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Application of goal-based standards philosophy in maintenance management of bulk carrier hull structure

Wu Wen Xiang
World Maritime University

WORLD MARITIME UNIVERSITY

Dalian, China

APPLICATION OF GOAL-BASED STANDARDS PHILOSOPHY IN MAINTENANCE MANAGEMENT OF BULK CARRIER HULL STRUCTURE

By

WU WEN XIANG

China

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DEDICATED TO

MY FATHER PASSED AWAY,

WISHING

HE COULD REST IN PEACE

Declaration

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

Wu wen xiang

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Supervised by:

Shen hua

Professor

Dalian Maritime University

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Abstract

The dissertation is a research of constructing a regulatory framework to integrate international regulations concerning maintenance management of bulk carrier hull structure. The framework is top-down and hierarchical, and its construction is governed by the Goal-Based Standards philosophy. First of all, the nature of the framework was clarified in order to define the scope of the research.

As a paradigm of Goal-Based Standards philosophy applied in practice, the Common Structural Rules of IACS was investigated with a view to helping comprehension of the characteristics of the upper three tiers in the framework, i.e. goals, functional requirements and verification of compliance criteria. By insight into the characteristics, the principles to guide developing functional requirements under goals and the denotation of verification were revealed.

In context of maintenance management of bulk carrier hull structure, the composition of the upper three tiers in the framework was examined, taking into account the improvement of hull structure maintenance with a tendency towards proactive prevention, which contributed to the categorization of regulations when integrating them into the framework.

An exercise of constructing the framework of international regulations is presented on the case study of coating maintenance management of bulk carrier ballast tank, together with the essentials of the bottom tiers in the framework analyzed. In addition, an innovative way to develop standards and keep them under the control of recognized criteria is recommended by exemplification in the case study.

The concluding chapter reiterated the significance to infuse the risk-based methodology into the management of hull structure maintenance, summarized the key points in applying the Goal-Based Standards philosophy in construction of a regulatory framework and underlined the principles to integrate international regulations into the framework.

KEYWORDS: Goal-Based Standards, Maintenance Management, Bulk Carrier, Hull Structure,

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List of abbreviation

B	Breadth of ship, as defined in the Ch.II-1 Reg.2 of SOLAS
CSR	The Common Structural Rules for Bulk Carriers and Oil Tankers
D	Draught of ship, as defined in the Ch.II-1 Reg.2 of SOLAS
FSA	Formal Safety Assessment
GBS	Goal-Based Standards
L	Length of ship, as defined in the Ch.II-1 Reg.2 of SOLAS
NDT	Nondestructive Testing
SMS	Safety Management System

Chapter I Introduction

Application of the Goal-Based Standards (GBS) philosophy progressed quickly. In the 23rd session of IMO Assembly, to establish GBS for the design and construction of new ships was adopted as a strategic plan of the Organization, from then on, researches of GBS had come into enthusiasm. The birth of the Common Structure Rules (CSR) for bulk carriers and oil tankers was one of remarkable achievements, so far, in applying the GBS philosophy. As regards the philosophy itself, basic concepts continued updating. The latest trend in the researches of GBS was to explore the possibility of a linkage between GBS and Formal Safety Analysis (FSA), which captured the soul of GBS because the concept of risk was the core of the approach to develop substructure under the goal(s), particularly where the GBS philosophy was applied in researches of safety, the concept was an only known idea with general applicability (Skjong, 2005, pp. 3). Should the concept of risk disappear, the GBS philosophy would verge on the commonplace, and it would be not any significant differences that a framework structured in whether GBS or other philosophies whatever.

1.1 Importance of the study

Maintenance is such an important stage in the operational life of a ship that bears the responsibilities, most of the time, to guard ship safety. With regard to maintenance management of bulk carrier hull structure, there are numerous technical and managerial requirements, internationally, distributed in existing Conventions, regulations, rules, guidelines, codes and pertinent standards, and it is a question to integrate the requirements into a framework. The integration is not to sort through these requirements in their names but to categorize the substance of these requirements according to their function in regulating. Making an outline for the categorization is the tone of this paper. Furthermore, the profile of the framework depends on the philosophy governing its construction. When it is borne in mind that hull structure maintenance belongs to the safety issues, GBS philosophy is, of course, a favorable choice of the architect.

From another perspective, the importance of the study is to connect hull structure maintenance with the improvement of safety management. Notwithstanding the leaps of modern management of industrial maintenance, conservative practices remain in bulk carrier hull structure maintenance. Modern maintenance trends to taking proactive measures but hull structure maintenance stands still failure-responded. This stagnation is because, in part, complex structure and poor accessibility of bulk carrier obstruct a rigorous detection, which impairs gathering information and hence prejudices effective maintenance, but lack of risk-based methodology is at the bottom of the awkwardness. It is imperative to improve the maintenance management of bulk carrier hull structure, and integrating the existing pertinent requirements into the goal-based framework is, without question, meant for the improvement.

1.2 Objectives of the study

Figure 1 – A goal-based framework (Source: Allan, 2005)

A Goal-based framework is depicted in *figure* 1. In brief, the ultimate objective of the study is to integrate existing internationally technical and managerial requirements concerning bulk carrier hull structure maintenance into a goal-based framework. To attain this objective, following questions should be given proper answer prior to the construction, and the answers to the questions are regarded as subordinate objectives.

-- What is the comprehension, performed by IACS in the CSR, of goals, functional requirements and verification of compliance criteria in a goal-based framework?

-- What relationship between the tiers in the framework?

-- What are the underlying principles to guide developing functional requirements under the goal(s)?

-- What is the composition of the goals, functional requirements and verification of compliance criteria in context of maintenance management of bulk carrier hull structure?

-- What are the role and characteristics of the bottom tiers in the framework?

These questions are not raised explicitly one by one in the paper, but the answers to them run through following chapters.

1.3 Scope and approach of the study

Is the goal-based framework mandatory or voluntary? This is a question should be cleared up prior to the study. The author believes that the framework is neutral on the whole, neither leaning towards exclusive determination nor allowing of adoption or alteration at random. Be that as it may, the tone of regulation is palpable, at least, in the upper three tiers of the framework. In view of it, the accent of the research is on such tiers, i.e. goals, functional requirements and verification of compliance criteria, and the term, framework of international regulations, is used in this paper. With respect to the tier IV and V in the framework, they are out of the scope of the research because the number of components in these tiers, for example procedures, guidelines, codes of practice as well as industrial standards, is dramatic, and if discussion on them went into details, the considerable weight of this discussion would make it incompatible with other contents and break the balance of the paper. However, the characteristics of the tier IV and V in composition is described briefly by exemplification in the chapter of case study.

In keeping with the existing international regulations concerning maintenance management of bulk carrier hull structure, the scope of the study covers all bulk carriers regardless of their size. But, it has to be admitted that the well-meaning study should have been of insufficient technical support in case of a bulk carrier neither engaging in unrestricted voyage nor exceeding 90 m in length. This is because this type of bulk carriers is usually not classified, in which the Rules of Classification Societies is not necessarily applied. Not only length but also some characteristics of ship, e.g. L/B or B/D, are the restriction of Rules' applicability. For bulk carriers to which the Rules of Classification Societies does not apply, lack of pertinent parameters in assessments is a real question, and this shortage is detrimental to a sound composition of "verification of compliance criteria". To deal with the problem, it is supposed that bulk carriers mentioned in this paper are all supported sufficiently by technicalities either from Rules or from individual consideration by Classification Societies.

The main approach of the study is literature search. Relevant academic papers, seminar presentations, resolutions of IMO, guidelines and recommendations of IACS and international regulations as well as rules are collected and examined to support the study.

1.4 Order of presentation

The conception of this paper was presented in the order suggested by the top-down framework. On the basis of insight into the GBS philosophy in the CSR of IACS, detailed discussion on the composition of upper tiers in the framework of international regulations were carried out in turn. The arrangement of sections in a chapter was either in accordance with sequences of a managerial process, e.g. in chapter IV, or in view of the relationship between different tiers, such as in chapter III & V. Chapter

VI made a case study on the coating maintenance management of bulk carrier ballast tank, which helped recognizing the significance of GBS philosophy applied in structuring a framework of international regulations. As regards the paragraphs in sections, there was no intended arrangement. The last chapter made a conclusion for the discussion in the paper, not only summarizing the key points of the discussion but also restating the author's opinions about the approach to improve maintenance management of bulk carrier hull structure.

Chapter II Insight into the GBS philosophy in the CSR of IACS

2.1 Goal and functional requirement

Goal, defined by Webster, is the final purpose or aim; the end to which a design tends or which a person aims to reach or attain. Goal stands at the top of a hierarchical framework of international regulations according to the GBS philosophy, and this position is overarching. To launch out into the goal-based framework, clear goal must be sure in the first instance. Developing functional requirement, in a sense, is to decode goal. The approach to decode goal determines the profile of the framework, and this is the reason why there are different frameworks flowed from the same goal(s).

2.1.1 Goal

It is well known that the primary goals of maritime regulation are safety, protection of the environment and security. The goals are be-all and end all of everything regulated, but they are too general to put across concrete objectives when a certain subject such as hull structure maintenance is presented. Therefore, the three goals are rather regarded as three domains of maritime regulation in which concrete objectives involve.

Figure 2 shows statistic information of bulk carrier accidents from 1990 to 2002. As

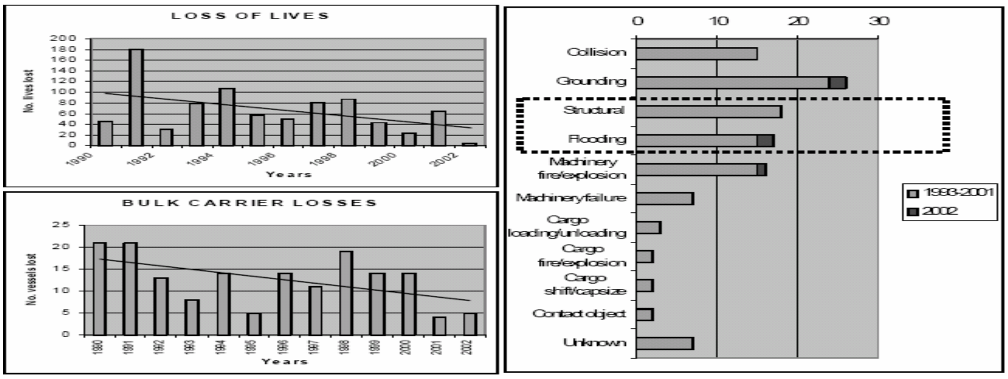


Figure 2 – Statistic information of bulk carrier accidents: 1990-2002. (Source: Leslie, 2004)

seen in the bar charts, while the loss of lives and vessels due to bulk carrier accidents appearing, in general, a declining trend in the period of 12 years, structural failure and flooding remain high proportions of categories of the accidents. In view of it, international maritime industry kept up the effort to improve the structural safety of bulk carrier during design, manufacture, maintenance and operation.

For hull structure maintenance, the concrete objectives are suggested by the definition of maintenance. Maintenance is defined as "the activities intended to preserve or promptly restore the safety, performance, reliability and availability of structures, systems and components to ensure superior performance of their intended function when required" (Weinstein, & Chung, 1999, p.p.1061). Obviously, the terms – safety, performance, reliability and availability – suggest a clue to concrete objectives, for example, the connotation of safety on board encompass safety of human life, safety of work condition and safety of property. As safety and performance or safety and reliability interact in nature, the objectives conceived are likely to overlap, which should be avoided as far as possible. In addition, the feasibility to be measure of the objectives should be taken into consideration (Leslie, 2004). Only the objectives adapted to measurement enable the establishment of the framework to be under control.

2.1.2 The principles for developing functional requirements

To develop functional requirements, or to say, to decode the goals, is the key step to construct a goal-based framework of international regulations. A successful development of functional requirements rests on two factors – coordination and proper approach. Coordination needs a mechanism to enable diverse requirements coexistent, and this issue is addressed by cooperation among stakeholders including the Administration, Classification Societies, ship designer, manufacturer and ship owner as well as operator. Proper approach is the way to infuse a scientific methodology into the construction of the framework, named risk management.

2.1.2.1 Stakeholders and cooperation

Classification Societies are reluctant to assume more responsibilities for hull structure safety except for technical review, it follows that other responsibilities have to be shared by stakeholders such as ship owner, operator, ship designer, manufacturer and the Administration. Where discuss focusing on hull structure maintenance, the status of ship owner and operator as stakeholders is without question. If ship operation broke the limits for safe, threat of risk even real accidents would make ship owner and operator paid for it, no matter whether the ship operation had been verified. The reason ship designer and manufacturer are also considered as stakeholders of hull structure maintenance is that maintenance can not be addressed separately form the technical background of design and manufacture. The design basis including loading condition, environmental condition, etc. and the manufacture quality of ship provide guide to hull structure maintenance, therefore, the degree to which the design and manufacture fulfill the need of ship operation is the threshold of hull structure maintenance. For the Administration, it goes without saying that administrative responsibilities fall on it particularly in case of accident, because hull structure maintenance is inherent in the system of ship safety.

Notwithstanding few comments on individual stakeholders' responsibilities for hull structure safety to be found in the CSR, the principle of cooperation among all interested parties is underlined. The principle is also implied by the duties of Classification Society on ensuring hull structure safety, which can be summarized, inter alia, as follows:

- set the standards for the safety and functionality of hull structure;
- specify requirements and procedures for the information and documentation of design;
- carry out a technical review of the design plans and related documents for a vessel to verify compliance with the applicable rules.
- confirm workmanship of shipbuilding, including alignment and tolerances, is in accordance with acceptable standards;
- fulfill adequate supervision and quality control during shipbuilding;
- confirm shipbuilding is carried out by qualified and experienced personnel;
- made a scheme of Classification Society survey and carry out it;
- confirm the ship in service is maintained in good condition and in accordance with international and Classification Society requirements
- verify the quality system of designer, manufacturer and operator in compliance with the Classification Society requirements;
- establish own quality control systems to ensure effectiveness of the activities mentioned above.

It is noteworthy that the assumption of responsibility of Classification Society only addresses the hull structural aspects of classification but not involves statutory aspects. Considering statutory requirements such as life saving, subdivisions, stability, fire protection, etc. impinge on the operational and cargo carrying arrangements of ship and hence may affect its structure safety, when Classification Society carries out statutory surveys, the fulfillment of duties delegated by the Administration is also related to ship hull structure safety.

2.1.2.2 Risk management

Risk is the combination of frequency and consequences. Although elimination of risk is impossible, it is able to control risk. The methodology of risk management is scientific due to its proactive nature. The main body of risk management is to evaluate the frequency and consequences of risk by a systematic review and then provide appropriate risk control measures. The CSR requires that a systematic review to demonstrate an equivalent level of safety is to be carried out for novel design outside the pertinent limitation specified, and by an example the systematic review is described consisting of three stages which are hazard identification, consequences and critical hazard management (The edition of Common Structural Rules for oil tanker, 2005, Para. 3.1.1.2).

Intuitively, limits are the trigger of a systematic review, but it is only one hand and not enough for the timely initiation of the review. On the other hand, it is indispensable that information of the object to be reviewed. In terms of hull structure maintenance, information of structural components has particular significance because the physical situation of hull structure materials, on the whole, is deteriorated progressively in the operational life of ship. The dynamic nature of in-service structure safety is quite different with the static feature of design, so information gathered and structured is as important as limits for the initiation of a systematic review.

Assessment is a method used frequently in the systematic review. Theoretically, risk assessment is comprised of two parts: the probability of occurrence of each hazard and the consequences of the hazard if it occurs really. The fact that few factors of hull structural failure are due to human error in relation to machinery and electrical appliances makes the assessment of the probability of hazard occurring in hull structure more likely to be neglected, which is a notable drawback of the systematic review carried out presently in the management of hull structure maintenance. Be that as it may, the methodology of risk management enables the revolution of existing failure-responded maintenance system to see the light at the end of tunnel.

2.2 Verification of compliance

The tier III in the goal-based regulatory framework, verification of compliance criteria, is the connecting link between functional requirements and the numerous of supporting "standards". It is the role of link makes verification of compliance criteria the part in the framework with the most likely to be pressed. For the reason of balance under pressures, the verification has to fulfill multi-dimensioned requirements and the responsibilities of verification have to be shared by stakeholders.

2.2.1 Multi-dimensioned verification

The dimensions of verification are determined according to functional requirements. As discussed earlier, the criteria for verification of compliance offered in the CSR, for example the equivalent stress, allowable stress, etc. are only used for the assessment of hull structural strength. However, hull structure maintenance involves not only structural strength but also coating, ship operation and management. In the light of it, additional dimensions of verification such as managerial activities, crew's working safety, etc. are to be expected. Besides of classification survey, inspection carried out by the Administration puts examination to hull structure maintenance in place and performs function of verification.

Verification to ship management, in the present maritime safety regime, is attained mainly by the audit to implementation of ISM Code. With respect to the implementation of ISM Code, it must be highlighted that the Code is structured in the methodology of quality control but not risk management, so the ship safety management system established in accordance with the Code has a disadvantage in information gathering, risk assessment and optimization of decision-making, although the need for identification of potential emergency in the management system has been mentioned (ISM Code, 2000, Para. 8.1). In other words, ISM Code does not rationalize adequately an audit to risk management. Seeking help from pertinent procedures and guidelines, for example a guide of IACS to risk assessment in ship operation, is a way out of this mess.

2.2.2 Verification and authority

Verification, in strict meaning, does not refer to the check and conformation based-on civil relation, for example, ship owner check whether the carrying capability of ship design fulfils his or her requirements. A verification recognized should be performed by the authorities because there is a need to publicize the administrative relationship between two interested parties of the verification. More importantly, recognition of the standards observed is implicit in the verification. For procedures, codes of practice as well as industrial standards belongs to the tier IV and V, the recognition is desirable. This is because these standards are adopted by free choice, if they were recognized by the authorities, or to say, gaining admission to a regulatory framework, the service based on the standards would see a wonderful prospect in market and fruitful revenue. As regards the verification performed by ship owner, it is in full of meaning a check to the fulfillment of contractual obligation, which should not be incorporated into the regulatory framework, to say nothing of the illogical idea which has ship designers verifying their own job. In practice, the authorities may delegate their own duties to the organization recognized, i.e. Classification Societies, thus put the organization on a dual status. In context of hull structure maintenance, it is also the case. Although the issues concerning hull structure fall into, historically, the scope of classification, there is not exclusion of them from the maritime safety regime (The edition of CSR for oil tanker, 2005, Paragraph 4.1.2.1). Requirements for hull structure are also specified by national regulations and international regulations such as SOLAS, MARPOL and Load Line convention, etc. Where Classification Societies carry out statutory surveys on behalf of the Administration, the authorized verification has been performed as it is.

Chapter III The objectives of maintenance management of bulk carrier hull structure

To establish objectives is the first phase of structuring hierarchically the goal-based framework of international regulations concerning maintenance management of bulk carrier hull structure. The objectives extend in four dimensions – integrity, durability, capacity and crew protection, the former three ones of which focus on structure safety and the last one emphasizes personal safety on board ship. Each of the objectives interacts and they work together to construct a holistic domain of the objectives of hull structure maintenance management. From another perspective, the objectives can be summarized as compliance with mandatory regulations and rules and applicable codes, guidelines and standards recommended by IMO, the Administration, Classification Societies and maritime industries that are taken into account.

3.1 Integrity

3.1.1 Undamaged structure

A general view of a single skin bulk carrier and a typical cargo hold configuration are shown in Appendix 1. Usual damage to hull structure includes crack, rupture and deformation, which may be caused by poor design, improper operation or accidental contact such as collision. The direct consequence of small structural damage is breaking the prudently designed working condition of local structural members and hence causes them damaged to severer degree or in extended area, at last results in irretrievable structure failure. Structural damage is generally rectified by refinishing, correction or renewal, but it does not means every members of ship hull structure shall be maintained as good as in new building. For a bulk carrier in service, existence of certain structural damage, e.g. deformation to a degree, is acceptable unless it exceeds the related standards. Even considerable damage in some cases, for example deformation found in webs of frame, have to be stiffened by temporary measures due to the rigorous workmanship of thorough repair which is too hard for riding crew to carry out.

3.1.2 Water-tightness

Water-tightness is the connotation of structural integrity and is preserved if there is non-existence of hull structural damage on board. Water penetrations may also arise from serious corrosion of structural members, e.g. open deck, bulkhead, main floor and some plating serving as boundaries of the watertight compartments. Researches show that quite a lot of accidents of bulk carrier structural failure begin with flooding in the foremost cargo hold, which is attributable to water penetration from deck openings due to heavy green sea. The unique layout of bulk carrier without shielding structure on fore open deck aggravates the consequence of green sea, thus preserving water-tightness of deck openings in the fore region, including hatch cover and deck fittings, is vital to prevent flooding in the foremost cargo hold. Failure of water-tightness may cause ship loss of buoyancy and destruction of stability so that capsize the vessel. Any type of water-tightness failure on board is substantial threat to ship safety and shall be eliminated as soon as possible.

3.2 Durability

3.2.1 Resistance to structural fatigue

Structural fatigue is chronic effect of structure degradation, so it is regarded rather as a “process” than a result. Deficiencies of structural fatigue appear normally as crack and break, although it is not the case when the words said conversely. Fatigue of hull structure result from complicated factors, for example material nature, bad workmanship, navigation in extreme weather condition, improper cargo loading/unloading operation, water ballast exchange at sea, wear and tear, even corrosion is testified a causative factor to structural fatigue. Considering the diversity of causal factors mentioned above, methods to enhance hull structural resistance to fatigue should be developed on the basis of root cause analysis. In terms of ship maintenance, moderate navigational environment, cargo loading/unloading and ballast operation as well as steel anticorrosion is demonstrated effective to alleviate hull structural fatigue.

3.2.2 Coat protection

Corrosion of hull structure is unavoidable due to execrable environment at sea: salinity of seawater, temperature, dissolved oxygen content, marine fouling, speed of flow, stray-current, humidity, etc. For the corrosion of bulk carrier structure, cargo corroding and mechanical abrasion during cargo loading/unloading are so significant as to be taken into consideration. Generally, the corrosive consequence of steel structure aggravates gradually as time going by even though the corrosion rate may continue decreasing with time where the corrosion product layer restricting the supply of oxygen. Bulk carrier structure, therefore, stands in an increasingly deteriorating condition, and the objective of corrosion mitigation is to restrict the scope of rust and extent of coating failure in a given term.

3.3 Carrying capacity

3.3.1 Overstress prevention

Overstress of hull structure to be encountered probably in ship service has been deliberatively dealt with in the stage of ship design. If everything remained as scenarios assumed, it would no longer be a matter. Apart from uncertain navigational environment, however, the improper cargo loading/unloading operation may cause considerable stress centralization on local structure. For example, some ports can fill holds at a rate exceeding 16,000 tons/h, so that an overshoot by 2 minutes can lead to serious overstressing (Grundy, 2003, pp. 546). It is not yet a practical reality to measure synchronously the stress distribution in ship hull structure during cargo loading/unloading, particularly to say nothing of detecting symptoms of overstress in fully loaded condition. But fortunately, advanced professional institutions have developed computerization-based software to optimize the plan of cargo loading/unloading, which affords protecting hull structural from overstress. The prearrangement provides ship operator a reliable approach to go for safe loading without overstress of hull structure.

3.3.2 Net scantling reservation

Structure net scantling can be prescribed as an explicit indicator of structural strength required to sustain the loads, excluding any addition for corrosion and voluntarily added thickness such as the owner's extra margin. A depiction of corrosion addition for bulk carrier hull structure is shown in Appendix 2. The philosophy behind the net scantling approach is to (a) provide a direct link between the thickness used for strength calculations during the new building stage and the minimum thickness accepted during the operational phase; (b) enable the status of hull structure with respect to corrosion to be clearly ascertained throughout the life of a ship (The edition of CSR for oil tanker, 2005, Para. 6.3.4.1). Although structure net scantling reservation reaps the benefits of steel anticorrosion, what it reflects is the physical characteristics of hull structure material required by ship carrying capacity. Coating failure may occur but structure net scantling can not be offended in any case. In fact, structure net scantling is such a limit that a fulsome close to it is unallowable and must be tackled by structure renewal.

3.4 Crew protection

3.4.1 Personal safety and health

Personal safety and health of seafarers in employment are of great concern to ship owner as well as authorized inspector and the Administration. For bulk carrier, provisions concerning the prevention of accidents and occupational disease have been laid down by Flag States legislations, or other appropriate means which make the requirements mandatory. These provisions stress on, inter alia, ship hull structural features, special safety measures on/below deck, loading/unloading equipment as well as personal protective equipment for seafarers, which put the related requirements of ILO Prevention of Accidents (Seafarers) Convention, 1970 (No.134) into practice. The implementation of these mandatory provisions is the duty of ship owner and essentials of maintenance management.

3.4.2 Working condition

Scant ventilation and lighting, in addition to cargo dust make the working condition of crew on board bulk carrier abominable, and particularly in cargo hold region the situation is worse. Auxiliary labor such as leveling cargo heap off on loading and sweeping cargo residues after unloading has quite intensity. The significance of hull structure maintenance is to alleviate the psychological pressure of crew by making it better that the hardware circumstances of working. At least, for large equipment e.g. hatch cover which is attached on hull and sensitive to the physical condition of structural members, maintenance of hull structure facilitates the equipment operation and hence saves labor. In broader sense, loosed joint and deformed plate web of ship hull structure are main origin of vibration and noise on board, and to eliminate these deficiencies benefits improvement of crew’s working condition.

Chapter IV Functional requirements for maintenance management of bulk carrier hull structure

To define functions of maintenance management comes down to practice a management theory. Geert Waeyenbergh and Liliance Pintelon argue that a framework for maintenance concept development comprises six steps – identification of objectives and resources, identification of the most important system, criticality analysis, and decision, optimization of maintenance policy and performance measurement & continuous improvement, also the framework start with data gathering (Waeyenbergh & Pintelon, 2002, pp. 306). To condense the idea, such elements as information, identification, analysis, decision, monitoring and modification are essential for the development of maintenance concept. This is to say that functions of maintenance management are the very outputs of the elements fulfilling in a lifecycle of maintenance. In addition, personnel resource remains such important status in management that the competence of crew should be taken into consideration for sound hull structure maintenance.

4.1 Information

Any successful maintenance and repair procedure start with good information. The information for bulk carrier structure maintenance can be classified in two categories: historical data and actual information. To categorize information is in favor of perception to the restriction of each type of them in order to make information analysis critical.

4.1.1 Historical data

Historical data is convenient to obtain. Besides of documents kept by ship-owner, original design plans, manufacture records, survey reports and repair information can be provided by relevant organizations at request of ship operators. Usefully statistic information enable ship operator to have an overview of ship structure safety situation, and historical accident information plays important role in identification of critical structural area on board. The conspicuous disadvantage of historical data is that it fails to reflect current changes of structural safety situation. Over reliance on information of previous records and survey reports may mislead the judgment of structure safety situation on board bulk carrier.

4.1.2 Actual information

Actual information is more important in a sense. The actual information, gathered mainly during inspection on board, comprises not only deficiencies to be found but also the scope or areas to be examined during inspection. Although scope or areas to be inspected extend gradually with a bulk carrier aging, there are always numerous of objectives left out of examination due to the mechanism of random sample of survey to ship in service. The inspection of a prudent bulk carrier operator should be a supplementary to Classification survey in order to ensure no important information is neglected, particularly in the interval of ship survey. The considerable drawback of actual information is the sensitivity of them to operational condition, thus it should be screened appropriately before use in order to keep clear of the negative influence of operational condition diversities.

4.2 Assessment

4.2.1 Approach to categorized assessment

Risk assessments in hull structure safety of bulk carrier in service can be categorized as criticality analysis of structural deficiencies to be found, assessment of structural coating condition and assessments of structural strength. The former two categories of assessment are done by comparing the information gathered during inspection with pertinent standards, while the last one bases on computerized modeling and calculation. Criticality analysis of deficiencies and assessment of coating condition can be done by Classification societies as well as ship owner so long as the implementation of standards is consistent. Structural strength assessments comprise direct strength assessment, i.e. yielding, buckling and ultimate strength assessment, of primary supporting members, detailed stress assessment and hot spot stress analysis of fatigue strength assessment. For the reason of complex calculation, structural strength assessments are generally handed to professional institutions such as Classification Societies to complete. It is noteworthy to point out that the assumption of load and boundary condition of structure in finite element analysis depends on the real operation of ship, and hence impinges on the accuracy of structural strength assessments. In view of it, to be aware of the prerequisite of assessments in detail is important for ship owner.

4.2.2 Identification of critical structural areas based on assessment

An important job subsequent to risk assessments is to identify critical structural areas of bulk carrier. Critical structural areas are sensitive to stress and corrosion thus the structural components in the areas are most likely to suffer cracking, buckling, corrosion, etc. Structural deficiencies in critical areas tend to rapid deterioration and then cause substantial structure failure of bulk carrier. To identify the critical structural areas on board is for the decision of highlighted inspection and prioritized rectification. Where critical structural areas have been located initially, close-up examination, thickness measurement, and tank testing if deemed necessary, are to be carried out to confirm the right of location. As the scope of critical structural areas of bulk carrier is changeable in the operational life of ship, continual identification is entailed.

4.3 Response

4.3.1 Contingency preparedness

Common accidents such as collision, grounding, and flooding as well as fire can cause damage to bulk carrier hull structure. In addition, the risk of heavy weather damage, improper loading/unloading and shifting of cargo should be taken into consideration for the structural contingency preparedness. As technique and procedure are very important for the response to structural emergency, the keystone of contingency preparedness is to be supported in technicalities promptly from the ship company onshore. The shore-based contingency preparedness should comprise, inter alia, (a) procedures for the mobilization of an appropriate company emergency response team; (b) the information of ship particulars, plans, stability and cargo information as well as maintenance equipment on board; (c) checklists to assist in systematic questioning of the hull structural situation during the response; and (d) the composition and duties of the persons on board and onshore acting within the response.

4.3.2 Intervals of maintenance routine

"The inspections and corresponding maintenance measures should be integrated into the ship's operational maintenance routine." (ISM Code, 2000, Para. 10.4,) With respect to hull maintenance routine, an important consideration is proper intervals. Maintenance intervals should be established based on the following:

-- The manufacturer's recommendations and specifications;

-- Predictive maintenance determination techniques (i.e. series of assessment);

-- Practical experience in the hull maintenance;

-- Practical or operational restrictions, e.g. maintenance that can be performed only in shipyard or dry-dock;

-- Intervals specified as part of class, Convention, administration and company requirements.

(IACS Recommendation No. 74, 2004, p.6)

4.3.3 Voyage repair and scheme for repair in shipyard or dry-dock

Maintenance and overhaul of ship hull structure in accordance with manufacturer's recommended procedures and established marine practice, which does not affect ship's classification, can be carried out by a riding crew during a voyage. As regards such maintenance and overhauls may result in consideration of ship classification, they should be noted in the ship's log and submitted to Classification for use in determining further survey requirements (IACS Unified requirements Z 13, 1995, p.3). In some cases, contemplated repairs to primary hull structures, i.e. main longitudinal and transverse members and their attachments, can also be done in voyage provided the repair plan has been submitted to the Classification Society for approval in advance and the repair job is attended by a Surveyor's riding-ship survey or at regular intervals to confirm fit-up, alignment and general workmanship in compliance with Classification recommendations. Even though the repair plan makes good preparation for voyage repair, it is recognized that complete rectification, in some cases, can be performed only in shipyard or dry-dock. From this viewpoint, making scheme for repair in shipyard or dry-dock is associated with maintenance routine.

4.4 Dynamic process of management

4.4.1 Monitoring

Briefly, there are two stages in the process of bulk carrier hull structure maintenance need monitoring. One is to follow up to the change of physical condition of structural components in critical areas on board and the other is to ascertain the effectiveness of response to structural deficiencies. It goes without saying that the connotation of the latter monitoring covers more than the former one which is rather named highlighted inspection. Effectiveness of response to structural deficiencies is embodied in either to reduce the likelihood of adverse events occurrence or to lower the severity of accidents consequences so monitoring to the effectiveness of rectifying measures not only relies on gauging and testing but also needs statistical analysis. The function of gathering information enables monitoring to motivate the review of maintenance decision-making.

4.4.2 Review and modification

Review does not mean audit although the two terms are usually used confusedly. The target of review is the effectiveness of maintenance response, while audit is to verify the compliance of management. Review is frequent as if staying a lower managerial level, but it is the very feature enables review to respond well to the uncertainty of risk. Review, including Master's review and that carried out by authorized person(s), must be independent. For this reason, it is vital that communication between the monitoring doer and the reviewer, particularly the transfer of monitoring information. Modification should be initiated as soon as possible for weakness of maintenance management identified during review and discussed on board before the commencement of activities in order to allow the vessel realize where continual improvement is required.

4.4.3 Documentation

The last chain of the dynamic process of maintenance management is documentation. Documentation is an effective means to consolidate well-tried practices although the conflict between documentation and efficiency of management remains fact. This issue is addressed by reducing the number and size of documentation, for example, using flow charts, forms or checklists to simplify expression, keeping cross-references to a minimum to make amendment much easier. As "each ship should carry on board all documentation relevant to that ship" (ISM Code, 2000, Para. 11.3), to identify the scope of documentation is important for management on board, otherwise not only documentation but also the whole management will change to a large and unacceptable bureaucratic burden. Electronic documentation is an innovation accompanied with computerization of management. For the safety of electronic documentation, some additional measures such as security of access, backup, virus protection and the reliability of power supplies should be taken into considerations.

4.5 Personnel resource

Personnel resource should have been inherent in subjects of management, but unfortunately it is out of place in risk management. The weakness is "bottleneck" of risk management in practice, and to correct it is the reason why identifying personnel resource as an individual element of functional requirements for hull structure maintenance.

4.5.1 Training and motivation

Although each ship is manned with qualified, certificated and medically fit seafarers as required by international and national maritime safety regulations, it does not mean that the staff on board is competent for the duties imposed by management. Safety awareness, skill and language capacity are three main subjects of crew training and concerns of managing maintenance personnel as well. There is no full-time crew on board responsible for hull structural inspection and repair, also it is impossible to increase manning specially for this job thus training provided by ship company plays a major role in raising personal competence. In addition, assistance of the ship company on shore is an important source of competent persons. Motivation of the crew may be achieved by the Master explaining to them how they can personally benefit from fruit of hull structure maintenance as well as encouraging their perception of ownership. This could be achieved through meetings between the Master and crew members who are requested to participate in the fulfillment of the continuous improvement of maintenance management.

4.5.2 Observance of STCW

Making use of personnel resource on board to maintain hull structure is frequently in conflict with observance of STCW convention. According to the convention, the minimum rest periods of ship crews shall be ensured to prevent human fatigue unless an emergency or drill or other overriding operational conditions occur. More importantly, the minimum rest periods specified should not be interpreted as implying that all other hours may be devoted to watch-keeping or other duties (STCW, 1995, code B-VIII/3). In real life, "overriding operational conditions" and "duties other than watch-keeping" are the very pretext used by imprudent ship operators for self-reliant maintenance on board. Imaginably, sometimes they pay for the decision, safety accidents occurring. Managing personnel resource on board for hull structure maintenance must be on the premise that no violation of STCW convention takes place. To program labor support for maintenance reasonably, the working hours or rest periods of seafarers concerned should be recorded and maintained.

Chapter V Verification of compliance criteria to maintenance management of bulk carrier hull structure

To examine the compliance of managerial activities, series of criteria are deployed. In other words, by comparing the output of management with the criteria, it is ascertained that the managerial activities achieve, to what degree, the goals and functional requirements of bulk carrier hull structure maintenance. The criteria involve structural safety situation, structural accessibility, audit and evaluation as well as personal qualification.

5.1 Structure safety situation

5.1.1 Stress limit

Stress limit is employed in structural strength assessment as an indicator of risk. With respect to bulk carrier in service, a special survey program should be work out in advance of periodical survey by ship owner in cooperation with the administration (Resolution A. 744(18), 1993). A very important content of the special survey program is the identification of critical structural areas on board based on risk assessment, which offers a clue to the extent of close-up survey. Usually, criticality analysis of structural deficiencies to be found on board and the assessment of structural coating condition provide enough information for the identification, but such case as accident damage or a considerable change of cargo type entails structural strength assessment. So far, there is no particular stress limit defined for ship in service, and the stress limit used for ship design is the sole standard. For the consideration of safety redundancy in the ship operational life, this treatment is reasonable. The details of stress limit mentioned above can be obtained in the Rules of Classification Societies. The motivation of ship owner knowing the stress limit is to keep discretion of the carry capacity of the ship rather than to memory the bald numbers.

5.1.2 Structure integrity

It is not difficult to detect the deficiencies of hull structural integrity such as fracture, water penetration, etc. if the cleanness, lighting and accessibility in the area inspected is satisfied and the means of inspection is proper. The usual fatigue deficiencies and the place in which they are likely to occur, the probable causes to the deficiencies as well as corresponding corrective measures are summarized empirically in Appendix 3 (See Table 1). In comparison with the insupportable cracking and water penetration, local deformation to a degree can be accepted unless it exceeds allowable limits. Appendix 4 copied the IACS recommended standards and limits of structural member straightness and plating fairness for shipbuilding and repair quality. The standards are suitable for structural renewal of in service ship as well, while the limits can be applied for reference to structural rectification.

5.1.3 Material thickness

In the light of net scantling methodology applied in bulk carrier structural safety, the parameter of material thickness used to determine local renewal of structure is $t_{renewal}$, obtained by subtracting the total wastage allowance from the as-built thickness $t_{as\text{-}built}$. The total wastage allowance is given as wastage allowance plus additional owners extra margin, and the wastage allowance is obtained by deducting the thickness $t_{corr\text{-}2.5}$ from the corrosion addition (t_{corr}). Where $t_{corr\text{-}2.5}$ is the amount of corrosion anticipated or predicted to occur in the two and half years between surveys. The actual amount of wastage allowed in service is taken as (a) locally: the full corrosion addition less an amount for typical wastage between the survey periods; and (b) globally: the full global overall corrosion addition less an amount for typical wastage between the survey periods. The global wastage is monitored in service by evaluating the current global characteristics of the ship.

(CSR, 2005, Para. 6.3.4.4)

5.1.4 Coating condition

It is recognized that the coating condition of hull structure is rated in three categories – GOOD/FAIR/POOR (see Table 2). Common coating deficiencies comprise crack,

Table 2 – Rating system of coating condition of hull structure

	GOOD	FAIR	POOR
Breakdown of coating or area rusted (1)	＜3 %	3 – 20 %	＞20 %
Area of hard rust scale (1)	--	＜10 %	⩾10 %
Local breakdown of coating or rust on edges or weld lines (2)	＜20 %	20 – 50 %	＞50 %

Notes
(1) % is the percentage of the area under consideration or of the “critical structural area”
(2) % is the percentage of edges or weld lines in the area under consideration or of the “critical structural area”
(3) Spot rusting i.e. rusting in spot without visible failure of coating

(Source: IACS Recommendation No. 87, 2004, p.5)

loss of adherence, blistering, and types of corrosion such as rusting, pitting corrosion, crevice corrosion, bacteria corrosion, etc. which are depicted clearly by IACS recommendation 87. ISO 4628 provides series of pictorial standards for designation of intensity, quantity and size of the common coating deficiencies mentioned above. As no definite distinction among the rates of coating condition, identification of information gathered is as important for the assessment as familiarizing with the standards. Application of digital technology facilitates the storage and transfer of photographic records of the information about coating condition and hence enables correct judgment rested on effort of a panel.

5.2 Structure accessibility

To ensure all components of a ship's structure to be surveyed on a regular basis throughout their operational life, it is essential to provide suitable means of access to the hull structure for the purpose of carrying out overall and close-up surveys and inspections. Ships should be designed and built with due consideration as to how they will be surveyed by Administration inspectors and classification society surveyors during their in-service life and how the crew will be able to monitor the condition of the ship (ship structure access manual, 2005, p. 5).

5.2.1 Accessible means

Briefly, there are four access means, i.e. permanent means, portable means, movable means and other alternative means employed for structural accessibility on board. The detailed description of each of them is provided by the "Manual". Whatever accessible means needs periodical inspection and prior-to-used examination carried out by the crew and/or an authorized person. The former inspection is to ascertain the continual effectiveness of the means of access by taking account of any impairment imposed by adverse circumstances such as corrosive atmosphere that may be within the space intended to equipments storage. The latter examination is carried out after the space to be inspected has been ventilated, cleaned and illuminated duly to confirm the means of access in good preparation for employment. Should any damage or deterioration be found in inspection/examination, and the deficiencies were considered to affect safe use of the equipments, measures should be put in place to ensure that the damaged or deteriorated section(s) are not to be further used prior to completing effective repair.

5.2.2 Operational instructions

Instructions to operation begin with planning. The plan includes both the means of access intended to use and the details of an overall or close-up inspection within the space. For the portable and movable means of access, for example ladder, small platform and staging as portable means, cherry picker, wire-lift platform and raft as movable means, and hydraulic arm vehicle, etc. the provision of operational instructions is essential. The instructions also include adequate knowledge about the suitability of the means of access for a given space, with which the operator must be familiar. During inspection, adequate communication between the inspectors and the equipment operators even a backup team (if necessary) should be prepared. In some cases, it is important to hold safety meeting prior to inspection for the purpose of involved members' coordination (ship structure access manual, 2005, p. 12).

5.3 Compliance of management

To verify the compliance of management is so complicate that a means with the acme of perfection for the verification does not exist. So far, audit is thought as one of effective means for verification of management. As regards evaluation of the effectiveness of management, it is out of the verification aiming to publicize administrative relationship in spite of the popularity of the issue.

5.3.1 Audit to management

Generalization is a notable feature of the criteria used in audit to management, and this is because management is susceptible to external environment and has to keep flexible to fulfill its functional requirements. From this point, the consistence of audit is a matter of great concern. Extensive implementation of ISM Code paves the way for consistent audit to the management of ship safety. According to ISM Code, every ship company should develop, implement and maintain a Safety Management System (SMS), and audit to the system, including internal audit and external audit, is carried out periodically. It is noteworthy that audit can only verify the compliance of the ship with respect to the relevant standards at the time and within the scope of its performance. Audit is a sample process and is not exhaustive in nature. Where non-conformities have not been found and reported, it does not mean none exist (IACS recommendation No. 41, 2005, p.3). Therefore, the certification of audit is a prima facie evidence for compliant management on board.

5.3.2 Prime indexes of compliant management

In the light of experience, taking appropriate indexes is helpful in judging promptly on the compliance of a management system where the criteria of verification are generalized. The primary indexes are explicit assignment of crew's duties and well-thought-out working procedure. Looking through ISM Code, more than half chapters are coping with the two issues – duties and procedures. For maintenance management of bulk carrier hull structure, the key point to assignment of duties is identifying the scope of maintenance which can be decided on board and carried out by riding crew, while maintenance out of the scope fall back on ship company. Working procedure should substantiate that the maintenance is governed by risk concept. To develop the procedures should take into account such noticeable factors as history of structure damage, the aging of ship, identification of critical areas of hull structure and the consequences of a given structural failure.

5.4 Personnel organized

5.4.1 Organization feature

ISM Code assumes there are separated roles and responsibilities between ship and the ship company (IACS recommendation No. 41, 2005, p.15). This assumption is obviously impracticable in single-ship and owner-master operation that is the very feature of a lot of bulk carriers. Sometimes the bulk carriers are contracted to be managed by a company outside, and then the organization problem is easier to solve;

other time the ship is the only “site” of the company thus a full-time manager is to be added on board or the role of manager is played by the Master. In whatever case, the supreme management decision-maker is onboard but not onshore. Particularly, the feature of “onboard organization” puts bulk carrier hull structure maintenance at a considerable disadvantage because the review in management process is not entirely independent thus the initiation of modification may be constrained. This problem should be addressed by refinement of the review procedure.

5.4.2 Training schedule

Training schedule consists of two parts: familiarizing with new assignments and instructing. New assignments related to ship personnel may include another ship, a different job or promotion. Familiarizing with new assignments is the process that allows a person embarking for the first time on board bulk carrier or transferred to new assignments to become familiar with hull structure. Familiarization may be accomplished by either lingual information or visual aids such as videos, manuals, etc. The choice and level of details to assist familiarization depends on individual experience and the job responsibilities (IACS Recommendation No. 41, 2005, p.23). Should individuals require essential familiarization with an assignment prior to sailing, then the ship company must identify such requirements and develop an appropriate plan. Instructional materials on board include essential instructions and instructions to equipments operation. Essential instructions define clearly the crew members’ role within the ship’s organization and ensure that they are prepared prior to taking up their duties on board. Instructions to equipments operation provide information to the operation of important equipments, for example, hatch covers attached to primary structural members and the aided equipments employed in inspection and repair on board.

5.4.3 Qualified persons

Weakness of organization can be remedied by qualified personnel. Considering the organizational feature of bulk carrier operation, personal qualification should be emphasized at any time. For hull structure maintenance management, qualified persons comprise qualified Master, qualified site manager (if applicable), qualified operator of movable and portable means of access, qualified NDT operator, qualified assessor, qualified internal auditors to SMS and qualified welder as well as painter. For the persons whose opinion is likely to exercise any influence on the decision-making of hull structure maintenance, professional knowledge and practical experience are very important, in addition, he or she must be given to adequate authority. Qualified persons may be gained by recruitment or selection of personnel if an appraisal system in place.

Chapter VI A case study in coating maintenance management of bulk carrier ballast tank

In this chapter, coating maintenance management of bulk carrier ballast tank is used as an example to illustrate the composition of a goal-based framework of international regulations. Considering the instruments of IMO are vital source of the international maritime regulations, demonstration of the composition is founded on IMO Conventions and the Resolutions of Assembly.

6.1 The goal of coating maintenance management of ballast tank

The Re.11/Ch.I of SOLAS requires that "*the condition of the ship* and its equipment shall be maintained to conform with the provisions of the present regulations to ensure that the ship *in all respects* will remain fit to proceed to sea without danger to the ship or persons on board", obviously, to regulate coating maintenance of ship is an issue the Regulation covers. Researches show that material wastage on board bulk carrier is a contributory factor to structural weakness (Gardiner, & Melchers, 2003, p. 548), so there is logic to give coating protection prominence in hull structural maintenance. Nevertheless, coating itself is also trapped in progressive deterioration, and particularly in ballast tank coating maintenance is more difficult than imagined due to frequent ballasting operation. The feature of degradation suggests that the goal of coating maintenance management of ballast tank is to restore coating condition in the space as far as possible thus to prevent hull structural failure attributable to material wastage.

6.2 Functional requirements of ballast tank coating maintenance management

Functional requirements of management are closely related to the process of management. A typical management process of coating maintenance is illustrated by the flow chart (see *figure* 3). In brief, the process can be divided into three stages,

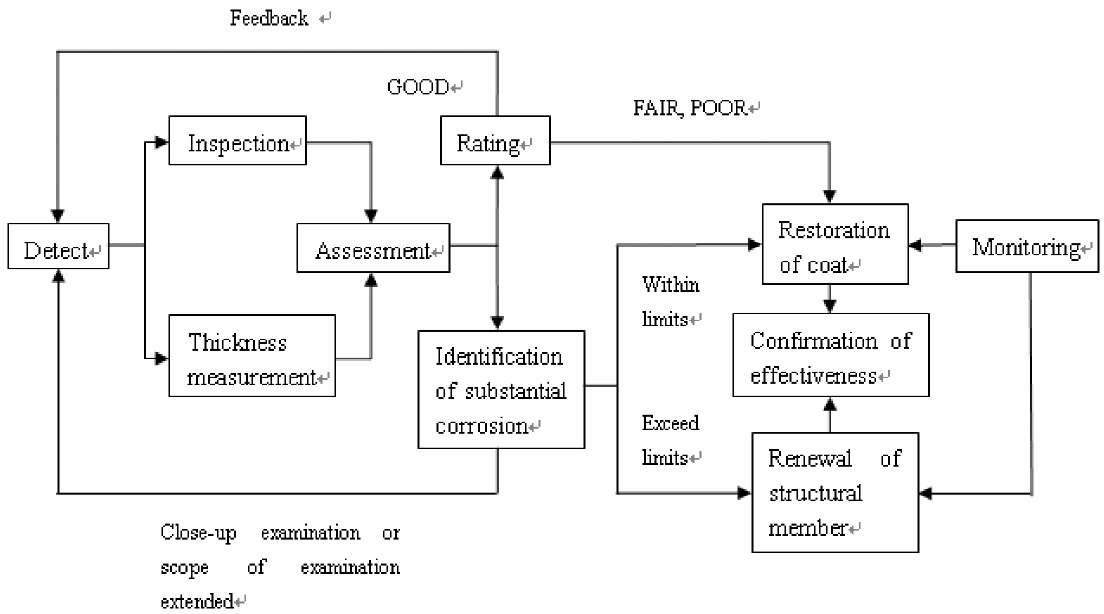


Figure 3 – a flow chart of management process of coating maintenance. (Source: Author)

detecting, assessing and monitoring, which are the main subjects of functional requirements for coating maintenance management on board. As regards personnel resource, it remains a concern, but has not been discussed in detail in the section for the intension of the paper to stress on risk management.

6.2.1 Detecting

There are two means, in the main, to detect material corrosion situation on board ship, namely, inspection and thickness measurement. So far, the governing document providing procedures for inspection and thickness measurement to hull structure of bulk carrier is the Resolution A. 744 (18) of IMO – "Guidelines on the Enhanced Program of Inspection during Surveys (ESP) of Bulk Carriers and Oil Tankers". In this document, the interval, scope and program of inspection and thickness measurement are set up as mandatory requirements, and the duties of implementing the requirements are imposed on the Administration or the organization on behalf of it.

Be that as it may, it does not mean that the duties of ship owner on inspection are relieved, and this idea is affirmed in another document of IMO – the Resolution A. 797 (19). It reads that “ship owners should take appropriate measures to ensure, inter alia, that a planned maintenance scheme is implemented and the restoration of damage to coatings is included in the planned maintenance scheme”. By extension, items of inspection and thickness measurement are to be included in the scheme. The Resolution A. 866(20) of IMO goes one step further in this direction. As recommended in the paragraph 2.3, “terminal operators and members of the ship's crew themselves should regularly inspect … ballast tanks with a view to detecting damage and defects, and the documentation of enhanced survey program (ESP) should be used as guidance …” This is to say that the principles and methods of ESP can be applied in the maintenance scheme of ship owner, and undoubtedly the application will regulate the function of coating maintenance management carried out by ship owner.

6.2.2 Assessing

With respect to assessment of coating condition, there are also many functional requirements found in the three documents, for example “the planning document of close-up survey should comply with a procedure for the application of risk assessment developed by the Organization” (Resolution A. 744(18) of IMO, 1993, Paragraph 5.1.3). It is unnecessary here to pick out all functional requirements for assessment of coating condition in the documents, but the point in the functional requirements deserves attention. To promote the efficiency of coating maintenance, the concept “areas under consideration” and “substantial corrosion” are introduced in the stage of assessment. The number and location of “areas under consideration” varies with different types of ballast tank such as wing ballast tank, double hull side tank and double bottom ballast tank because different areas on board are exposed to different risk of corrosion. For example, a boundary between ballast tank and bunk tank with means of heating is more vulnerable to corrosion so that the boundary is meant to be paid more attention when assessing the probability of coating failure on board. "Substantial corrosion" is identified by thickness measurement, and the identification initiates different responses, either inspection enhanced, i.e. scope extended, close-up examination involved, etc., or deficiencies rectified. To identify "substantial corrosion" is, in effect, assessing consequences of corrosion risk of hull structure in ballast tank. "Areas under consideration" and "substantial corrosion" reflect the very two aspects of risk, probability and consequences. Although it is not often referred to as such, the present practice in assessing coating condition on board is an exercise of risk assessment.

6.2.3 Monitoring

In the risk-based management of coating maintenance, the accent of monitoring is rather on the effectiveness of rectification than on the rectifying measures. The procedures of coating maintenance including pre-treatment, dry film thickness gauging, etc. vary with different lifetime of coating targeted, but it is questionable whether the lifetime targeted, e.g. 5, 10 or 15 years, matches the probability of corrosion risk on board a given bulk carrier. Notwithstanding extensive researches having been carried out, estimating the probability of corrosion risk on bulk carrier still has to rest on empirical model parameters because of the high variability of corrosion rates (Gardiner, & Melchers, 2003, pp. 549). In other words, it is unrealizable to predict accurately how long time the coating in a ballast tank can keep in good condition before program for maintenance, so monitoring to the effectiveness of rectification is the feasible solution to optimize the program of coating maintenance. However, the monitoring to effectiveness is, in practice, usually substituted by classification survey, which not only confuses the duties of ship owner on monitoring but also impairs the function of monitoring due to the restrictions of classification survey on inspection interval. There is advice that ship owner initiate, as a minimum, an annual inspection of all ballast tanks by riding crew (Recommendation 87 of IACS, 2004, p.11). So far, few functional requirements for ship owner's monitoring to the effectiveness of coating maintenance have been found in existing international regulations except that ambiguous description concerning the issue provided by ISM Code – "ship company should ensure that appropriate corrective action is taken" (ISM Code, 2000, Paragraph 10.2.2). The drawback should be overcome during the construction of the framework of regulations concerning coating maintenance management of bulk carrier ballast tank.

6.3 Verification of compliance criteria to coating maintenance management of ballast tank

In accordance with functional requirements, to verify the management of coating maintenance is looking into the managerial activities of ship owner, which puts aside the service of paint companies and ship owner's check to the service. In terms of coating maintenance management, the criteria used in verification of compliance involve coating condition, procedure of coating and working safety.

6.3.1 Coating condition

Coating condition is the most objective criterion used to judge the effectiveness of coating maintenance management. A successful management of coating maintenance ensures that the coating condition of hull structure including ballast tank is maintained in or restored to GOOD condition as far as possible. The authoritative definitions of the parameters, GOOD/FAIR/POOR, in the rating system were made by Resolution A. 744(18) of IMO. Recommendation No. 87 of IACS clarified these definitions in order to achieve unified interpretation and implementation. These definitions and clarifications provide criteria to assess coating condition and then to verify the maintenance management in compliance with functional requirements.

6.3.2 Procedures of coating

Control over coating quality benefits from complete procedures. The most efficient way to preserve the coating system is to repair any defects found during the in-service inspections (Resolution A. 798(19), 1995, Para. 6.2), and re-coating of all the defective surfaces should be carried out in accordance with the manufacturer's specifications and ship owner's managerial procedures. The procedures consist of, inter alia,

-- Procedure of coating selection,

-- Procedure of tank pre-treatment,

-- Procedure of steel material surface preparation and check,

-- Procedure of managing the site for coating application,

-- Procedure of inspection and test after coating application, and

-- Procedure of confirming qualification of persons involved.

The procedures should be in compliance with pertinent requirements of IMO resolutions mentioned above and incorporated into SMS. Audit to the procedures, carried out in accordance with requirements of ISM Code, is the verification to the management of coating maintenance.

6.3.3 Working safety

A main concern of coating maintenance management is that the health and safety of riding crews involved in inspection to coating condition are at risk. On the one hand, inspecting the in-service coating condition of tank entails entry into enclosed space. Prior to the entry and during work, appropriate testing of the atmosphere of the space should be carried out. The Resolution A. 864(20) of IMO provided, in detail, requirements for test procedures, test content and acceptable limits, test equipment and operator as well as additional ventilation where the findings of test unacceptable. The requirements are criteria used to verify the safety of crew's inspection. On the other hand, when inspecting the restoration of coating crews are exposed to flammable solvents and skin-harmed material contained in paints, to say nothing of powders or dust formed during sanding operation or spraying mist which is detrimental to crew's health. Precautions should be taken to reduce the risks of safety and health. Although the Resolution A. 864(20) did not refer to concrete criteria of precautions, it recognized the Administration had power to regulate the issue.

6.4 Supporting "standards" in the framework of regulations

In the goal-based framework of international regulations, the tiers below verification of compliance criteria are occupied by "standards" which play roles of support, although the term "standards" is inappropriate, strictly speaking, to name a wide variety of documents in the tier IV and V.

6.4.1 The tier IV in the framework

Apart from the CSR, the rules of individual Classification Societies that cover the bulk carriers to which the CSR does not applies are to be included in the tier IV so long as they are recognized by the Administration. Procedures and guidelines are also components in the tier IV when certain content of them referred to as functional requirements and criteria have been abstracted, no matter the procedures and guidelines are tailored for bulk carrier or generally applicable to ships. In addition, Circulars of IMO subcommittee and unified requirements/interpretation and recommendation of IACS, in which international industrial standards have been incorporated, are important sector of the tier IV in composition.

6.4.2 The tier V in the framework

On the bottom of the goal-based regulatory framework are industrial standards, codes of practice and safety and quality system for ship building, operation, maintenance, training, manning, etc. Diversity is the attractive characteristics of documents in this tier as if the names of them suggest. Industrial standards of different countries vary in threshold; safety and quality systems differ widely due to managerial means of certain ships; even such soft codes of practice in ship manning and seafarer training recommended by STCW are on mature reflection of respective national legislations. In terms of coating maintenance of bulk carrier ballast tank, series of standards set by ISO and numerous of manufacturer's specification about coating application lay the foundation for the regulatory framework.

6.4.3 Development of supporting "standards"

Supporting "standards" must be verified before integrated into the regulatory framework, regardless of the free adoption of them. The point of verification is whether safety thresholds set in the "standards" satisfy recognized criteria. In context of risk management, the thresholds are expressed by failure probabilities. The time-dependent reliability projections of coating on board ship are shown in *figure* 4, assuming that restoration of coating is initiated when the failure probability reach the threshold of $P_f = 10^{-3}$, and that the overlooked corrosion and inferior repair quality lead to repair efficiency discounted by 4.2%. As seen in *figure* 4, the climbing

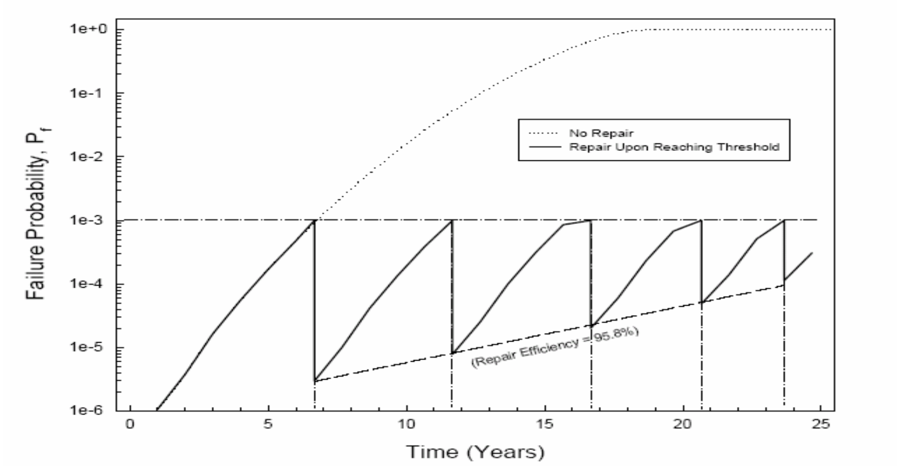


Figure 4 – The reliability projection of coating on board. (Source: Ship Structure Committee, 2002)

trend of tooth root of the reliability projection curve represents degradation of the whole coating condition which, as well as the utmost limit of failure probability, must be lower than the recognized criteria. The time between two adjacent restorations can be understood as inspection interval which plays vital role in controlling the aggravation of failure probability, particularly where the reliability projection curve is steep. Estimating failure probabilities of coating condition in a given circumstance with a view to optimizing inspection interval, for example the interval shorten progressively with coating aging, is an innovative method to keep pertinent standards under the control of recognized safety criteria.

Chapter VII Conclusion

In the development of hull structure maintenance, a tendency towards proactive prevention is the inevitable, which entails maintenance being grounded in the concept of risk. With the spread of risk-based maintenance, the procedures, criteria, etc. functioning in the maintenance should be regulated as other issues of ship safety are treated in the maritime regulatory regime. Notwithstanding numerous requirements pertinent to maintenance management distributed in existing international regulations, an integration of them into a framework is desirable.

For structuring a framework of regulations, GBS is the most advisable philosophy to be followed in the construction, because it opens the way to infuse the concept of risk into regulating. In the goal-based framework, goal is overarching, understandable and feasible to be measured and stands at the top of the framework of regulations. Developing functional requirements is to decode the goal(s), and the approach to decode determines the profile of the framework. A successful development of functional requirements depends on cooperation of stakeholders regardless of the arrangement of responsibilities among them. A well-thought-of approach to develop functional requirements under the goals of hull structure maintenance is risk management due to its proactive nature. Verification of compliance criteria are the connecting link between functional requirements and the bottom tiers of the hierarchical framework. The criteria to verification fulfill multi-dimensioned requirements, and the dimensions are determined in accordance with functional requirements. Verification, in strict meaning, should be performed by the authorities because there is a need to publicize the administrative relationship between the two parties in verification.

Building the goal-based framework of international regulations concerning maintenance management of bulk carrier hull structure is to integrate the existing international regulations pertinent to the subject, which will benefit a spanned comprehension of the regulations. Making connection between the integration with the improvement of hull structure maintenance management, the radical progress of hull structure maintenance management consists in the methodology of risk management coming to fruition. The framework of international regulations is set up for this purpose, and the compositions of upper three tiers in the framework are identified in three aspects: technical parameters, managerial compliance and personnel resource. From another perspective, the composition should be sought from IMO Conventions and the Resolutions of Assembly because the instruments of IMO are vital source of the international maritime regulations. The most conspicuous feature of the tier IV and V in the framework is the diversity of the supporting "standards". The key point to control the integration of the "standards" into the regulatory framework is to verify the threshold set in them complied with recognized criteria. Estimating failure probability of a hazard factor and then adjusting control measures correspondently is an innovative way to keep standards under the control of criteria. As regards the incompatible standards, they will be screened out during verification, preventing detriment to the ground of the framework, so as to ensure the framework of international regulations in a dynamic position.

(Words 11,000)

References

Akpan, U. O., Koko, T. S., Ayyub, B., & Dunbar, T. E. (2001). Risk assessment of aging ship hull structure in the presence of corrosion and fatigue. *Marine Structures*, 15, 211-231.

Allan, T. (2005). *International Maritime Organization current safety issues and goal-based standards*. Presentation at Dalian Maritime University, China.

American Bureau of Shipping. (2005). *Common structure rules & ABS safe-hull express*. New York: Author.

Bievre, A. D. (2004). Goal based standards and common rules of class. In Baltic and International Maritime Council, *BIMCO bulletin* (pp. 26-27). London: Author.

Bishop, P., Bloomfield, R., & Guerra, S. (2004). *The future of goal-based assurance cases*. Retrieved January 2, 2006 from the World Wide Web: http://www.pgb@adlard.com .

Brewer, S. D. (2004). Towards common rules. *Det Norske Veritas Forum*, 18-20.

Chen, C. -T., Chen, Y.-W., & Yuan, J. (2002). On a dynamic preventive maintenance policy for a system under inspection. *Reliability engineering and system safety*, 80, 41-47.

Convention (No. 134) Prevention of Accidents (Seafarers) Convention, 1970, International Labor Organization, (1970).

Convention (No. 147) concerning Minimum Standards in Merchant Ships, 1976, International Labor Organization, (1976).

Cross, F. B. (1997). Facts and values in risk assessment. *Reliability engineering and system safety*, 59, 27-40.

Det Norske Veritas. (2000). Corrosion protection of tanks and cargo holds. *DNV technical report No. BGN-R3600197*. Oslo: Author.

Dunbara, T. E., Peggb, N., Taheric, F., & Jianga, L. (2004). A computational investigation of the effects of localized corrosion on plates and stiffened panels. *Marine structures*, 17, 385-402.

Durango, P. L., & Madanat, S. M. (2002). Optimal maintenance and repair policies in infrastructure management under uncertain facility deterioration rates: an adaptive control approach. *Transportation research Part A*, 36, 763-778.

Eduljee, G. H. (2000). Trends in risk assessment and risk management. *The science and the total environment*, 249, 13-23.

Gardiner, C. P., & Melchers, R. E. (2003). Corrosion analysis of bulk carriers, Part I: operational parameters influencing corrosion rates. *Marine Structures*, 16, 547-566.

Grundy P. (2003). Bulk carriers, *Marine Structures*, 16, 545-546.

Guedes Soares, C., & Garbatov, Y. (1999). Reliability of maintained, corrosion protected plates subjected to non-linear corrosion and compressive loads. *Marine Structures*, 12, 425-445.

Hipkina, I. B., & Cock, D. (1999). TQM and BPR: lessons for maintenance management. *Omega, the international journal of management science*, 28, 277-292

Hoppe, B. H. (2004). *The work of International Maritime Organization on goal-based new ship construction standards*. Paper presented at the European Maritime Safety Administrations Technical Meeting on Goal-Based Standards, Paris, France.

International Association of Classification Societies. (1995). *Corrosion protection coating for salt ballast spaces – Unified requirements Z 8* (Rev. 1). London: Author.

International Association of Classification Societies. (1995). *Voyage repairs and maintenance – Unified requirements Z 13* (Rev. 1). London: Author.

International Association of Classification Societies. (1997). *Corrosion protection coating for cargo hold spaces on bulk carriers – Unified requirements Z 9* (corrected 1). London: Author.

International Association of Classification Societies. (2003). *Confined space safe practice – Recommendation No. 72* (Rev. 1). London: Author.

International Association of Classification Societies. (2004). *A guide to risk assessment in ship operation*. London: Author.

International Association of Classification Societies. (2004). *A guide to managing maintenance – Recommendation No. 74*. London: Author.

International Association of Classification Societies. (2004). *Common Structural Rules: Core environmental and safety parameters used as basis in the Joint Tanker Project (JTP) and Joint Bulker Project (JBP)*. London: Author.

International Association of Classification Societies. (2004). *Guidelines for surveys, assessment and repair of hull structure: bulk carriers – Recommendation No. 76* (Rev. 2). London: Author.

International Association of Classification Societies. (2004). *Guidelines for coating maintenance & repair for ballast tanks and combined cargo/ballast tanks on oil tankers – Recommendation No. 87*. London: Author.

International Association of Classification Societies. (2004). *Shipbuilding and repair quality standard – Recommendation No. 47* (Rev. 2). London: Author.

International Association of Classification Societies. (2005). *Guidelines for approval/acceptance of alternative means of access – Recommendation No. 91*. London: Author.

International Association of Classification Societies. (2005). *Guidance for IACS auditors to ISM code – Recommendation No. 41* (Rev. 3). London: Author.

International Association of Classification Societies. (2005). *Ship structure access manual – Recommendation No. 90*. London: Author.

International Association of Classification Societies. (2006). *Hull surveys of bulk carriers – Unified requirements Z 10.2* (corrected 1). London: Author.

International Association of Classification Society. (2005). *The Common Structural Rules for Bulk Carriers and Oil Tankers*. London: Author.

International Convention for the Safety of Life at Sea, 1974, International Maritime Organization, (1974).

International Convention on Load Lines, 1966, International Maritime organization, (1966).

International Convention on Standards of Training, Certification and Watch-keeping for Seafarers, 1978, as amended in 1995, International Maritime Organization, (1995).

International Management Code for the Safe Operation of Ships and for Pollution Prevention, International Maritime Organization, (2000).

International Maritime Organization. (2001). *Guideline for implementation of ISM code by administration*. London: Author.

International Maritime Organization. (2004). Goal-based standards under development at IMO maritime safety committee. *Maritime Safety Committee 79th session press briefing*. Retrieved 20 July 2005 from the World Wide Web: http://www.imo.org/Home/html .

International Maritime Organization. (2004, October). *Comments on goal-based standards and formal safety assessment* (MSC 79/6/19). London: Author.

International Maritime Organization. (2004, September). *A goal-based new ship construction standards (GBS) approach* (MSC 79/6/12). London: Author.

International Maritime Organization. (2005, March). *Comments on document MSC 80/6* (MSC 80/6/3). London: Author.
Jonsson, P. (1999). Company-wide integration of strategic maintenance: An empirical analysis. *International journal of production economics*, 60-61, 155-164.

Jonsson, P. (2000). Towards a holistic understanding of disruptions in operations Management. *Journal of operations management*, 18, 701-718.

Kelly, T. P., & McDermid, J. A. (2001). A systematic approach to safety case maintenance. *Reliability engineering and system safety*, 71, 271-284.

Khan, F. I., & Haddara, M. M. (2003). Risk-based maintenance (RBM): a quantitative approach for maintenance/inspection scheduling and planning. *Journal of loss prevention in the process industrials*, 16, 561-573.

Krige, G. J. (1998). Management of structural maintenance. In Elsevier science, *Journal of construct and steel* (Rev. vol. 46, Nos. 1-3, pp. 409-410). UK: Author.

Langdon, M. (2003). Class changes ahead. *Motor ship*, 84, 10-14.

Leslie, R. (2004). *Can classification societies respond to the new challenges?* Presentation on maritime transport workshop, Paris, France.

Linderman, K., McKone -S. K. E., & Anderson, J. C. (2004). An integrated systems approach to process control and maintenance. *European journal of operational research*, 164, 324-340.

Luce, S. (1998). Choice criteria in conditional preventive maintenance. *Mechanical system and signal processing*, 13 (1), 163-168.

Marquez, A. C., & Guptab, J. N. D. (2004). Contemporary maintenance management: process, framework and supporting pillars. *Omega, the International journal of management science*, 34, 313-326.

McKone, K. E., Schroeder, R. G., & Cua, K. O. (1998). Total productive maintenance: a contextual view. *Journal of operations management*, 17, 123-144.

Montague, P. (2004). Reducing the harms associated with risk assessments. *Environmental impact assessment review*, 24, 733-748.

Moya -C. -C., M. (2004). The control of the setting up of a predictive maintenance program using a system of indicators. *Omega, the International journal of management science*, 32, 57-75.

Nakai, T., Matsushita, H., & Yamamoto, N. (2004). Effect of pitting corrosion on local strength of hold frames of bulk carriers (2nd Report)—Lateral-distortional buckling and local face buckling. *Marine Structures*, 17, 612-641.

Rankin, W., Hibit, R., Allen, J., & Sargent, Robert (2000). Development and evaluation of the maintenance error decision aid process. *International journal of industrial ergonomics*, 26, 261-276.

Resolution of Assembly 713 (17): *Safety of ships carrying solid bulk cargoes*, International Maritime Organization, (1991).

Resolution of Assembly 744 (18): *Guideline on the enhanced inspections program during surveys of bulk carriers and oil tankers,* International Maritime Organization, (1993).

Resolution of Assembly 797 (19): *Safety of ships carrying solid bulk cargoes*, International Maritime Organization, (1995).

Resolution of Assembly 798 (19): *Guidelines for the selection, application and maintenance of corrosion prevention systems of dedicated seawater ballast tanks*, International Maritime Organization, (1995).

Resolution of Assembly 864 (20): *Recommendations for entering enclosed spaces aboard ships,* International Maritime Organization, (1997).

Resolution of Assembly 866 (20): *Guidance to ship's crews and terminal personnel for bulk carrier inspections*, International Maritime Organization. (1997).

Sander, P., & Wang, W. (2000). Maintenance and reliability. *International journal of production economics*, 67, 1-2.

Saranga, H., & Knezevic, J. (2000). Reliability prediction for condition-based maintained systems. *Reliability engineering and system safety*, 71, 219-224.

Scarf, P. A. (1997). On the application of mathematic models in maintenance. *European journal of operational research*, 99, 493-506.

Sheu, S. -H., Lin, Y. -B., & Liao, G. -L. (2005). Optimum policies for a system with general imperfect maintenance. *Reliability engineering and system safety*, 91, 362-369.

Ship Structure Committee of U. S. Coast Guard, (2002). *Risk informed inspection of marine vessels*. Washington D.C.: Author.

Ship Structure Committee of U. S. Coast Guard. (1997). *State of the art in hull response monitoring system*. Washington D.C.: Author.

Ship Structure Committee of U. S. Coast Guard. (2003). *Fracture toughness of a ship structure*. Washington D.C.: Author.

Skjong R. (2005). *General Principles for Structural Standards*. Presentation at the 80th session of International Maritime Organization Maritime Safety Committee in London, Britain.

Swanson, L. (1997). An empirical study of the relationship between production technology and maintenance management. *International journal of production economics*, 53, 191-207.

Swanson, L. (2001). Linking maintenance strategies to performance. *International journal of production economics*, 70, 237-244.

Swanson, L. (2003). An information-processing model of maintenance management. *International journal of production economics*, 83, 45-64.

Taylor, J. C. (2000). The evolution and effectiveness of Maintenance Resource Management. *International journal of industrial ergonomics*, 26, 201-215.

The joint bulker project of International Association of Classification Societies. (2005). *General introduction to technical background of CSR*. London: Author.

Vanneste, S. G., & Wassonhove, L. N. V. (1994). An integrated and structured approach to improve maintenance. *European journal of operational research*, 82, 241-257.

Vatn, J., Hokstad, P., & Bodsberg, L. (1996). An overall model of maintenance optimization. *Reliability engineering and system safety*, 51, 241-257.

Waeyenbergh, G., & Pintelon, L. (2001). A framework for maintenance concept development. *International journal of production economics*, 77, 299-313.

Waeyenbergh, G., & Pintelon, L. (2004). Maintenance concept development: A case study. *International journal of production economics*, 89, 395-405.

Wang, J., Yang, J. B., Sen, P., & Ruxton, T. (1996). Safety based design and maintenance optimization of large marine engineering system. *Applied ocean research*, 18, 13-27.

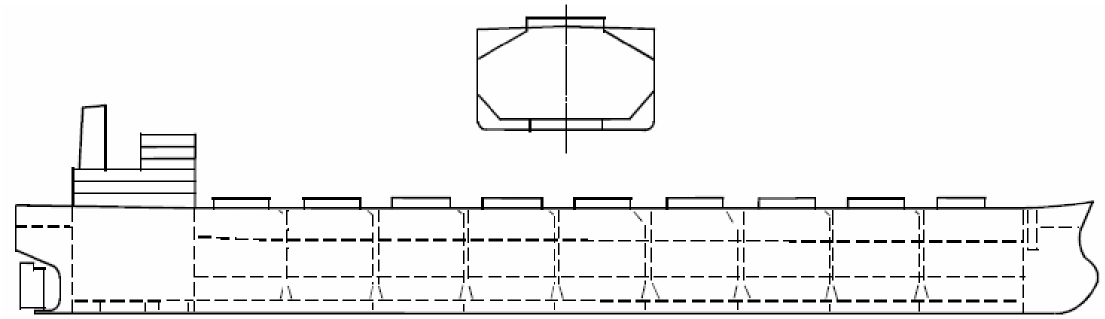
Weinstein, L., & Chung, C. -H. (1999). Integrating maintenance and production decisions in a hierarchical production planning environment. *Computers and operations research*, 26, 1059-1074.

Wirsching, P. H., Ferensic, J., & Thayamballi, A. (1997). Reliability with respect to ultimate strength of corroding ship hull. *Marine Structures*, 10, 501-518.

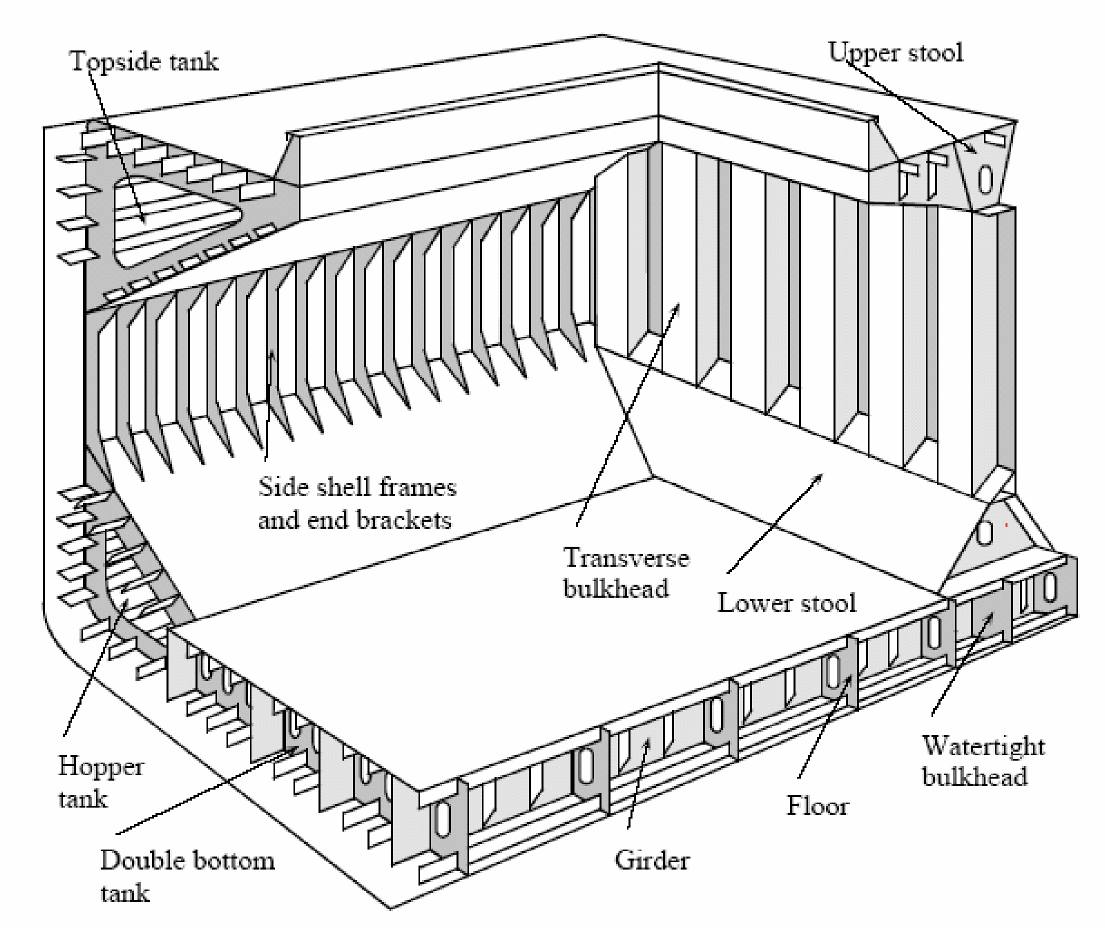
Wu, S., & Clements -C. D., (2005). Preventive maintenance models with random maintenance quality. *Reliability engineering and system safety*, 90, 99-105.

Appendix 1

A general view of a single skin bulk carrier



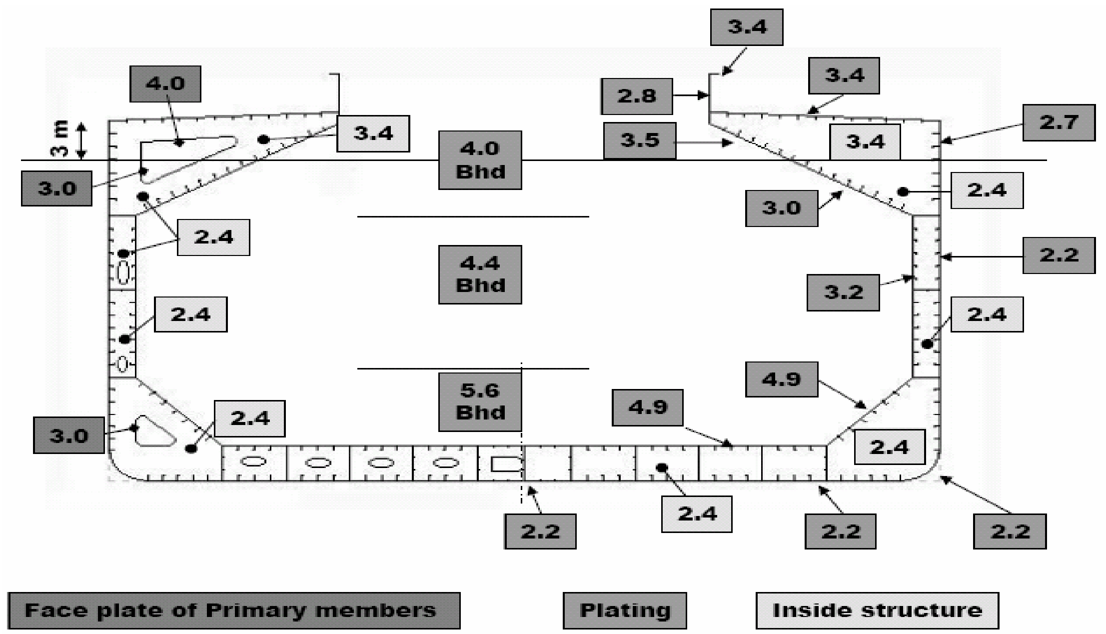
A typical cargo hold configuration



Source: IACS Recommendation No. 76, 2004

Appendix 2

Corrosion Additions

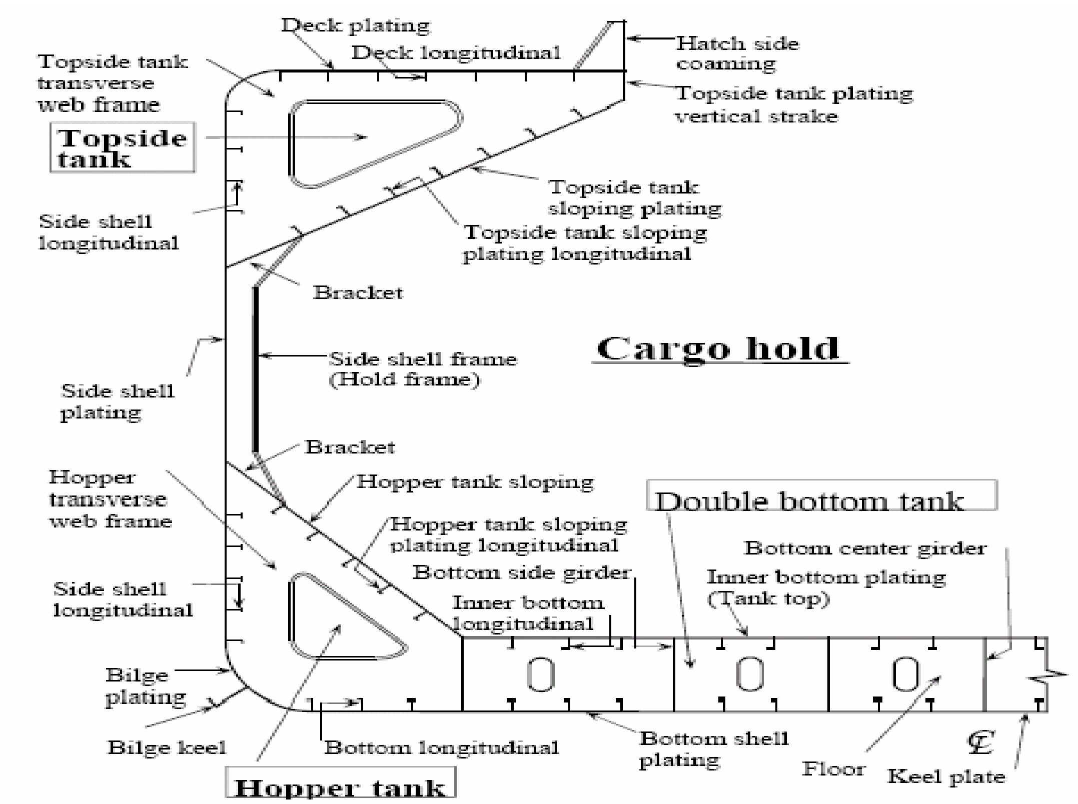


Source: Leslie, 2004

Note: (1) The abbreviation “BHD” means bulkhead;

(2) The numbers in the figure 3 represent the corrosion additions of structure scantling;

(3) Nomenclature of structural members in the figure 3 is depicted as below.



Source: IACS Recommendation No. 76, 2004

Appendix 3

Table 1 – The usual fatigue deficiencies of hull structure

Items	Probable cause	Corresponding correction
Fracture at hatch corner	Stress concentration	The corner plating renewal
Fractures of welded seam between thick plate and thin plate at cross deck	In-plane bending in cross deck strip due to torsion (longitudinal) movements of ship sides.	Insert plate of suitable intermediate thickness
Fractures in the web or in the deck at the toes of the longitudinal hatch coaming termination bracket	Stress concentrations	Additional deck stiffener
Fractures in deck plating initiated from weld of access manhole	Heavy weather	Re-welding
Fractures around cut-outs in cross deck girder	Stress concentrations	Fractured web plate renewal
Fractures in hatch end beam at knuckle joint	Stress concentrations	Fractured part renewal
Fractures in hatch end beam at the joint to topside tank	Stress concentrations	Fractured part renewal
Fractures in hatch coaming top plate at the termination of rail for hatch cover	Stress concentrations	Fractured plate renewal
Fractures in hatch coaming top plate initiated from butt weld of compression bar	Heavy weather	Fractured part renewal
Fractures in deck plating at the pilot ladder access of bulwarks	Stress concentrations	Fractured deck plating renewal, additional stiffener, increased fillet weld at ends
Fractures around unstiffened lightening holes and manholes in wash bulkhead in top-side tank	Stress concentration	Fractured plate renewal, appropriate reinforcement
Fractures in transverse web at sniped end of stiffener in top-side tank	Stress concentration	Modifying stiffener
Fractures in longitudinal at transverse web frame or bulkhead in top-side tank	Stress concentration	The fracture can be gouged-out and welded, or the fractured part renew.
Fractures in transverse brackets in	Stress	Larger brackets inserted

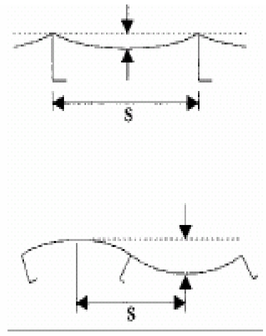
top-side tank	concentration, Inadvertent overloading.	
Fractures at toes of transverse bracket in top-side tank	Stress concentration	Additional bracket and edge stiffener
Fractures in brackets at termination of frame in cargo hold	Stress concentration	The fracture can be gouged-out and welded, or the fractured part renewal
Fractures in side shell frame at bracket's toe in cargo hold	Stress concentration	The fracture can be gouged-out and welded, or the fractured part renewal
Fractures at the supporting brackets in way of the collision bulkhead with no side shell panting stringer in hold	Stress concentration	Fractured plate renewal
Fractures in way of horizontal diaphragm in the connecting trunk between topside tank and hopper double bottom tank, on after side of collision bulkhead	Stress concentration	Fractured plate renewal
Fractures in way of continuation/extension brackets in aftermost hold at the engine room bulkhead	Stress concentration	Fractured plate renewal
Fractures at weld connections to stool shelf plate	Stress concentration	Fractures to be gouged-out and re-welded, fitting welded plate collars in way of the scallop
Fractures in the web of the corrugation initiating at intersection of adjacent shedder plates	Stress concentration	Fractured plate renewal
Fractures at weld connections of floors in way of inner bottom and side girders, and plating of bulkhead stool	Stress concentration at the welds due to scallops	The scallops will require to be fitted with welded collar plates
Fractures in longitudinal at floor/transverse web frame or bulkhead in double bottom tank	Stress concentration	The fracture can be gouged-out and welded, or the fractured part renewal
Fractures in bottom and inner bottom longitudinal in way of inner bottom and bulkhead stool boundaries	Stress concentration	The fracture can be gouged-out and welded, or the fractured part renewal

Fractures in longitudinal in way of bilge well	Stress concentration	The fracture can be gouged-out and welded, or the fractured part renewal
Fractures at weld connection of transverse brackets in double bottom tank	Stress concentration, Inadvertent overloading	Insert plating of increased thickness or size
Fractures in bottom shell/side shell/hopper sloping plating at the corner drain hole/air hole in longitudinal	Stress concentration	The fractured plating renewal
Fractures in bottom plating along side girder and/or bottom longitudinal	Vibration	The fractured plating renewal
Fracture of bow transverse web in way of cut-outs for side longitudinal	Dynamic seaway loading in way of bow flare	Insert plate with increased thickness and/or additional stiffening
Fractures at toe of web frame bracket connection to stringer platform bracket in fore end structure	Dynamic seaway loading in way of bow flare	Insert plate with increased thickness and/or additional stiffening
Fractures in bulkhead in way of rudder trunk	Vibration	The fractured plating renewal
Fractures at the connection of floors and girders/side brackets in aft end structure	Vibration	The fractured plating renewal
Fractures in side shell plating at the connection to propeller boss	Vibration	The fractured plating renewal
Fractures in stern tube at the connection to stern frame	Vibration	The fractured plating renewal
Fractures in brackets at main engine foundation	Vibration	Fractures are to be gouged-out and re-welded, modifying brackets, or inserting pieces and additional flanges.

(Source: Author)

Appendix 4

Fairness of plating between frames

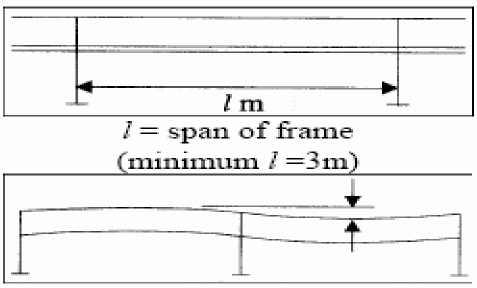
Item		Standard	Limit	Remarks
Shell plate	Parallel part (side & bottom shell)	4 mm	8 mm	 300 ＜ S ＜ 1000
	Fore and aft part	5 mm		
Tank top plate		4 mm		
Bulkhead	Longitudinal bulkhead, transverse bulk head	6 mm		
Strength deck	Parallel part	4 mm	8 mm	
	Fore and aft part	6 mm	9 mm	
	Covered part	7 mm	9 mm	
Second deck	Bare part	6 mm	8 mm	
	Covered part	7 mm	9 mm	
Forecastle deck, poop deck	Bare part	4 mm	8 mm	
	Covered part	6 mm	9 mm	
Superstructure deck	Bare part	4 mm	6 mm	
	Covered part	7 mm	9 mm	
House wall	Outside wall	4 mm	6 mm	
	Inside wall	6 mm	8 mm	
	Covered part	7 mm	9 mm	
Interior Member (web of girder, etc.)		5 mm	7 mm	
Floor and girder in double bottom		5 mm	7 mm	

Fairness of plating with frames

Item		Standard	Limit
Shell plate	Parallel part (side & bottom shell)	±2/1000 mm	±3/1000 mm
	Fore and aft part	±3/1000 mm	±4/1000 mm
Strength deck and top plate of double bottom		±3/1000 mm	±4/1000 mm
Bulkhead		±4/1000 mm	±5/1000 mm
Others		±5/1000 mm	±6/1000 mm

Remark:

L = span of frame to be measured between on transverse space



(min. l = 3 m)

Source: IACS Recommendation No. 47, 2004