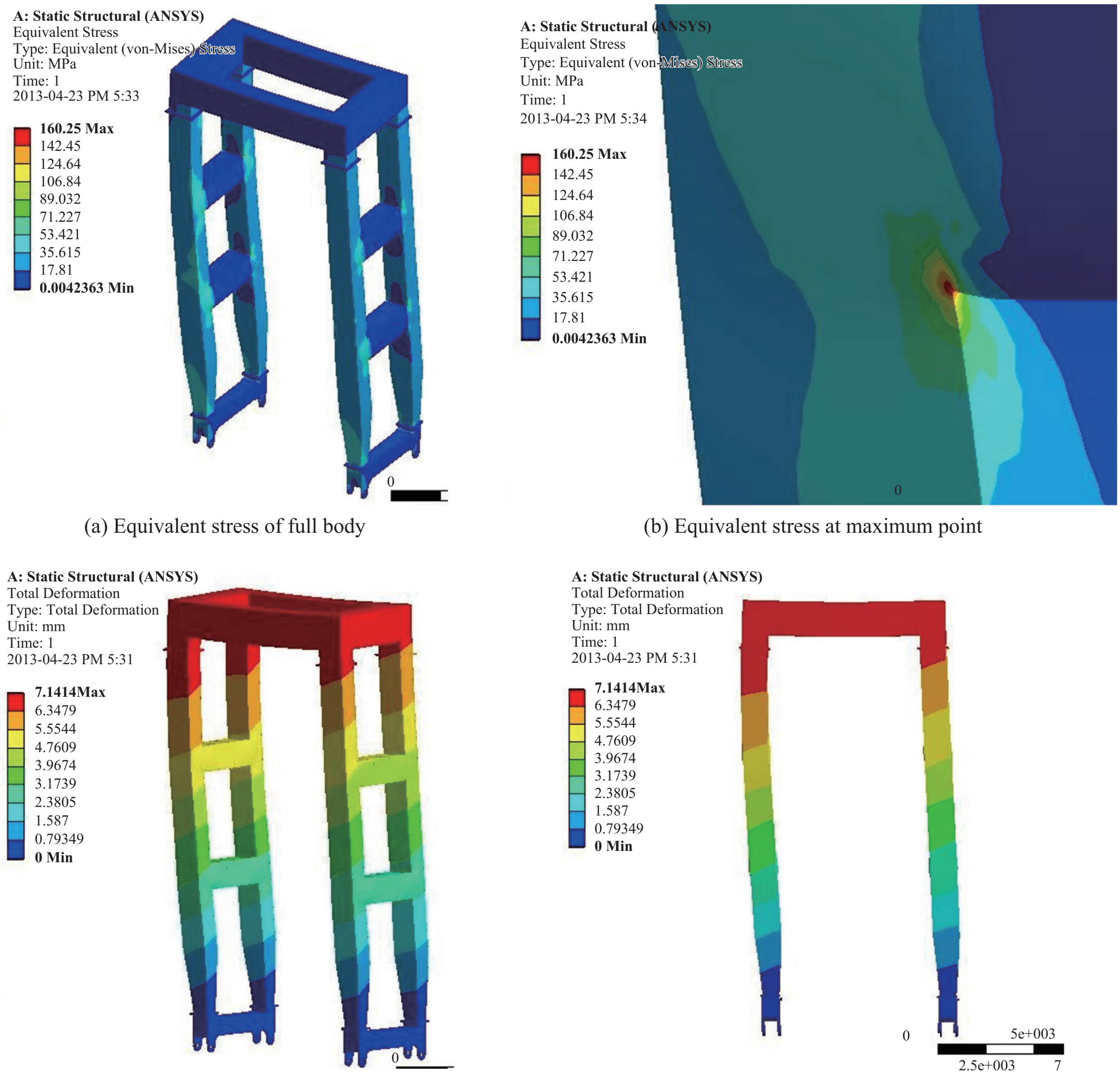
Fig. 8 shows the results of the structural analysis conducted on the BOP gantry crane. The stress value was approximately 160 Mpa, which was the maximum value measured at the lower corner of a leg connection part. The structural change induced by wind load, roll motion, and pitch motion was approximately 7.14 mm. However, the safety value of the analysis result was 2.24, indicating that the structure designed is safe.

Fig. 8(a) shows the equivalent stress of the full body. An observation of the overall stress distribution revealed that the load was generated by the wind acting on the side of the structure. The crane leg connection part was subjected to less stress because the load was distributed.

Fig. 8(b) illustrates the equivalent stress at the maximum point. The point of maximum stress was observed at the lower corner of the leg connection part. However, corners disappeared during the manufacturing of the crane. Therefore, the stress concentration is eliminated naturally. Moreover, the crane was reanalyzed after modifying the model at the maximum stress point.

Fig. 8(c) shows a normal view of total deformation. The crane appeared to be leaning to the left because of rolling and pitching; moreover, the deformation of the top of the crane was greater than that of the fixed bottom of the crane, and the maximum strain was 7.14 mm at the topside.

Fig. 8(d) shows a front view of total deformation. The analysis results revealed that the model was deformed toward the left. However, the results exaggerated the deformation. The actual deformation was considerably smaller than the structure size; therefore, it did not affect the stability of the structure.



(a) Equivalent stress of full body (b) Equivalent stress at maximum point

(c) Normal view of total deformation (d) Front view of total deformation

Fig. 8. Results of structure analysis for a BOP gantry crane.

IV. CONCLUSION

This study optimized the design of equipment for a domestic BOP gantry crane drillship/rig. A hydraulic system was designed to control the crane system, and ANSYS was used for executing structural analysis. The following results were obtained.

The crane hydraulic system was used to develop a BOP gantry crane analysis model, and the movements of the stack device, aux winch, and winch trolley system were determined. Simulation X, a commercial software program, can be combined with the BOP gantry crane hydraulic system to design a new hydraulic circuit, improve existing circuits, and develop parts.

The results revealed that the safety factor was 2.24, which was higher than the regulation safety value (1.5), demonstrating the safety of the designed structure. Three-dimensional modeling and the analysis results may be used in the development of future BOP gantry crane technology for designing actual equipment.

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