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A Study of Hull Stress Monitoring System considering Thermal Effect

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Abstract : *This paper presents hull stress monitoring system installed in LNGC damaged by a Typhoon. Elongation/contraction of removed areas has been assessed in terms of possible residual stress that will take place in replaced blocks when the applied load is removed. The bending moment of a vessel changes actually in terms of loss of longitudinal members and the change of weight distribution in repair procedure. The change of bending moment affects mainly in hull stress of longitudinal members. Hull stress monitoring system was installed on upper deck to prove LNGC stable in the criteria to be less than 40MPa during the period of repair procedure. A temperature measuring system was also installed to exclude the additional stress due to thermal effect from the measured hull stress. As a result, the hull stress was modified with the data measured by the temperature measuring system. This hull stress considering thermal effect was used as a guide stress to check the safety of LNGC during the period of repair procedure.*

Key words : *Hull stress monitoring system, Thermal effect, Gap sensor, SUS*

1. Introduction

LNG carrier damaged by typhoon, Maemi, was berthed at E quay in DSME to repair her damaged parts. She was under two ballast conditions (i.e. Dock-Out ballast condition and ballast condition for repair) used in repairing period. These ballast conditions made her to be hogging condition as Fig. 1 and resulted in her deformation in terms of bending moment. Site manager required monitoring the hull stress on upper deck near Frame No. 90 in order to check the safety of LNGC.

Generally hull stress monitoring system gives crews the information of hull stress during vessel's service. This information helps crews to determine quickly the safety of structure and control ship's velocity and path in the variable sea condition. IMO(1994) recommended to install a hull stress monitoring system (HSMS) in bulk carrier with over 20,000 DWT and LR(1991) established a rule for Hull Surveillance System (HSS) in August-1991. Since 1980 years, advanced countries including U.S.A. and Japan developed and commercialized hull stress monitoring system (Slaughter et al., 1997). In 1988, Structure R&D team in DSME performed a joint project with KIMM(Korea Institute of Machinery & Materials) and developed a hull stress monitoring system. A simplified model based on the developed model was installed on upper deck of LNGC. Allowable stress was calculated to use as the safe criteria of the repair procedure. The simulation test was performed to check an accuracy and safety of this system before a practical measurement and hull stress distribution was measured for four days. It was confirmed that the shape of hull stress was the half of sine curve with daily period through this simulation test. The stress variation resulted from gap variation due to thermal expansion. Site manager required getting the pure hull stress due to hull girder bending moment except thermal effect. Finally thermal measuring system was used to modify the hull stress including thermal effect.

This paper presents the principle of the hull stress monitoring system considering thermal effect and results of the modified hull stress.

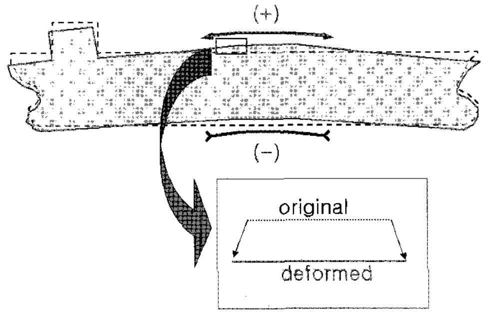

Fig. 1 Hogging condition

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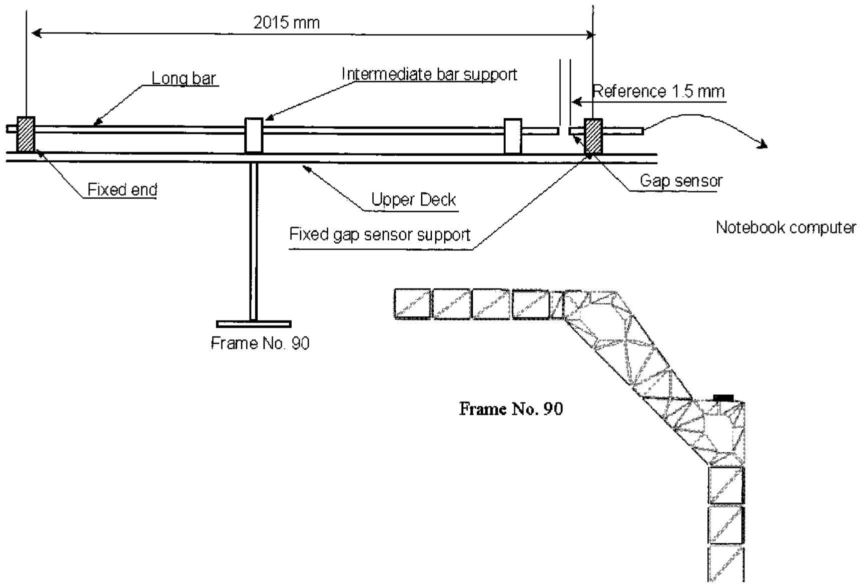
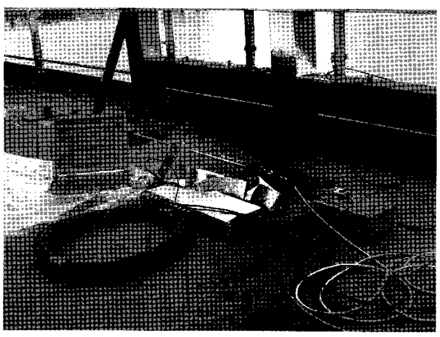
2. Hull stress monitoring system

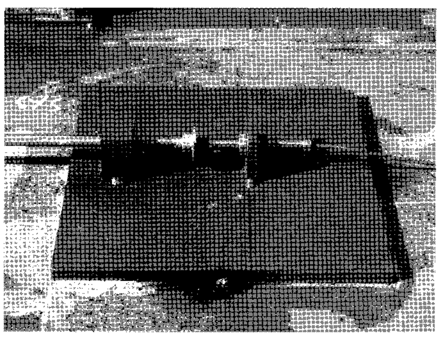
Hull stress monitoring system was installed on upper deck near Fr. 90 as shown in Fig. 2. This system used a gap sensor to measure the distance between a gap sensor and the end of bar. The change of distance occurred mainly by the change of hull girder bending moment. Though LNGC maintained constantly each ballast condition at repair steps, the hull girder bending moment was changed to some extent by means of cutting procedure in repair steps. The simulation test was performed to check an accuracy and safety of this system before a practical measurement. The hull stress distribution in the simulation test had been measured for four days. Any repair procedures didn't perform for the most part of the simulation test period and a repair procedure started after 230,000sec as shown in Fig. 3. From the results of the simulation test, it was confirmed that the shape of hull stress was the half of sine curve with daily period as shown in Fig. 3. The stress variation resulted from gap variation due to thermal expansion. The principle of gap variation is explained as Fig. 4. When general materials are heated, they expanded. And they are cooled, they compressed. However their coefficient of thermal expansion are different. The coefficient of thermal expansion of SUS(steel use stainless) is higher than that of the structural steel. SUS and structural steel tend to compress at night. The gap length increases because SUS compresses more rapidly than structural steel and the increment of gap length raises the hull stress. Oppositely stainless and structural steel tend to expand in a day. The gap length decreases because SUS expands more rapidly than structural steel and the decrease of gap length reduces the hull stress. Site manager required getting the pure hull stress except thermal effect induced by hull girder bending moment. Finally thermal measuring system was needed to modify the hull stress including thermal effect.



(a) Diagram of hull stress monitoring system



(b) Installation of hull stress monitoring system



(c) Gap sensor in hull stress monitoring system

Fig. 2 Hull stress monitoring system

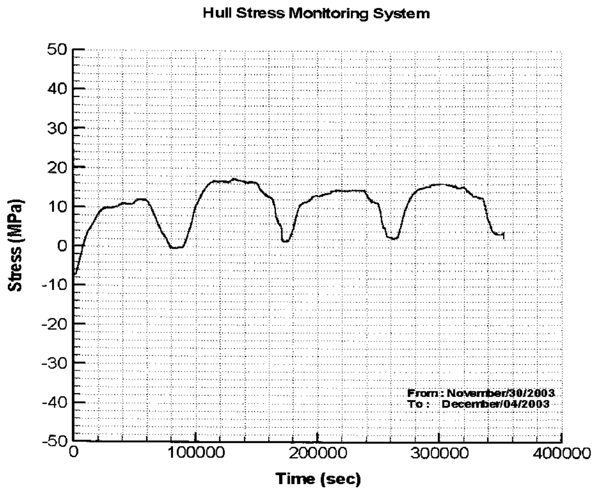


Fig. 3 Hull stress due to thermal effect

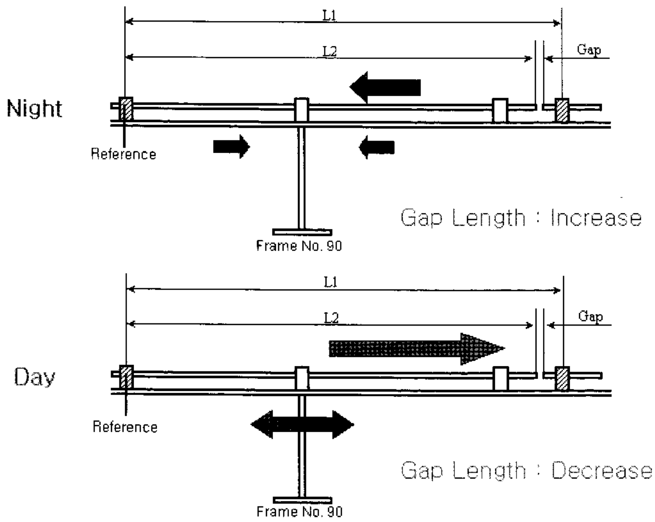
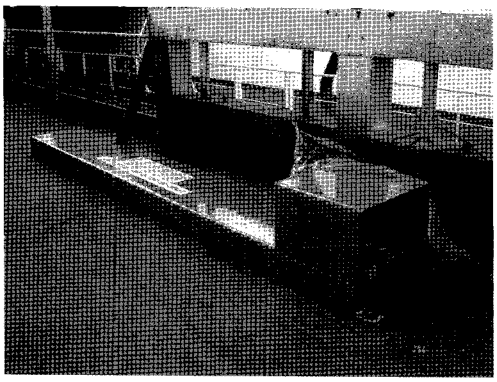
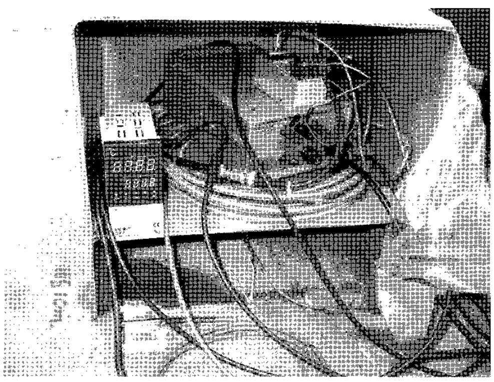


Fig. 4 The principle of gap variation



(a) Hull stress monitoring system with a temperature measuring system



(b) Installation of temperature measuring system

Fig. 5 Temperature measuring system

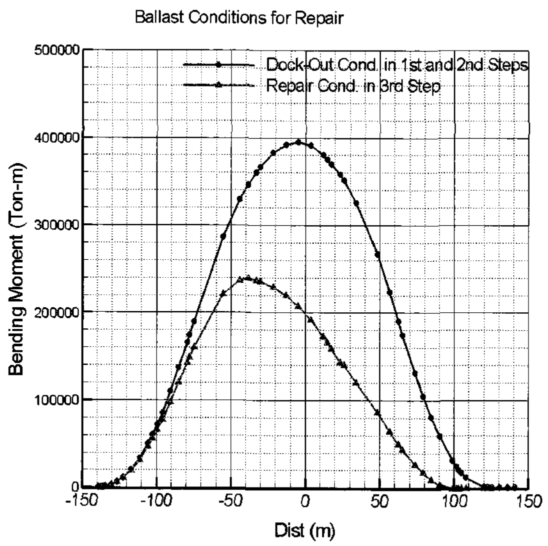


Fig. 6 Still water bending moment distribution for two ballast conditions

3. Temperature measuring system

Gap sensor in the hull stress monitoring system measures the distance between gap sensor and end of SUS bar. The variation of distance is induced mainly by hull girder bending moment and also may occur by the difference of thermal expansion between SUS and structural steel. Generally the diurnal range is 7～12 degree in winter. As a result, the hull stress calculated from the variation of distance includes not only the stress due to hull girder bending moment but also the additional stress due to thermal effect. The temperature measuring system was consisted of a thermal sensor of P type and a temperature controller. It was installed to measure the change of temperature on upper deck as shown in Fig. 5. The measured temperature was used to exclude the additional stress due to thermal effect from the hull stress measured by the hull stress monitoring system.

4. Determine allowable stress

Before repairing the vessel, a computerized structural simulation, i.e. FE analysis, had been carried out to prevent possible subsequent damage and to choose an appropriate repair condition. Three FE models were prepared and used for analysis based on two different ballast conditions. The bending moment curves in considered ballast conditions are shown in Fig. 6. FE analysis results had been evaluated in terms of applied stress around removed areas and strain of the removed areas. The strain of the removed areas was assessed using the criteria provided by Bureau Veritas Class, which says the possible maximum residual stress should be less than 40MPa. The allowable factor was determined using the relationship of the residual stress in longitudinal member obtained from the results of structural analysis with the limit stress proposed by BV. The allowable stresses were calculated using this allowable factor and the hull stress on upper deck occurred theoretically by hull girder bending moment.

▣ Allowable Stress in 1st and 2nd Steps

: $\sigma_{allowable} = 31.2\,MPa$

▣ Allowable Stress in 3rd Step

: $\sigma_{allowable} = 27.2\,MPa$

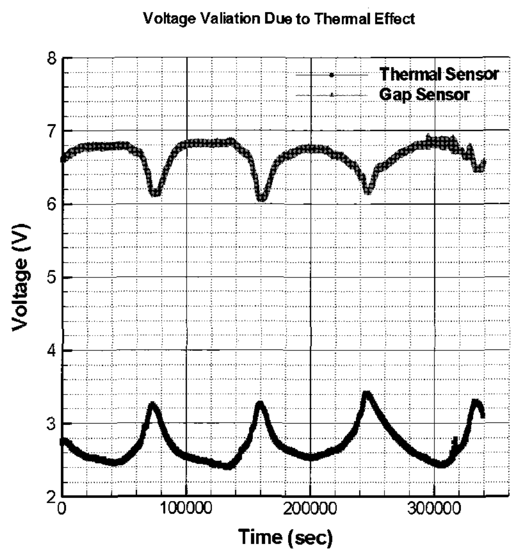
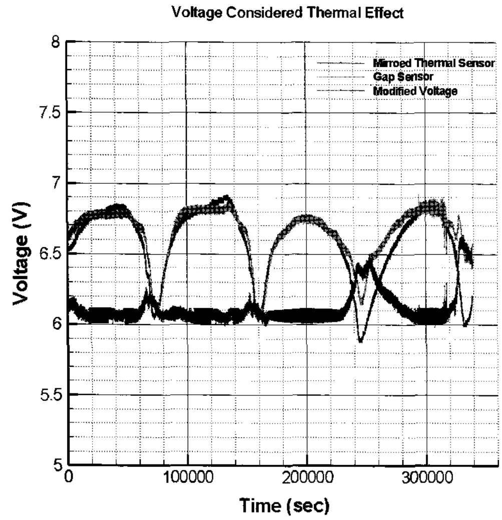


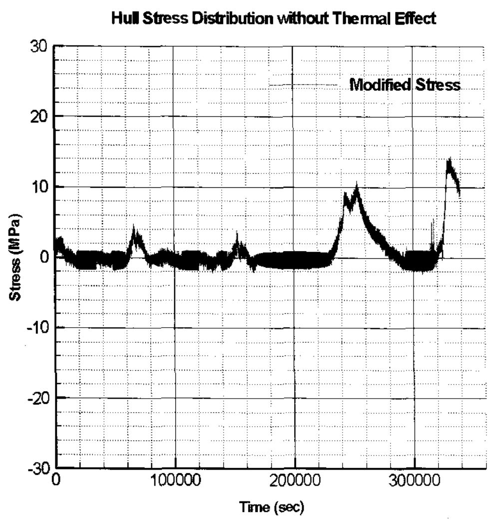
Fig. 7 Voltage variation of gap sensor and thermal sensor due to thermal effect

5. Modification procedure of hull stress

The temperature measuring system with thermal sensor of P type measures temperature on upper deck. The output range of temperature measuring controller is 1～5 voltage. The voltage calibration data dependent on temperature may be represented by a linear function. The simulation test was performed to calibrate this system before repairing step. The voltages of gap sensor and thermal sensor were shown in reverse shape and their amplitudes were very similar as shown in Fig. 7. As shown in Fig. 7, the ballast condition and longitudinal strength of the ship were maintained constant before the time 300,000sec that repair procedure started. As a result, the voltage signal of gap sensor should have been flat. But the voltage signal shape of gap sensor was shown in semi-elliptical form and it resulted in the similarity to the voltage signal shape of thermal sensor.



(a) Voltage modified from voltage of gap sensor



(b) Stress modified from stress of gap sensor

Fig. 8 Modified results excluded thermal effect

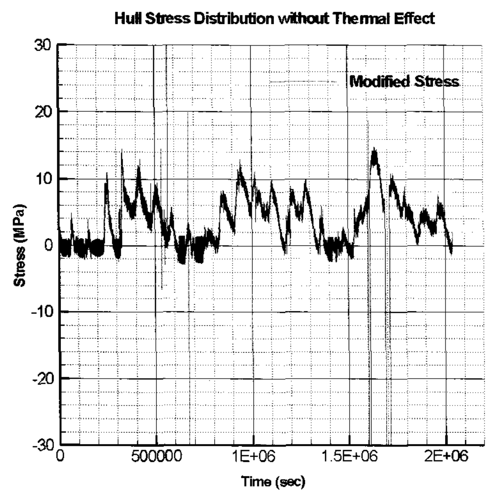


Fig. 9 Hull stress distribution during 1st and 2nd repair steps

This means that hull took compression or tension because of change of temperature. The unstable signals at 60,000 and 140,000sec in Fig. 8 (a) resulted from the difference of thermal expansion between SUS and structural steel at the time of sunrise. This insufficiency needs to be modified subsequently. The sudden change of voltage signal of gap sensor at 240,000sec in Fig. 8 (a) was the time of the change of ballast condition before the actual repair procedure and another sudden change at 320,000sec was the time of removal of longitudinal member in order to perform the actual repair procedure. To monitor the hull stress due to change of longitudinal strength, the voltage signal produced from thermal effect was extracted from the voltage signal of gap sensor and this procedure resulted in the modified voltage as shown in Fig. 8 (a). As a result, the hull stress distribution without thermal effect was obtained using a transition factor between voltage and stress. The variation of peak value in Fig. 9 was occurred owing to the change of longitudinal strength that resulted from the removal of longitudinal members during repair procedure.

6. Conclusion

(1) Hull stress monitoring system considering thermal effect consisted of a gap sensor, a thermal sensor, and a computer to measure change of hull stress due to repair steps.

(2) The modified voltage was obtained from the extraction procedure using the voltage signal measured by the thermal sensor. And the hull stress distribution without thermal effect was obtained using a transition factor between voltage and stress.

(3) As shown in Fig. 8(b), repair procedures started after 230,000sec and it was confirmed that the modified hull stress remained around zero before repair procedures did. The increment of the modified stress at 320,000sec in Fig. 8 (b) occurred by the change of the longitudinal strength after that.

(4) Fig. 9 is the hull stress distribution measured by this system during the period of repair procedure. As a result, the modified hull stress was the stress value excluding the additional stress occurred from thermal effect. It was used as a guide stress to check the safety of a damaged ship during the period of repair procedure.

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