

LIFE-TIME STRUCTURAL INTEGRITY AND TANKER OPERATIONS.

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SYNOPSIS

Structure is a key part of tanker safety in design, construction and operation. Safe tanker design is straightforward though many good concepts such as twin screw will not be common and unless legislated. Common Structural Rules (CSR), gives a framework for adjusting the risk of failure. One can build safer than "rule minimum" tankers.

IACS's No.47 Shipbuilding and Repair Quality Standard and SOLAS's Performance Standards for Protective Coatings (PSPC) provide minimal construction standards. An owner may negotiate higher standards or widen their applicability to structure such as cargo tanks.

After delivery the tanker operator "plays the cards that he was dealt". This paper discusses good tanker structure related operating practices.

INTRODUCTION

Structure is a key part of tanker safety in design and operation. However some good structure safety concepts like twin screw will not be common unless legislated - these are not discussed.

Structural design with Common Structural Rules(CSR) gives a framework for adjusting the risk of failure. Using CSR one can build safer than "rule minimum" tankers and also compensate for expected construction shortcomings. For example one can give a maximum high tensile steel percentage or use CSR's Finite Element Analysis (FEA) to strengthen an Orange high stress design to a Green-Yellow low-medium stress design.

IACS's No.47 Shipbuilding and Repair Quality Standard with SOLAS's Performance Standards for Protective Coating (PSPC), gives a minimal construction standard that can be improved or extended. For example, by specifying: a greater paint Dry Film Thickness (DFT); closer tolerances for structural alignment; and the use of PSPC in cargo tanks.

A site team is needed to ensure that the contract and specification is met. Yards and their sub-contractors are fixed price builders and Quality Assurance is subordinated to Production. Class is the yard's choice and is usually chosen as the low total building cost bidder from several competing Classification Societies.

After delivery the ship operator's job is to meet Class, Flag and Port State requirements as cheaply as possible and stay on-hire. When a ship is sold the operators usually change. How regulations are met and what is the ship's condition depends upon the successive operators.

This paper discusses good structural operating practices.

Author's Biography

Dr. Kennedy has worked in ship owning, management and construction since MIT (1971/79). From 1982 he has been associated with the Papachristidis controlled Hellespont group and has at various times been a MD, CFO, Technical Manager, IT Manager, chief number cruncher and auditor. Although a tankerman, he recently recruited the leader of Hellespont's Offshore Fleet and delivered five Offshore Vessels. Dr. Kennedy handles all of Hellespont's NB design and constructions. He represents Hellespont at industry forums including the Tanker Structure Cooperative Forum. He was a supporting actor (the ship is the star) in Discovery Channel's Superships "Building the Hellespont Fairfax".

BACKGROUND

Design Decisions and Features Impact Technical Operations

The tanker's design controls the (operating expense) OPEX and profit projections.

Obvious structural aspects are:

- (1) length, beam, depth and whether there is a single screw or bow thruster;
- (2) ballast, cargo and fuel tank layouts and their deck piping;
- (3) fore and aft hull shapes and whether there is a sunken poop deck, forecastle, or bulbous bow;

Less obvious are:

- (4) internals such as corrugated bulkheads with stools and access structure(PMA);
- (5) steel types and thicknesses and where they were used;
- (6) the types and areas of protective coatings;
- (7) cargo and ballast pumproom(s) and connecting piping;
- (8) mooring arrangements - the number and position of the winches;
- (9) cranes and deck structures;
- (10) rudder, main engine foundations and shafting;
- (11) ballast water treatment facilities and inert gas system details;
- (12) whether or not there is a hull stress monitoring system or inerted ballast tanks.

Length restrictions will preclude some charters. Manifold positions will control placement of chiksan and hose connections. Steel thickness and protective coatings will influence tank cleaning, and long term coating and steel renewals.

Hydrodynamics dictates hull and propeller shapes. However most yards are only capable of making a "first cut" shape with an engine power that will meet the contract speed. The overall dimensions and the block coefficient is controlled by cargo deadweight and the building dock or slipway size.

Given the shape and size, the yard will use the least amount of steel and manhours possible subject to the signed General Arrangement(GA) and Class requirements. Structural details will be subjected to production optimization. Welding, materials, workmanship and even expected inspector scrutiny will be part of this optimization's input and whose output will steel thickness and type and structural details.

After CSR's Initial Scantling Evaluation(ISE), a FEA model will be made of the cargo area. This model uses a large mesh size - web frame by longitudinal elements. Brackets, manholes and connections are ignored or "averaged". Generic models of structural connections are used to estimate the time to 50% fatigue failure. A few critical connections are modeled with more detail and a very few (e.g. 8) may be FEA modeled with mesh size equal to plate thickness to estimate the time to 50% fatigue failure. The default CSR requirement is a minimum time to 50% fatigue failure of 25 years.

Too short design time or the desire for very speedy production often means that good structural alignments are not well designed in areas of corrugated bulkheads, stool connections and permanent means of access. Thicker plate or high tensile steel is often used to "fix" poor alignments.

In aft and forebody design, prescriptive rules are followed and FEA is not applied. Sometimes yards make an aft end FEA vibration models to adjust pillar and bulkheads to ensure that contractual vibration levels are not exceeded.

The GA's mooring number and size is controlled by Flag or Class rules but their exact position and structural connection details are not specified. Usually at their designed positions, yards make a local design using just thicker plates. The same is true at cranes, pipe supports and thrust block positions.

The enclosing aft hull structure should be non-flexible and the shaft system strong with slope boring of the aftmost bearing. Typically aft hulls are not rigid enough, the shafting and coupling bolts too flexible or undersized. Shaft pulling often results in drilled out reamer bolts. Many designs do not allow "pulling" the shafts without cutting the aft hull shell.

Ballast water management and treatment (BWT) influences structure through hull loads of overpressure if flow through

and alternate tank loading if sequential exchange. BWT means more piping and pumping electrical loads which means a bigger engine room and bigger generators. Inert gas systems affect cargo tank steel and coatings and, if inerted, the ballast tanks. Hull stress monitoring systems measure hull bending and bow acceleration. They can display real time hull flexing and bow forces such as slamming.

Construction Monitoring Including Detailed Construction Drawings

Operationally poor construction means paint problems and steel cracks. Bad outfitting means awkward valve positions; operationally risky control stands and poor line and hose handling. Good detailed design works can partly mitigate poor basic design. Local plate thickness and the type and size of stiffeners used in machinery foundations are the parameters of outfitting design. Step-up platforms and protective supports can help safe operation but any poor detail become crack initiators.

Corrugated bulkheads are increasingly used in tankers. Aligning the folds and stools of corrugated bulkheads with the frames and longitudinals can greatly improve fatigue life. The Tanker Structure Cooperative Forum¹ notes increasing outfitting problems caused by:

1. less experienced yards, surveyors and Class approval engineers.
2. the ignoring of outfitting details - not in the models;
3. limited machinery maker foundation guidelines and details;
4. increased sub-contracting with little feedback to the designer;
5. less involvement of operators in detailed design.

The result? Structural failures induced by poor outfitting design.

Construction Guidance:

IACS No.47 is generally accepted as a standard for new buildings but it does not cover all fabrication issues. Class rules and a good yard's standards book should cover more but not everything is documented. IACS's 47 is not perfect. It gives the *standard* but then gives a *maximum* limit which is usually double the *standard*. Unlimited works are then allowed at the *maximum*. In many yards the workers consistently work at the *maximums* and I have seen production departments deliberately design in an alignment to use the *maximum limit*. Most Classes note areas (e.g. ABS AB-CM) where Class is to be extra vigilant, for example the work must be within the standard tolerance but why "only in these areas"? Isn't "standard", standard?

Temperature and humidity controls such as "don't weld high tensile below zero Celsius" and "don't weld wet steel" are rules but their application details are subject to being detected and then to "negotiation". PSPC is mandatory for ballast tanks, voluntary for void spaces and maybe someday for cargo tanks. It gives surface preparation and coating details but in many places it has many aspects subject to interpretation, for example inter-coat surface testing. Or, the 90/90 rule applied to 320 microns means that no area has less than 288 microns tested at a "few" spots. The trickier areas need more spots checked and a DFT of 320 microns is not magic. Provided no mud-cracking, more DFT is generally better.

Workmanship Practices:

The yard's quality assurance should enforce good workmanship standards, however most yards use rotating sub-contractors with ever changing workers who "QA" themselves. They are only audited by the yard's usually understaffed quality assurance sub-department. Sub-contractor to sub-contractor welding and alignments often vary tremendously which is a sign of inexperienced and poorly trained workers.

Yard coating guidelines are meager. "We follow PSPC" is the refrain but the details are not in the hymn book. Grinding and coating preparation works always have "shifting" sub-contractors. Different contractors are for welding and painting or even for "grinding" versus "painting". When the secondary blast of a block shows welding undercuts or porosity, who fixes it? From surface preparation to the last coat's drying stage temperature, humidity, dust, salt, etc. must be continually checked - not just once.

At the Tanker Structure Cooperative Forum's Shipbuilders 2010 Conference in Tokyo these papers were presented:

"Corrugate Bulkhead Damages" by Mr.Hasan Ocakli, LR

"Design Development of Corrugate Bulkhead" by Mr.Tatsuya Hayashi, ClassNK

"Outfitting Related Structural Defects" by Mr.Laurent Bianch, TOTAL

"Simplified Fatigue Guideline for Deck Opening and Outfitting Supports" by Mr.Kyungseok Lee, DSME

Quality Failures:

Theoretically quality is made by production, enforced by QA, audited by Class and spot confirmed by the site team. In reality its a rare yard where QA can tame the production schedule and it takes a strong Class surveyor and a demanding site team to require fixes to workmanship that violates the standards. Class invariably words its *complaints* with "ACCEPTED SUBJECT TO...". Mistakes are then often pushed to the next production stage until finally at the end it can no longer be fixed without major works. The proper way is to "REJECT FOR FOLLOWING REASONS" and force immediate repair. The site team must do it or it won't happen.

Maintaining of coating standards is difficult and there are tremendous commercial pressures to implicitly accept difficult to detect mistakes. Unfortunately most mistakes greatly affect coating lifetime. It is usually a fight to obtain a block's re-blast and re-coat *merely* because a worker painted over a *little* wet steel or he did not "sand paper" the paint underneath when the inter-coat time was exceeded by *only* a few days. Bad welding can only be partly disguised by grinding and painting with *protective* shop primer but painting over a bad surface or painting at times of high humidity is almost impossible to detect at the final inspection. Regular unofficial inspections and patrolling are required.

Some larger yards have steel tensile and notch testing facilities but generally use it sparingly if at all. Everyone depends upon the mill to block material control chain. Dimensional control or thickness can be easily measured but was the plate really DH36? May be at the mill the plate was labeled correctly. Was this label transferred properly to all cuts and subsequently re-cut small plate pieces? Did the welders who faired the brackets and did the repairs destroy the high tensile properties? Several times I have seen wrong steel in wrong places and I have seen orange hot steel fairing. Some steel testing should be done. And if there is a non-invasive high tensile or notch test method, please notify the author.

Paint is subject to age, temperature during storage, mixing, and batch control problems. The paint maker does only limited batch testing. Paint quality assurance must test the actual paint applied. There is a fast, easy non-destructive test (near infrared Spectroscopy) that can do this but almost no one - yards, paint makers, Class, site teams - does it.

DISCUSSION

Operational Structural Concerns

Cargo loading, carriage and discharge depend on the ship's structure. An operator knows he cannot modify the ship's design and its construction quality. He can study the design by reviewing its basic drawings. He operates after studying needed manuals and drawings. Most operator questions are about piping connections, machinery and control systems. For the structure the operator refers almost exclusively to the "Trim and Stability Booklet", "Loadicator", "General Arrangement", "Mooring Diagrams", "Piping" and "Paint Specification and Repair".

Table I DRAWINGS AND THE OPERATOR

1. **Trim and Stability Booklet.**

The Trim and Stability Booklet (T+S) contains statutory and contractual loading conditions. It shows tank "liquid levels"; ship's drafts, heels and trims; and the ship's longitudinal shear forces and bending moments. The shear force and bending moment "envelope" must be strong enough for all listed conditions. Operational restrictions such as a minimum forward draft to avoid slamming and excluded tank fill levels to avoid sloshing are listed. Port/Starboard staggered loading patterns may be "prohibited".

2. **Loading Instrument (Loadicator).**

The loadicator, a computer program running on a dedicated PC, calculates and shows shear forces and bending moments for input loading conditions. Sometimes there is an automatic calculation, display and alarm for real-time cargo levels which are input by the remote level gauging system. For loading conditions not in the T+S the loadicator is used.

Loadicators are deficient in the input and calculation of racking and dynamics such as slamming, pitching and rolling. Loadicators cover overall longitudinal strength and do not include details of corrugated bulkheads, stools, or of accommodation, bow and deck structures. Most loadicators are based on tank tables which show for liquid levels, the tanks' weights and centroids. Along with the intact hull's longitudinal section moduli these are used to determine trim, heel, shear forces, bending moments and deflections. Usually these tables are obtained from different models than those of construction. Generally loadicators do not model hull damages and it is a requirement that the operator contract to an approved shore side modeling service (e.g. RRDA).

3. **General Arrangement, Capacity Drawing and Mooring Arrangement.**

The routine drawings used by an operator are the General Arrangement (GA), the Capacity and Mooring Arrangements which give the ship's layout, manifold locations, and locations of the winches and bits. Tank layouts and draft versus displacement allows an overall cargo check. This is often sufficient for a terminal to accept the ship and to determine the cargo lift. Cargo details such as, grade segregation, require more detail.

4. **Hull Piping, Cargo and Ballast Piping Diagrams.**

These diagrams answer cargo questions such as "How many grades? In which tanks? With what valve segregation?" During operations, they can be used to adjust the loading or discharge plan. A chief officer may detect a problem before it becomes important. He may adjust the load or discharge plan to temporarily eliminate a potential risk. For example, adjacent tanks may be discharged at the same time to eliminate a possible internal leak.

5. **Midship Section/Transverse Bulkhead (MS) and Construction Profile.**

These drawings are used to troubleshoot structural faults. Steel thickness measurements are compared with those on the drawings. These drawings also show bulkheads, webs, and stringer structures and are consulted whenever there is a hull concern. The construction profile shows the steel's type and thickness in a "quilt pattern". In the case of cracking or buckling these may explain why there were problems. Renewals and repairs will use these drawings to restore and improve the damaged structure.

6. **Paint Specification and Paint Maker Repair Procedures.**

What kind of paint? How many coats? The DFTs?

The paint specification is used to answer these questions especially at dry dockings. For the hull, expected lifetime, roughness, compatibility, etc. are additional concerns. Ballast and cargo tank coatings have the same concerns especially in older ships that require coating repairs or renewals. The paint maker's procedures should give guidelines for what type of repairs may work and what type of new paint will be compatible with any remaining old paint. Generally repair procedures are for repairing mechanical damages such as chipped paint caused by dropped tools. These damages should be fixed so that the damage does not grow from undercutting, cargo chemicals or ballast mud. Coating renewals may be demanded by both the Flag/Class "penalty" of annual inspections for not "good" coatings and the commercial penalty of a Condition Assessment Programme grade worse than CAPS 2.

The operator considers the daily operating regime as structural wear and tear that will be fixed at the dockings. Currently most internal tank coatings start to fail after 10 to 15 years of service and this means a tremendous increase in coating repair time. A riding team may be used to shorten dry dock coating repairs and to keep a good reputation and CAPS.

It is the operator who maintains the ship's structure and who sometimes fixes design and construction problems. I have seen cracks develop from poor bracket toes and "missing" slot-collars and seen these fixed by the operator with better toes and collar plates.

Operating Practices - Good and Bad for the Structure

The operator's basic practices will be similar for old and new ships but the specifics and priorities will differ. Always the first step is to ensure that the data and drawings of the ship are both onboard and ashore.

1. Structural Drawings/Data:

As discussed above the following must be onboard and ashore:

- Trim and Stability Booklet.
- Loading Instrument (Loadicator).
- General Arrangement, Capacity Drawing and Mooring Arrangement.
- Hull Piping, Cargo and Ballast Piping Diagrams.
- Midship Section/Transverse Bulkhead (MS) and Construction Profile.
- Paint Specification and Paint Maker Repair Procedures.

The FEA model's colored stress output levels for the structure and its "fatigue" connections helps to determine areas of concern and to make an inspection plan. They should be onboard and ashore for good communications. Structural outfitting details are needed to understand photos and to discuss repair jobs with Class and workshops. A drawing is often better than a photo in identifying what is important.

The shore should have a working copy of the loadicator. This enables confirmation of ship's load condition and facilitates cargo discussions between ship and shore. Hull repair works may require an unusual load condition that can only be checked by the loadicator.

2. Driving the ship and Hull Monitoring:

Crew generally will not knowingly load a ship to her maximum shear force or bending moment and chief engineers don't want to run the main engine at more than 80-90%. However the bridge team, especially on large ships in an aft wheel house, will often drive the ships hard in heavy weather.

An operator can install a hull monitoring system which has deck strain gauges and a bow accelerometer. The system will display the actual bending moments and bow forces in the wheel house and record them on a PC. While Oil companies *like* ships to have such equipment, the real user is the bridge team who will have actual structural feedback during good and bad weather. The data can be transmitted ashore and may be presented to the charterer.

Advance weather routing can also reduce long term fatigue associated with bow slamming and hull flexing caused by heavy seas but a hull monitoring system records the actual sea impact. The micro weather and sea state near the ship frequently differs from the larger grid-size and scale of weather routing services. Wind, waves, swell heights and directions have influence on each specific ship's dynamic responses and these can vary significantly from those "predicted" by a general "ship model".

Having a direct measure of the sea impacts will help in making the "correct" corrective action.

3. Inspections/photos crew and shore:

If there is a collision or grounding the office will send a representative to the ship who will investigate the damage and determine the fix. In addition there is also a possibility of internal damages resulting from the failure of the venting system (i.e. the PV/V valves). Usually the reports of such damage come from the ship and are inspected and photographed by the crew. Most operators send a representative to oversee any repairs or to prepare a job description for quotation.

Most operators require the crew to inspect all ballast and cargo tanks at least once per dry dock cycle (every three to five years). Naturally if there is a problem with cargo lines, hydraulics or valves the crew will be in the tank. Whatever the reason or timing, when in the tank photos should be taken of both the overall tank condition and of various standard positions within the tanks. These will enable an understanding of coating failures and steel corrosion.

I would recommend taking:

- paint DFT readings at the same standard locations.
- steel thickness readings.
- pictures of hammered anodes (hammered to ensure zinc hydride removal).
- photos of paint scribe tests and photos of past scribings.

Over time, the above data and dated photos will give a quantitative appraisal of the coating and steel conditions. Whenever a superintendent visits he should either go into a few "fresh" tanks or those tanks whose reports were particularly bad.

A good test of a ballast tank anodic protection and coating condition is to measure the voltage potential of the tank through time. With a silver chloride (AgCl) reference cell the voltage between the seawater and the tank's

steel should be about 850 mV. When ballasted, the anodes "pump" electrons into the steel hull and ensure that the steel hull stays intact by not putting its "own" electrons into the water. The plotted voltage in a well protected tank should go from 0 to 850 mV in less than two days. In an under-protected tank the voltage will stay low and never reach 850 mV. If, for example, the voltage stays at 450 mV then this means the steel is rapidly corroding. Put anodes in immediately and start preparing for a coating job.

A tanker's inert gas system (IGS) produces a gas with less than 5% oxygen. This gas usually has a SO₂ (sulfur dioxide) level after the IGS scrubber that is roughly 1% of the fuel's sulfur. A 3% sulfur fuel will yield 300 ppm SO₂ in the inert gas. This gas will cause sulfuric acid corrosion near the IGS outlets. Photos and measurements of DFT and steel wastage near the IGS outlets should be made. A good or double scrubber can reduce this level to less than a harmless 2ppm. Ideally there should be no scrubber water carryover and the gas should be "dry". There is no corrosion when there is no or low oxygen. Inert gas stops corrosion.

Mud buildup in a tank is bad because with sulfur reducing bacteria, such mud can help form a highly corrosive bio-film. If the tanker is operating frequently in muddy waters the ballast exchange may not remove the mud and the crew should periodically "fire hose" the mud from the tanks. Inspect the tanks when this is done.

Cargo tank inspection should be done whenever convenient. This will ensure that the crude or product tank washing is working well, the tubing and valves are good and that the steel and coating conditions are satisfactory. Poor washing means lingering crude deposits which are corrosion sites.

Mechanical damages to a ballast or cargo tank's coating should be "repaired" by fresh water rinsing, solvent wiping, drying, and applying coatings (at least two coats and better three). Photos should be taken with the date and location noted.

The hydride coating on the anodes can disguise the real wastage. A hammer or crowbar to remove outer coatings is necessary. The anode's condition should be noted and if it looks "half" wasted then renew the anode. If the steel bar skewering the anode rusts through at the anode's ends the anode, now a useless dangerous weight, must be removed to stop mechanical damage to the coating and hydraulic control tubing.

The standard anode types are aluminum and zinc. Aluminum hydride deposits near the anode are dangerously slippery and if an aluminum anode falls or is dropped it can generate a spark sufficient to ignite any hydrocarbon vapors. Zinc anodes do not have slippery deposits and a falling zinc anode cannot cause an "explosive" spark. Hydride deposits on anodes, not uncommon in well painted tanks, can infrequently become an insulator. Hammering or scraping will reactivate the anode.

4. Divers, Groundings and Collisions:

The hull must be surveyed by Class about every 2.5 years. Groundings and collisions are reason for additional inspections that may require divers. It costs little for divers to video/photograph the hull during inspection.

Besides looking for structural problems the divers can also:

- clean the engine room intake/outlet (sea chests grills) of growth.
- check/photograph the propeller for cavitation and other damages.
- polish the propeller.
- check/photograph the hull condition (damage and marine growth).
- measure rudder pintle wear/down/clearances.
- report on external propeller shaft seal condition and the rope guard.
- check/photograph the bulbous bow anchor chain chafing areas.

5. Deck Problems

The main deck has its share of corrosion and potential cracks. The deck is the outermost fiber - globally the most highly stressed place. Transverse cracks can start at bad outfitting detail which can cause a weak area or one that is detrimentally "hard". For example, drip trays can become the outer fiber and attempt to carry the ship's bending moment or a mid-deck boson storehouse can induce cracks at its deck connection.

The main deck structures are often maintenance headaches. Low drip trays must be removed and the deck underneath *really* cleaned, grinded, wiped down and then painted to a DFT of 300 microns. If this is not done then there will be significant corrosion on the deck underneath.

A weak thrust block on the cargo piping system may result in pipe support movement and the cracking of deck connections. Stairs, valve platforms, etc. are connected to the main hull structure and poor detail will result in corrosion areas from cargo sulfur, saltwater entrapment and high local stress.

The deck should be checked regularly and trouble areas photographed, fixed, cleaned, prepared and painted. Do not paint over rust. I have seen areas that had a good looking paint job but when walked on felt strangely cushioned. Painting over rust and then painting over the paint that is on top of the rust can result in a multi-layer paint surface on top an ever growing inward rust "cushion". Not good.

Operating Practices - Class, CAPS, Dry Docks and Underway Repairs

If PSPC is properly followed the ballast tank coatings should last for 15 years without any repairs other than those for small mechanical damages. At the end of 15 years the coating should be more than "good" and any future deterioration should be gradual and in areas that have had a "harder life" such as on a plate whose other "side" has heating coils. Eventually PSPC regulations may cover void spaces and even crude oil tanks. This should improve the long term protection of structural steel.

All tanks should be inspected and their steel and coatings measured and recorded. A failing coating should be protected by installing many anodes which will postpone steel wastage when the tanks are full of sea water. Any substantial corrosion will require inserts and replacement. After such repair the surface and welds need preparation and proper coating. Too many small welded pieces are bad and prone to corrosion. Avoid the quilt look and replace the larger encompassing areas.

Small areas of failed coating can be chipped, fresh water washed, grinded, solvent wiped, and painted with two and more coats. Larger failed areas need water, grit or slurry blasting and then the wipe down and painting. The cost of repairing large areas in-situ can cost 20-40 USD/m². It is not only the failed areas but also the adjacent good old coating areas that require cleaning, "feather" blasting and then painting.

Treating a ballast tank on the run means not filling that tank. The ship and the office can often route the ship so that the tank under repair can remain empty. But if, for example, meeting an air draft requirements means filling then afterwards this tank must again be fresh water washed, etc. With blasters and dehumidifiers an experienced team can fix ballast tank areas with the possible exception of the hopper. A team could stage the hopper but it would mean a lot more equipment and time. Tank coating works not done "on the go" must be done in a yard where there is manpower and equipment. The coating renewal job includes:

- demarcating the areas for old coating removal.
- deciding how much adjacent areas to feather and/or roughen.
- fresh water washing (the chloride ppm of the water must be low).
- scraping, cleaning and blasting of the affected areas.
- checking and maintaining the environment(temperature, humidity).
- inspecting the areas before painting (e.g. Bresle - salt and dust).
- stripe coats and coatings with proper inter-coat time.
- the final inspection and acceptance of the DFT (dry film thickness).

Low cost yards may have plenty of manpower but will they have the enough of the needed equipment? Can the yard provide trustworthy quality assurance or must the operator "police" the job or just audit it? How long will the job take? How much offhire?

Quality assurance measures must be rigorously enforced. It makes no sense to spend 20-40 USD/m² and not do a good job. Commercially the need for annual inspections in those tank areas not "GOOD" and the difficulties in chartering with a bad CAPS will push the owners to fix the coatings.

CONCLUSIONS

CSR, PSPC and IACS No.47 provide a design and construction framework. This framework can allow design upgrading and its guidance is helpful even if it is not complete. The owner must ensure that the yard builds in accord with the specification.

The operator is given a designed and constructed ship. Structurally, the operator relies on these plans: General Arrangement, Trim and Stability Booklet, the Loadicator, Capacity Drawing, Mooring Arrangement, and Hull and Cargo/Ballast Piping. For repairs and structural problems he also uses the Midship Section/Bulkheads and Construction Profile and for coatings the Paint Specification/Repair Guide. Both shore and ship must have these drawings.

The operator must inspect the ship and tanks regularly, and record and photograph their condition. Tank cathodic protection may be measured from anode wastage and by time plotting the voltage potential in the ballast tanks. Mechanical damages to the coating should be repaired and recorded. Whenever the coating is failing put in plenty of zinc anodes and confirm the tanks potential to ensure good anode connections inside.

While weather routing may help in lowering structural fatigue the best way to minimizing weather and sea impact is to

directly monitor hull bending moments and bow forces. These can provide the bridge team with actual ship forces such as slamming and longitudinal flexing. This should make sure that the ship is not driven hard and provide a record.

The ship's structure requires that the inert gas and venting system work well. If the gas is well "scrubbed" then any tank corrosion can be slowed down or stopped in anoded and inerted cargo or ballast tanks. In some voyages there may be ballast tank mud buildup which should be hosed out.

When tank coatings fail extra anodes should be installed and inerting considered. A coating repair team with blasting gear and dehumidifiers may be necessary to avoid substantial corrosion and a bad CAPS rating. The dry dock specification should include quotes for ballast tank coating refurbishment.

In summary an operator should:

- ensure he has the key plans ashore and onboard.
- inspect periodically in detail all ballast/cargo tanks.
- ensure that the PV/V is working. Inspect tanks with any excuse.
- wash out mud and make sure there enough anodes (check 0->850mV).
- install a hull monitoring(strain gauges and bow accelerometer).
- inspect periodically the external hull - clean sea chest grids.
- consider upgrading the inert gas system and inerting all tanks.
- check the deck for cracks and never ever paint over rust.

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