Longitudinal ship’s hull strength monitoring with optical fiber sensors

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Abstract – Longitudinal ship’s hull strength is the most fundamental strength of a ship structure, and many research works have been done from this aspect. In this paper we aim to obtain a possibility to determine hull girder strength using optical fiber sensors. Collected data can be used as handy to verification of transverse, longitudinal and local strength for a momentary loading condition and to help make timely decisions in the event of an emergency which has been arising from accident. The ship’s strength analysis is listed. The longitudinal strength distributions are described in a detail. Real time monitoring ship's hull with optical fiber sensors is proposed.

Keywords – ship’s hull, strength monitoring, optical fiber sensor

1. INTRODUCTION

The longitudinal strength is the most important criteria for structural design of ship hulls, which is generally represented by the maximum bending moment that the hull cross-section can withstand. In the past three decades, a numerous of research has taken place to determine and predict ship hulls strength. In recent few years, there has been a growing interest in implementing optical fiber sensors on ship. Optical fiber sensors also can be used on ship’s hull structural monitoring system.

The optical fiber technology, using all benefits from advantages of optical fibers and communications systems, has been applied as sensors in measuring different nonelectrical and electrical values. Their very small dimensions, low physical mass, easy installation, immunity to the electromagnetic fields and possibility of real-time monitoring, justify the installation of the optical fiber sensors in the very demanding ship environment. This paper aims at describing ship hull strength monitoring with distributed optical fiber sensors.

2. THE IMPORTANCE OF SURVEILLANCE SHIP’S HULL

Ship’s hull in longitudinal direction has been subdividing into compartments. The objective in subdividing a ship into compartments, as an essential issue in it design, has been to protect of a ship, crew and the cargo it carries from possible serious damages incurred by accidents. Rules and regulations (national and international – such as Load Line, MARPOL, SOLAS, rules of Classification Societies, etc.) specify minimal requirements for ship’s strength.

Ship’s hull may be exposed to an extreme load in some occasions when the ship fails to escape from storm weather or when the cargo and/or ballast is improperly loaded. In additions, because aging ships may have suffered damages due to hull corrosion and fatigue, their structural resistance may weaken and further collapse under an ordinary load, which are even smaller than ultimate safe designed loads. A ship may collapse after an accident (collision, grounding, explosion, etc.) because of inadequate longitudinal strength.

Fig. 1. Collapse of MT “Prestige”

The consequences of an accident on a ship’s strength are seldom investigated, and it has been actual only there is a major loss of ship's, life at sea, cargo and or when there is oil pollution from damaged ships. In this case public sensation motivates the development of new standards and procedures for
accidental loads, in particular, the loads after ship collision or grounding accidents. Minimal dimensions of ship’s structural elements have been specified by Classification Societies. Longitudinal strength calculations may be used for the verification of those elements and for further it additionally adjustments.

3. SHIP’S LONGITUDINAL STRENGTH

When a ship is floating or moving through the water, there are many forces acting on its hull. How forces act is largely determined by the kind of ship. Types of forces that occur are the same for every ship, but the magnitudes and points of action depend on the shape of the ship’s hull. The pattern of forces on a ship’s hull is largely depends on the following parameters: the weight of the empty ship (light ship weight), the weight and distribution of the cargo, fuel, ballast, provisions, fresh water etc, hydrostatic pressure on the hull applied by the water, hydrodynamic forces resulting from the movement of the ship on the waves, etc. These and other forces cause the ship to deflect. When the force disappears, the ship will regain its original shape due to ship’s hull flexibility. In some case the forces exceed a certain limit, permanent deformation can be occur. Length of very large carrier exceeds 300 m, and especially forces with high magnitude acting on its hull in longitudinal direction. Ship strength generally represents the ship’s structural ability to resist the effects of outside forces When a ship is in calm water, the total upward force (buoyancy forces) will equal the total weight of the ship (displacement of the ship) as the first law of flotation states.

![Fig. 2. Forces acting on ship's hull](image)

Locally this equilibrium will not be realized because the ship is not a rectangular homogeneous object. The local differences between upward pressure of buoyancy and the ship’s local weight give rise to shearing forces, $Q_x$, that lead to longitudinal tensions and the bending moment, $M_x$. The greatest forces moments and stresses that affect the ship hull are expressed as bending and buckling in the longitudinal vertical plane.

The longitudinal distributions along the hull girder of shear forces and bending moment can then be derived by the following integration [4]:

\[
D = \int_0^L q_t \cdot dx, \quad U = \int_0^L q_u \cdot dx \quad (1)
\]

\[
Q_x = Q_u - Q_t = \int_0^x q_u \cdot dx - \int_0^x q_t \cdot dx \quad (2)
\]

where :
- $q_t$ – ship weight distribution up to the observed cross section,
- $q_u$ – buoyancy force distribution up to the observed cross section,
- $q_x$ – load distribution due to transverse force $Q_x$ up to the observed cross section,
- $Q_t$ – ship weight intensity on the observed cross section,
- $Q_u$ – buoyancy force intensity on the observed cross section.

Transverse force $Q_x$ has a positive sign value if its direction from upward to downward, and respectively $Q_x$ has a negative sign value in case of a direction contrary to that previously mentioned. At the ship ends (as state at first law of flotation) transversal forces are equal to zero.

The bending moment on still water indicates how loading weight distribution affects on longitudinal strength. Bending moments value are also different over the particular cross section, because besides the difference between buoyancy and weight force itself, there is also the difference between the center of gravity of the ship’s mass at cross section and center of gravity of submerged part cross section.
Bending moment can be expressed as hogging or sagging deflection depending on its acting direction. Hogging indicates that the vertical deflection of a ship's hull, in longitudinal direction, where the hull midships is bent upwards, as a result of cargo distribution and/or the way the ship is supported by a wave at sea. Respectively, sagging indicates that the vertical deflection of a ship's hull in longitudinal direction, where the hull midships is bent downward, as a result of cargo distribution and/or the way the ship is supported at sea. Deflections of the ship can be observed on figure 4.

![Fig. 4. Ship's deflection](image)

The direct evaluation procedure requires, for a given loading condition, a derivation, section by section, of vertical resultants of gravitational (weight) and buoyancy forces, applied along the longitudinal axis of the beam. To obtain the weight distribution \( w(x) \), the ship length is subdivided into portions: for each of them, the total weight and center of gravity is determined summing up contributions from all items present on board between the two bounding sections. The distribution for \( w(x) \) is then usually approximated by a linear (trapezoidal) curve for the considered ship portion. The procedure is usually applied separately for different types of weight items, grouping together the weights of the ship in lightweight conditions and those (cargo, ballast, consumables) typical of a loading condition. [2]

The prediction of the behavior of the ship in waves represents a key point in the quantification of both global and local loads acting on the ship's hull. The action of waves modifies the pressure distribution along the hull surface. The differential pressure between the situation in waves and in calm water (weight distribution of the ship is unchanged and an unequal buoyancy distribution) generates on the transverse section additional bending moment.

![Fig. 5. Distribution of buoyancy on calm water and wave conditions](image)

The ship is positioned on a statical wave of given characteristics in a condition of equilibrium between weight and static buoyancy. Numerous research have determined that the biggest wave load appears when a wave length is approximately equal to the ship’s length. The ship course has to match the wave direction.

Among all groups of approaches on determination ship's longitudinal strength (closed-form formulae, simplified analytical methods and nonlinear simulations), the above consider simplified analytical methods are favored by most analysts. These approaches save modeling time and provide reliable results. A simplified method has been placed as the first choice in extensive related research of determination ultimate hull girder strength.

The continuous improvement of knowledge regarding the behavior of ship’s hull at various conditions has led to the development of various new methods in determination hull girder strength. In recent few years, there has been a growing interest in implementing optical fiber sensors on ship. Optical fiber sensors also can be used on ship’s hull structural monitoring system.

We aim to obtain a possibility to determine hull girder strength using optical fiber sensors, which may be used as handy to verification of transverse, longitudinal and local strength for a momentary loading condition and to help make timely decisions in the event of an emergency which has been arising from accident.

### 4. SHIP'S HULL STRENGTH MONITORING WITH OPTICAL FIBER SENSORS

A significant contribution to uncertainties in the evaluation of calm water loads comes from the inputs to the procedure, in particular those related to quantification and location on board of weight items. This lack of precision regards the weight distribution for the ship in lightweight condition (hull structure, machinery, outfitting) but also the distribution of the various components of the deadweight (cargo, ballast, consumables). Some ship types are more exposed to uncertainties on the actual distribution of cargo weight than, for another type (on bulk carriers the cargo is very often heterogeneous distributed along the holds, contrary, on container ship actual weights of single containers can be kept under close control during operation. In addition, also model uncertainties arise from neglecting in determination center of buoyancy for observed cross section can be significant. [3]

Real time monitoring ship's hull with optical fiber sensors provide knowledge about the integrity of a consider ship. Data were used to obtain real time global condition of conditions of ship's hull. Optical fiber sensor monitoring can help to:

- predict structural damage,
- the verification of longitudinal strength,
- the verification of ultimate longitudinal strength after an accident,
- predict and verification of longitudinal strength during the ballast exchange.

Data collected by optical fiber sensor may at the time when ship’s hull be exposed to an extreme load (ship fails to escape from storm weather or when the cargo and/or ballast is improperly loaded) be useful for predict structural damage.

Suggested system permit monitoring of not only the magnitude of strength, but also its variation along the length of a continuous uninterrupted optical fiber. Distributed sensors also permit an easy and reliable comparison of a parameter at different points (the same interrogator takes measurement at different points) and the sensor cable measures at every point along the length with no “dead spots”. Described sensors make use of radar-type backscattering measuring method to make truly continuous measurements on unbroken optical fibers. The basic method of optical time-domain reflectometry concept using OTDR (Optical Time Domain Reflectometer) instrument for analyzing a fiber from one end only. The OTDR provides a trace that plot signal level versus distance, displaying event information such as pressurized zone or signal loss due to strain, displacement, etc. [1]

Every accident and resulting damage is different. Real time data obtained by optical fiber sensor provide to ship's master necessary information of residual and ultimate longitudinal strength after an accident. After all, accidents require many parameters to describe the damage a ship sustains after an accident.

Also data from hull monitoring system can also help in the optimization of ship design and it can provide maximum ship operational availability.

The elements of bottom ship’s hull and the deck are the most sensitive indicator of longitudinal strength. For this reason the authors suggested that the optical fiber sensor may be installed as shows on figure 6. and figure 7.

![Fig.6. Position of optical fiber sensors – longitudinally direction](image)

Fig. 7 is a sketch of a transverse section, which characterizes the geometry of a ship and ignores many details. This transverse section may be a double hull tanker, a bulk carrier, a container carrier, a single hull tanker or any other type of ship.

![Fig.7. Position of optical fiber sensors – transfer section](image)

Collection of high quality data under adverse sea conditions and commercial operations approach of such data for the ship's master and to other interesting user (ship's owner, classification societies, ship's insurance) to make properly conclusion about hull conditions and necessary action.

Data collected using optical fiber sensor can be kept as history track on measurement instrument and also stored on personal computer.

5. CONCLUSION

Various method and model has been used in numerous research on determination ship’s longitudinal strength. The continuous improvement of knowledge regarding the behavior of ship's hull at various conditions has led to the development of various new methods in determination hull girder strength. Real time data collected by optical fiber sensor aim to obtain a possibility to determine hull girder strength, which may be used as handy to verification of transverse, longitudinal and local strength for a momentary loading condition and to help make timely decisions in the event of an emergency which can be aroused from accident. Also significant contribution from the uncertain inputs in the research can be avoided by using optical fiber sensor. System permits monitoring of not only the magnitude of strength, but also its variation along the length of a continuous uninterrupted optical fiber.

REFERENCES