1. Introduction

The Kamigoto and Shirashima Oil Storage Bases in Japan are very large offshore structures that have been in operation for several years now. They were planned and designed as national storage bases from the lessons learnt after the first oil crisis in 1973, and are two of the ten oil storage bases constructed all over the country with an aggregate storage capacity of 50,000,000 kl. Most storage bases adopt the system of storing oil in on-ground tanks. The Kamigoto and Shirashima bases, the first of its kind in the world, are very large-scale oil storage systems formed by offshore structures where each oil storage system consists of oil storage barges lined up side by side (hereafter referred to as “storage barges”).

Since the definite plans were started to store oil in offshore barges in the end of 1970s, the storage barges were designed, surveyed and constructed under the Rules and Regulations of ClassNK, Japan’s classification society, (hereafter referred to as “the Rules”). Kamigoto and Shirashima commenced operation as oil storage bases when oil began to be stored in these bases in 1988 and 1995, respectively. The two bases have been operating smoothly since then with no accidents. This indicates that the environmental conditions determined/set at the design stage of these bases and the initial performance assigned to the structures have been adequately satisfied with the actual external forces acting on them during operating conditions. As floating offshore structures, naturally maintenance and inspection of the storage barges have been carried out routinely after the commencement of operation, and they have been dry-docked at specific periods and subjected to detailed inspections. With regard to the implementation of classification surveys including dry-docking of these barges, inspection records and other data of existing oil tankers were referred to before the commencement of operation of the oil bases. The method of implementation of survey was established by considering the beneficial conditions of the locations where the storage barges were installed; namely, conditions such as “storage barges moored under practically identical conditions in the breakwater, so that contact with other ships never occurs,” and “multiple layers of anti-corrosive coatings applied so that the spaces in tanks remain maintenance-free over a long term.” That is, the dry-docking of each storage barge once in twelve years, and the extensive implementation of bottom inspection by in-water surveys were recognized as adequately rational periodical survey methods at the time of the establishment of the Rules.

The outline of these offshore oil storage bases has been presented several times in the past UJNR. The survey system was explained in 1997, and the schedule for extensive revision of the Rules, which gives details of periodical surveys, has also been introduced. The objectives were to reduce risks during the towing of a very large storage barge to the repair-yard for dry-docking and to ensure the overall safety of the storage barge while curtailing the costs associated with dry-dock preparation work.

The Rules were enforced in July 1997 by introducing the “Planned Survey System,” but for the new system, to become a truly effective survey system, various kinds and enormous amounts of actual ship data need to be monitored and an optimum judgement system needs to be established. This report, firstly, describes the Rules applied during the construction of these offshore oil storage bases. Secondly, it explains the concepts of the amended Rules, and suggests the feasibility of applying the new Rules to the maintenance and control of very large offshore structures such as typified by the Mega-float. Finally, it introduces those investigations carried out on various technical topics.
by the organizations formed by the storage oil owner (the Japan National Oil Corporation), ship owners (the oil storage companies) and concerning parties where practical data are being accumulated to ensure the safe operation of storage barges under the new Rules.

2. Classification survey of oil storage barge: Concepts of survey during construction

A floating oil storage system consists of various kinds of equipment and systems including several units of storage barges, the mooring system for maintaining these storage barges at specific positions, crude oil receiving and discharging systems, various kinds of piping systems, power supply system, fire protection and fire fighting system, central control station and systems for preventing marine pollution. Thus, the safe operation of the oil storage system will be guaranteed when all the systems mentioned above have been organically linked and appropriate inspection and maintenance works have been performed regularly.

(The arrangement of the Kamigoto Oil Storage Base is shown in Fig. 1, and as the example of the construction of oil storage barge, that of the Shirashima Oil Storage Base is illustrated in Fig. 2 at the end of this report.)

In principle, the floating parts of the oil storage barge fall under the purview of classification survey. However, since the barges are operated from the central control station located on shore, some part of the on-shore systems associated with the oil storage barge also fall under the purview of the survey. Thus, the classification survey for this storage barge varied considerably compared to that of conventional ships. That is, in case of oil storage barge, most of the equipment that are generally fitted on board were installed on shore, and those equipment were also to be subjected to periodical surveys under the Class.

2.1 Classification survey during construction

The Kamigoto Oil Storage Base consisted of five storage barges, and each of these barges was independently assigned class notations as follows.

KAMIGOTO NO.1 NS* (Smooth Water Service)
(Oil Storage Barge, Oils Flash-point below 61°C)

Prior to the assignment of classification, ClassNK performed the design examination for plan-approval of the barges. However, the items mentioned below were examined with particular attention since they were problems specific to the storage barges.

(a) Specification
(b) General arrangement of storage system including onshore installations
(c) Operation manuals for storage system including onshore installations
(d) Data on sea and weather conditions at the sea area where the storage barges are located
(e) Data of the sea and weather as the design base (including the influence of breakwater and traffic route for towage)
(f) Procedures for structural analysis and calculation sheets for various loading conditions (including temporarily severe conditions during cargo (oil) loading/unloading, tank cleaning and towing)
(g) Intact and damage stability calculation sheets
(h) Long-term mooring arrangements and evaluation sheets
(i) Tank capacity plans and sounding tables
(j) Non-destructive test procedures and plans showing the points of application
(k) Power consumption tables
(l) Plan showing the dangerous areas of the storage barge and list of equipment used in the dangerous areas
(m) Particulars of high voltage equipment provided in the storage barges
(n) Communications and lighting arrangements
(o) Connection diagrams between piping and electric wiring of the storage barge and onshore installations and evaluation sheets
(p) Evaluation sheets of rupture hatches
(q) Procedure of inspection by barge personnel

During the construction, various tests were carried out as part of the classification survey such as rupture hatch tests, tests to confirm operation of various equipment, non-destructive tests of structures and completion survey. Scantlings of structural members at specific positions were measured and recorded as initial data so that they could be referred as the standards during surveys in the future.
2.2 Periodical survey

Periodical surveys of the storage barge were implemented after commencement of its operation, based on the consideration that its dry-docking interval could be made very much longer compared to that of conventional ships. That is, while conventional ships were generally dry-docked for special survey at intervals of four to five years, only one of the storage barges representing the group was dry-docked and subjected to special survey in every four years. If no major problems were found, the condition of other storage barges was checked by in-water survey. This was the concept of the surveys for the storage barges. However, all the barges without exception were regulated to be dry-docked once in twelve years. Thus the opportunity for maintenance and inspection of each storage barge arises once in twelve years, which means the maintenance work on anti-corrosive coatings, equipment and machinery can be scheduled based on the premise of this dry-docking interval.

3. Amendments to classification survey Rules for storage barges

3.1 Concept of amendments

It became evident that unlike conventional ships or mobile offshore structures, oil storage barges or such offshore structures as semi-permanently aground or moored at a fixed location are extremely difficult to inspect at the pre-determined survey period and at the pre-determined survey location. The Rules initially prescribed that every storage barge had to be dry-docked once in twelve years, which was considerably longer than the four to five years period for conventional ships.

However, in case of the eight Shirashima oil storage barges, which were of identical design and operational application, this meant that in order to dry-dock and inspect all the barges within twelve years, one barge had to be dry-docked in approximately one and a half years. To dry-dock the storage barge, approximately one year is required for performing preparatory work such as shifting the oil stored in the barge to other storage barges, cleaning of the tanks, purging of the gases, and towing of the barge. Thus, the oil base (one of the barges) is always either under survey or preparatory work being carried out for dry-docking. Under such circumstances, a considerable amount of time for the oil storage base is taken up for surveys, and it is difficult to say that the original objective of the storage barges has been fulfilled.

To resolve this situation, studies were carried out to confirm whether the storage barges could be inspected, surveyed and repaired at the mooring site. The studies mentioned above were implemented by the Shipbuilding Research Center of Japan at the request of the Japan National Oil Corporation, and completed in 1995. The studies mainly focused on investigative techniques to ensure safety of the barge at the mooring site at a level equivalent to or higher than that realized during dry-docking inspections of the storage barge and concluded that the required level of safety could be fulfilled by combining the elemental techniques developed for this purpose.

Amendments to the Rules related to dry-docking inspections were made based on the results of the studies. There are also offshore structures other than oil storage barges for which dry-docking is difficult to do or sometimes impractical even if the interval for dry-docking inspections has been prescribed especially when the offshore structures are meant for performing special work.

For such structures also, it was decided to establish methods for implementing surveys based on the results of studies conducted on oil storage barges. These methods would serve as guidelines for performing rational surveys and ensuring safety of those structures over the long-term.

3.2 Main features of the new survey Rules

For the purpose of maintaining Class, offshore structures such as the oil storage barges and other type of floating structures should be surveyed periodically by the classification society with proper procedures: where those structures are identical form and practically the same loading conditions, anchored at the same location and consist of multiple units operated as an integral unit with on-shore facilities, or those structures that are semi-permanently aground when performing work, or other conventional type of ships for which conventional survey methods cannot be applied easily.
The “Planned Survey System” (system whereby survey is implemented according to approved survey procedures based on an approved survey plan) was adopted in the new Rule, and survey methods were prescribed for confirming the soundness of the ship structure from strength aspects in a rational and appropriate manner. The essential points of the system are as given below.

1. The survey plan and survey procedure were prepared according to the new Rules, and the timing for witnessing the survey was established according to the survey plan. In this way, the importance of the administrative capability and responsibility of the ship management company increased in relation to the survey period and the survey method. Thus, the establishment of an internal quality system was demanded from the ship management company formulating the survey plan to ensure the existence of a management system.

2. Since design conditions were set considering the environmental conditions in the sea areas where the said offshore structure was installed, its design was based on the premise that the natural environmental conditions could be correctly monitored in practice. If that offshore structure encountered more severe natural environmental conditions than that of pre-set design conditions, occasional inspection or occasional survey had to be carried out. The survey plan had to be reviewed based on the results of those inspection or survey.

3. To rationally perform the survey of the structure, the structural members constituting the structure were classified according to their level of importance. That is, the structural members were classified into the three categories mentioned below depending on the risk of damage to the members or on the effect of damage to the structural members. A diagnosis sheet was prepared beforehand from the aspects of safety of the structure.

(a) Category C: Structural members with high probability of damage or with major damage effects
(b) Category B: Structural members with medium probability of damage or with medium damage effects
(c) Category A: Structural members with low probability of damage or with minor damage effects

4. Survey methods were classified into three stages including the method of visual check of the condition(I); the method of carrying out detailed inspections including non-destructive inspection(II); and a more comprehensive and detailed inspection that included tests for conforming the overall structural functions(III). These surveys were called Level I, Level II and Level III surveys respectively. Requirements were also set for the necessary preparatory work for survey, such as cleaning of the survey locations and so on.

5. The category of structural members, the survey levels and the survey intervals were appropriately combined according to the level of importance and influence level of the members so that rational surveys could be carried out. That is, structural members with a high level of importance and high influence level were subjected to frequent detailed inspections. Structural members with low level of importance and low influence level were surveyed at longer intervals with simpler inspections. The categories and the survey intervals are summarized in the table below.

<table>
<thead>
<tr>
<th>Category</th>
<th>Every year</th>
<th>Every 2 or 3 years</th>
<th>Every 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category C</td>
<td>Level I</td>
<td>Level II</td>
<td>Level III</td>
</tr>
<tr>
<td>Category B</td>
<td>Level I</td>
<td>Level II</td>
<td></td>
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<tr>
<td>Category A</td>
<td>Level I</td>
<td></td>
<td>Level I</td>
</tr>
</tbody>
</table>

6. Structural members in the high importance and high influence level categories, namely Categories C and B were required to be monitored by an appropriate method so that the condition of the ship could be studied.

7. The survey locations, survey levels and survey intervals were reviewed periodically based on the results of surveys. Thus, a survey system that suited the actual conditions could be adopted and also could be applied in structures for longer period usage.

8. Judgement criteria were set that were more severe than those for conventional ships because the dry-docking period is longer and large-scale repairs are difficult to carry out when those structures are at mooring site.

3.3 Survey plan for offshore storage barges

The features of the offshore storage barges are as below.

1. Installed at a location surrounded by breakwater: wave conditions are calm and there is no danger of accidents
such as contact with other ships or grounding.

(2) Has a double-hull structure of ballast tanks, which surround all oil storage tanks. Ballast tanks are always filled with seawater and protect the oil storage tanks from fires.

(3) The structure of the storage tank is so rationally designed that the oil pressure acting on the bulkheads and bottom plating is mechanically balanced with the seawater pressure in the ballast tanks.

(4) Adequate measures against corrosion have been adopted by using anti-corrosive coatings. Secondary corrosion-protection measures have been implemented by providing sacrificial anodes.

(5) Since all barges with the same structural arrangement have been installed at the same location and have identical loading conditions, the results of detailed inspection of one barge allows the condition of the remaining storage barges to be predicted easily.

In view of the construction features of oil storage barges mentioned in (1) to (3) above, the margin of structural strength of the barge with oil stored in it is greater than that of the barge with no oil stored in it. In practice, the main task during the survey of the Kamigoto oil storage barges is not structural survey but the work of checking the effectiveness of anti-corrosion measures and the existence of corrosion. Consequently, the survey work mainly involves inspection of the paint condition, inspection of electrodes (checking electric potential and dimensions of electrodes), and inspection of wearing condition of structural members (plate thickness measurements), and the monitoring of gas pressure and visual inspection of upper deck and areas near the splash zone. As mentioned in (5) above, a typical storage barge may be selected from the series of barges and sampling survey implemented.

Considering the above, a new survey plan and survey procedure were prepared and it was decided to implement periodical surveys of the Kamigoto oil storage barges according to the survey schedule shown in Table 1 at the end of this report.

3.4 Concept of surveys of very large floating structures

The Technological Research Association of Mega-float of Japan carried out field tests on a massive floating structure of 1,000m length with a view to develop this structure as a floating airport. The floating structure, if constructed for actual use, may be estimated for over a long period of 100 years of usage.

In case major damage is found in oil storage barges during surveys, the barges can be repaired temporarily at the mooring site and permanently repaired after dry-docking them. However, structures such as floating airport cannot be repaired in dry-dock even if major damage is detected during the survey. Thus, it is important to perform preventative surveys on such structures that are more stringent than the surveys performed on oil storage barges. Since the structure is extremely huge, survey systems that rely on manpower alone are impractical. Robots and various kinds of detectors need to be employed for the surveys.

Even if robots and other detectors are used, for such structure as massive as the Mega-float, the locations to be surveyed should be carefully selected after considering the importance of the location to be monitored, the possibility of damage to that location, and the classification of the structural members to be inspected.

When structural members are classified, the effects due to damage, the ease of repairs and the ease of detection of damage at that location are to be taken into account. Thus, a survey system that can be used for very large floating structures is likely to be developed based on the similar concepts of the survey system adopted for the oil storage barges.

4. Maintenance of the oil storage barges at the mooring site

By applying the new Rules, it was decided to implement detailed inspections of one representative storage barge at the mooring site after gas-freeing the tanks during the special surveys, which is once in five years.

The storage barges, however, were designed and constructed on the premise that they would be dry-docked and repaired once in twelve years. Since conditions such as the service life of the equipment, means of access for maintenance and repairs during operation have not changed, the prolongation of the interval for close-up survey is likely to render suspension of operation by unexpected gas-freeing work and unavoidable dry-docking work. When
repairs to piping, valves and/or rupture hatches in the oil storage tank become necessary, it would be rational to suspend operation and implement “Major Repairs” wherein all equipment are simultaneously repaired. In this regard, the Shipbuilding Research Center of Japan carried out studies from 1996 to 1998 on the topic “Development of Maintenance Techniques of Oil Storage Barges at the Mooring Site” by the request from the Japan National Oil Corporation.

The studies covered three specific fields: corrosion/wastage prevention of equipment, hull structures and underwater parts of the outer shell. The concept of the studies was to establish the essence of a long-term maintenance system. Thus, a method of estimating the required timings for repairs of those items was developed. This method is intended for items that cannot be repaired over a prolonged interval of time as in the conventional survey system but have to be repaired by “Major Repairs.” For items that required emergency measures, a method of using temporarily installed equipment was developed. A suitable method for prolonging the operating period by partial preventative repairs was also developed. The main items in the three fields are given below.

- **Equipment**
  To prepare for the eventuality of breakdown of dual installations, such as in the case of valves and pipes in oil storage tanks and sealed tanks, the types and capacities of pumps to be temporarily installed were designed and the actual working method was considered. In addition to the above, repair methods were developed that were compatible with the actual condition of various kinds of equipment such as rupture hatches, liquid level gauges and breather valves.

- **Hull structure**
  Since exposed parts can be inspected by routine inspection, methods were developed for confirming the integrity of underwater parts of the hull. That is, in addition to visual examination for confirming the actual condition of parts outside the hull and partial plate thickness measurements, methods were developed to measure large deformations of the bottom part of the hull for understanding the overall condition of the structure. To facilitate the work of thickness measurements of the underwater plating (which is likely to increase in the future), elemental technology was developed to manufacture small-size ROV for that purpose.

- **Corrosion control of underwater parts of shell plating**
  Anti-corrosive coating protects the underwater part of the shell plating of the storage barge. Sacrificial anodes are also provided as a supplementary corrosion control measure. When deterioration of the coating propagates in the future, the anti-corrosion features may be inadequate even if anodes remain on the shell plating. Thus, estimation of the state of deterioration of coating is likely to become very important. To resolve this problem, a new control method was developed where control and measurement methods, data filing methods and simulations of anti-corrosive electric potential are systematically combined. This new method enables the actual condition of corrosion protection to be grasped, enhances the prediction accuracy and enables elaborate corrosion control. In the new control method, collected data is analyzed and evaluated at periodic intervals, and the standard values for corrosion control are revised constantly to enhance the accuracy. Thus, periodic collection of data, that is, monitoring becomes an extremely important element of the control method.

5. **Conclusion**

Already thirteen years have elapsed since Japan’s offshore oil base, which is the world’s largest steel offshore structure for actual use, commenced operation at sea. The maintenance and control system of the storage barges was planned initially for detailed inspections, maintenance and repairs, during dry-docking at least once in twelve years. However, this system was changed to a longer-term maintenance and control system at the mooring site with no provision of dry-docking facilities. This change was based on maintenance and control technology, which was confirmed feasible based on the results of energetic research and investigations carried out over a long period and on the service records of maintenance and inspections during the dry-docking of the Kamigoto oil storage barges that commenced operation first. The classification Rules related to periodical surveys was amended in line with this change.

On the other hand, the importance of routine maintenance and inspection work on the storage barges has arisen
because no longer required dry-docking assumed greater importance on new maintenance and repair jobs on machinery and equipment at the mooring site. Furthermore, the development of monitoring technologies for estimating the timings of major repairs, which necessitate dry-docking of the storage barges, began to be accelerated aiming at their rapid establishment.

At the end of this report regarding the oil storage system, we are very much anticipating in the near-future extra large floating structure realized on the basis of the long-term maintenance technology mentioned above. On this point, we emphasize that the developments henceforth of these studies should be watched with great interest.

Acknowledgement

We have referred to many reference materials\(^1\)-\(^4\) when preparing this report, and acknowledge our gratitude to the authors of them. Especially, regarding the reference of the results of Research Project, “Development of Maintenance Techniques of Oil Storage Barges at the Mooring Site”, we are very grateful to the Japan National Oil Corporation for their wholehearted cooperation.

References

   “Shirashima Floating Oil Stockpiling Terminal”.
   “Inspection and Maintenance for Very Large Floating Structures”.
3) Hirohiko Emi, Toshiro Arima, Susumu Harada and Zhu Ting-Yao (UJNR21-1997).
   “Recent Rule Development and Future Direction of Survey and Inspection Program for VLFSs”.
   “Inspection and Maintenance System R&D for Oil Storage Vessels at Mooring Site”.
   “On the Safety Assessment of Floating Oil Storage System”. Kobe, Japan
6) Hirotake Miyake, Kohzaburo Tamura, Yasuyuki Toge, Osamu Shiobara and Hiromitsu Kitagawa (International Workshop on Very Large Floating Structures, VLFS’96).
   “Research and Development of Inspection and Maintenance System for Oil Storage Vessels at Mooring Site”. Hayama, Japan
7) Susumu Harada (VLFS’96).
   “Recent Rule Development of Survey Program in Service for Very Large Floating Structures”. Hayama, Japan
8) Eiichi Muraoka (ISOPE 2000).
   “Survey and Maintenance of Oil Storage Vessels at Mooring Site”. Seattle, USA

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**Table 1: Survey Program for Kamigoto Oil Storage Barges under the revised Rule**

<table>
<thead>
<tr>
<th>Year</th>
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**Notes:**
- * means Special Survey for Representative Barge (Gas free and detailed inspection of the hull in Dry Dock)
- .. means Special Survey for other Barges at Mooring Site
- £ means Annual Survey for Representative Barge
- £ means Annual Survey for other Barges
- = means Intermediate Survey for Representative Barge
- = means Intermediate Survey for other Barges
- * means tentative schedule of Survey in Dry Dock
Fig. 1 Kamigoto Oil Storage Base

Fig. 2 Shirashima Oil Storage Barge
(a) Arrangement
(b) Structural Configuration