A MASTER'S GUIDE TO

Ships' Piping

RINA

The Standard

A MASTER'S GUIDE TO SHIPS' PIPING IS THE FOURTH PUBLICATION IN THE MASTER'S GUIDE SERIES.

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The Standard P&I Club's loss prevention programme focuses on best practice to avert those claims that are avoidable and that often result from crew error or equipment failure. In its continuing commitment to safety at sea and the prevention of accidents, casualties and pollution, the Club issues a variety of publications on safety-related subjects, of which this is one. For more information about these publications, please contact either the Managers' London Agents or any Charles Taylor office listed in this guide.

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Image: Pipes with grip-type joints

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INTRODUCTION

Everyone knows about the effect of corrosion on a ship's hull, but few people consider the effect of corrosion on piping. Pipes pose a hidden danger, a danger that is often forgotten about.

Pipes are silent workers, conveying fluid or allowing air to enter or to leave a space, and are the means by which many control systems operate. They are unnoticed until pipe failure occurs and a machine stops operating, a space floods or oil is spilled. Pipes penetrate almost every enclosed space, as well as the shell both above and below the waterline, and the weather deck. There is no system on a ship that has such enormous potential to cause fire, pollution, flooding or even total loss.

The majority of ships' pipes are constructed of ferrous material, a material that is attacked by all forms of corrosion. As a ship ages, so does the piping system. Maintenance is not always easy, because pipes, unlike the hull, are difficult to examine because of their numbers and inaccessibility. It is practically impossible to maintain them internally, where most corrosion takes place, and at times just as difficult to maintain a pipe's external surface. As a result, pipes can receive minimum maintenance, and pipe failure is often the result. As an operator once remarked when asked, "When is it necessary to replace a pipe?", "When it bursts."

AS AN OPERATOR ONCE REMARKED WHEN ASKED, "WHEN IS IT NECESSARY TO REPLACE A PIPE", "WHEN IT BURSTS."

The purpose of this guide is to alert ships' crews to the danger of catastrophic loss that can result from pipe failure. Our intention is to raise awareness of the limit of redundancy in pipe design and the difficulties involved in the surveying of ships' piping. Pipe failure will only be prevented by a proactive approach to inspection, maintenance and repair.

Eric Murdoch

Image: Deck cargo piping on a tanker

PIPES AND P&I CLAIMS

Failed pipes cause, or contribute to, many serious claims.

- Bagged grain on a small bulk carrier was damaged after water escaped from an air pipe running between a ballast tank and the cargo hold. The pipe had a corrosion crack where it connected to the tank top and water escaped through the crack when the ballast tank was overfilled. The ship was 18 years old, but nothing had ever been done to protect the pipe from corrosion; not even a lick of paint. Cost – $120,000. Repairs to the pipe would have cost less than $50.
- Bulk fertiliser was damaged when water escaped from a topside ballast tank via a sounding pipe that passed through the tank into the hold below. The pipe was cracked and holed inside the ballast tank which contained saltwater ballast and water drained from the tank into the hold. Cost – $380,000. Damaged sounding pipes are easily identified during inspections and repairs are inexpensive.
- A cargo ship foundered and four crewmen lost their lives, when a seawater-cooling pipe in the engine room burst and the engine had to be stopped. The ship was blown onto a lee shore where it broke up on the rocks. Cost – four lives and $1m. Corroded seawater pipes connecting directly to the shell are often wrongly repaired with a doubler. Doublers should not normally be used to repair shell plating.
- A product tanker was gravity ballasting into a segregated tank. The ballast line passed through a cargo tank. When ballast stopped flowing, a corrosion hole in the line allowed oil to escape into the sea through an open valve. Cost – $975,000.
- The main engine of a bulk carrier was seriously damaged when alumina in the cargo hold got into its fuel tank. There was a hole in the air pipe that passed through the cargo hold into the tank. Cost – $850,000. The pipe had never been properly examined during surveys.
- A diesel alternator caught fire after a low-pressure fuel oil pipe burst and sprayed oil onto the exhaust manifold. The pipe had been vibrating, and this movement had caused the pipe's wall to chafe and become thin. The claim cost a new alternator and $100,000, but the fitting of a pipe support would have cost a mere $2!

BASIC INFORMATION

- The majority of ships' pipes are made of mild steel.
- Flow rate, viscosity and pressure of fluid being carried determine a pipe's diameter.
- Pipes in areas of a ship where there is a risk of gas explosion are earthed because fluid flow can build up a static electricity charge. Bonding strips are used across flanged joints to maintain conductivity.
- Pipes that pass through other compartments pose potential subdivision issues, especially open-ended pipes.
- Pipes, especially open-ended ones, compromise the integrity of the compartments they pass through.
- The water circulating in cooling pipes will corrode them over time.
- Pipes passing through tanks containing liquid are exposed to corrosive attack on both surfaces.
- Pipes carrying liquefied gas seldom suffer internal corrosion.
- Visual checks of the external surfaces of a pipe will not indicate its condition because it could be internally corroded and have a reduced wall thickness.
- Most abrasive corrosion and consequent internal thinning happens where the pipe bends and at elbows.
- Liquid flowing quickly will be turbulent as a result of fluid separation and cavitation. Flow turbulence in a pipe will cause pitting. A pipe with the correct diameter for the job will eliminate turbulence.
- Pipes can be joined by butt-welding, with flange connections or mechanical joints. However, the number of flange connections allowed in the cargo pipes of a chemical tanker is strictly controlled by classification society rules.
- Good pipe alignment during assembly of a run prevents 'locked-in' stress.
- The use of expansion (mechanical) joints, such as dresser-type joints, is restricted to locations where pipes move because of thermal expansion or contraction, or ship bending. Classification society rules prohibit their use for the connection of cargo piping in chemical tankers. The most common expansion joints are compression couplings or slip-on joints.
- A pressure test of 1.5 times design pressure is a strength test; a test at the design pressure is a tightness test. Pressure testing can show the small cracks and holes that will not be found by a visual examination.
- Pipes are held in place by supports or clips that prevent movement from shock loads and vibration. Pipe failure is common when pipes are allowed to vibrate.
- Pipes carrying flammable liquids have as few joints as possible and these are shielded to prevent leaks from coming into contact with hot surfaces.
- Mechanical joints are not normally fitted on pipes carrying flammable liquids.

PIPES AND SHIP CLASSIFICATION SOCIETIES

Ship classification societies publish regulations for the design and installation of ship piping systems, defining strength, materials, system requirements (routeing), testing procedures and surveying requirements.

Classification society rules require ships' pipes to be inspected during annual, intermediate and renewal surveys.

Annual surveys

Pipes are checked visually. A pressure test is done if there is any doubt as to their integrity. Pipes connecting to the shell are subject to particular attention.

Intermediate surveys

The requirements are similar to those applying to annual surveys.

Renewal surveys

Pipes are checked visually and hammer-tested, with some also being pressure-tested. The surveyor will select which pipes are to be pressure-tested. Pipes carrying superheated steam, the fire main and those that are part of a fixed gas fire extinguishing system should always be tested. Some pipes might also be selected for dismantling and internal inspection.

A general outline of the survey requirements for different ship types is shown in Table 1 on page 6.

CLASSIFICATION SURVEY REQUIREMENTS

Classification societies have specific requirements with regard to ships' piping systems that follow the general survey criteria for the rest of the ship. The table below gives an outline of these requirements.

Table 1

Annual Survey

ALL SHIPS

All essential services are generally examined with particular attention given to all fixed fire extinguishing systems and to water/fire extinguishing systems. A test under working conditions of the fire main is arranged.

The bilge pumping systems are examined and tested.

TANKERS

In addition to the classification requirements applicable to the rest of the ship, the surveyor will complete, as far as is possible, a general examination of all cargo, steam and water ballast piping, including pipes located on deck, in the pump room, cofferdams, pipe tunnel(s) and void spaces.

Particular attention is given to:

- Inert gas piping to verify the absence of corrosion and gas leakage. A test under working conditions is arranged.
- The crude oil washing system and its fittings.
- The pump room.

BULK & DRY CARGO

In addition to the requirements for the rest of the ship, piping in cargo holds and water ballast tanks are generally examined as far as is possible, including pipes on deck, in void spaces, cofferdams and pipe tunnel(s).

Image: Spectacle flange

Table 1 cont

Intermediate Survey

ALL SHIPS
The scope of intermediate surveys is the same as annual surveys.

TANKERS
The annual survey requirements apply; however, depending upon the surveyor's findings during the general examination, he may require pipes to be dismantled, hydrostatically tested and have their wall thickness measured, or all three.

BULK & DRY CARGO
The scope of intermediate surveys is the same as annual surveys.

Renewal Survey

ALL SHIPS
The survey involves extensive examinations and checks to show that all piping systems are in satisfactory condition to allow the ship to operate and for the new period of class to be assigned (provided proper maintenance and required interim surveys are carried out).

Machinery and all piping systems used for essential services are examined and tested under working conditions, as considered necessary by the surveyor.

Steam pipes are specially examined. Superheated steam pipes with a steam temperature exceeding 450°C require additional tests.

In addition to the annual and intermediate survey requirements, fixed fire-fighting equipment is tested under working conditions, including relevant gas bottles, which are hydrostatically tested.

Compressed air pipes are removed for internal examination and are subjected to a hydrostatic test.

Piping systems for fuel or lubricating oil are carefully examined.

TANKERS
All piping systems within cargo tanks, saltwater ballast tanks, double-bottom tanks, pump rooms, pipe tunnel(s) and cofferdams, including void spaces adjacent to cargo tanks, and pipes that pass through the deck or connect to the shell, are examined and tested under working conditions. The surveyor checks for tightness and looks to establish if their condition is satisfactory.

In addition to annual and intermediate survey requirements, all machinery used for liquid cargo services is examined, including ventilation pipes, pressure vacuum valves and flame screens.

The inert gas systems are tested under working conditions. The systems' main components are examined internally.

On the basis of results of these examinations, additional checks can be required, which may include dismantling, hydrostatic tests and/or thickness measures, or all three.

BULK & DRY CARGO
All piping systems within cargo holds, saltwater ballast tanks, double-bottom tanks, pipe tunnels, cofferdams and void spaces adjacent to cargo holds, and pipes that pass through the deck or connect to the hull, are examined and tested under working conditions to ensure that they remain tight.

Image: Suction filter

SHIPS' PIPING SYSTEMS

Bilge system

The bilge system is used to remove small quantities of fluid that have leaked or condensed into a dry space. The system serves the machinery spaces, cargo holds, cofferdams, voids, stores, tunnels and pump rooms. Each space has its own piping but the pump is likely to be shared.

The capacity of a bilge system is defined by the diameter of the bilge main and pump capacity for the volume of the enclosed space.

In passenger and cargo ships where the engine room provides bilge pumping, the whole ship is the 'enclosed space'. The diameter of the bilge main is:

$d = 25+1.68\sqrt{L(B+D)}$

where,

d = internal diameter of bilge main, in millimetres

L = length between the ship's perpendiculars, in metres

B = extreme breadth, in metres

D = moulded depth, in metres

In a tanker with a separate cargo pumping and piping system, the 'enclosed space' is the engine room and the diameter of the bilge main is:

$d = 35+3\sqrt{Lo(B+D)}$

where,

Lo = length of the engine room, in metres

Cargo ships are required to have two bilge pumps with non-return valves fitted to prevent back-flow or cross-flow.

The pumping system in a passenger ship must be able to drain water from any dry space when one or more of the ship's other compartments are flooded. However, the system is not required to empty the flooded space. A flooded passenger ship is required to have at least one bilge pump, with its own power supply, available for pumping. Bilge suctions must have remotely operated suction valves. The minimum number of pumps required is three or four, depending on the ship's design.

Mud boxes and strum boxes (line filters) are fitted at the ends and in bilge lines to stop debris being sucked into the pipe.

The requirements for bilge systems on ships carrying dangerous goods are basically the same as for cargo ships. However, systems drawing fluids from gas-dangerous spaces are kept segregated with their own pumps and pipes, where appropriate, from systems serving gas-safe spaces.

Image: Deck piping

SHIPS' PIPING SYSTEMS

Ballast system

Ballast is taken on to increase a ship's draught, particularly the stern draught, when sailing without cargo. On a dry-cargo or passenger ship, the ballast system is operated from the engine room. On a tanker, the entire ballast system is located within the cargo area and is operated from a pump room.

Ballast piping is usually made of ordinary mild steel. A ship's size determines the capacity of its ballast system.

Ships' firefighting systems

Piping is used extensively throughout a ship for fire control purposes. The specific features of ships' fire-fighting equipment are governed by the Safety of Life at Sea Convention (SOLAS). Many SOLAS requirements have been put into classification society rules. They include:

- **Fire main**

  Mild steel piping fitted with hydrants for hoses where saltwater is used for manual firefighting. The fire main is designed for a typical working pressure of about 10 bar. Pipes in the fire main are affected by corrosion both externally and internally. Pipes are joined with flanged connections.

- **Sprinkler systems**

  Small-bore pipes kept permanently charged with freshwater at about 10 bar pressure. A sprinkler system is arranged to release automatically at temperatures of about 70°C, so the system can both detect and extinguish a fire. The system uses saltwater after the fresh. After use, it is flushed with freshwater to minimise corrosion. Some systems operate at higher pressures.

- **Water spray systems**

  Usually small-bore piping, which is dry when not in use. A water spray system is operated manually and looks similar to a sprinkler system.

- **Inert gas (IG) piping**

  Fitted on all tankers over 20,000 dwt and on all tankers fitted with crude oil washing (COW) systems. IG piping is usually large diameter low-pressure mild steel, with smaller diameter branch lines. The internal surface of inert gas piping does not usually corrode. The external surface is painted but will corrode if the paint coating deteriorates.

- **CO_2 piping**

  Relatively small bore hot galvanised mild steel piping designed to withstand the surge loads that occur with the release of CO_2. Main CO_2 lines are designed to withstand the same pressure as that of CO_2 bottles, while distribution lines off the main valve are designed for a lower pressure. Typically, the main line is pressure tested to 200 bar, the design pressure being at least 160 bar.

- **High-expansion foam**

  Uses foam with an expansion ratio of 900 to 1 in mild steel low-pressure piping. Pressure in the lines ranges from 4 to 5 bar. Foam compound in storage tanks is pumped to a foam generator. The system is required to deliver foam at a rate of one metre of compartment depth per minute.

Image: Low expansion foam monitor

SHIPS' PIPING SYSTEMS

- **Low expansion foam**

  Uses foam with an expansion ratio of 12 to 1 in mild steel low-pressure piping. Typical pressure in low expansion foam piping is 12 bar.

- **Dry powder**

  Used mainly for the fixed fire-extinguishing system on the deck of gas carriers and on older chemical tankers. Dry powder is held in tanks and is propelled by nitrogen gas stored in pressure bottles. Dry powder delivery pipes are pressurised to 18 bar.

Pipes carrying fuel oil and flammable liquids

There are two principal types of pipes that carry fuel and they are categorised by the pressure the pipe is designed to withstand. Low-pressure pipes are used to move fuel from a storage tank to a service tank to an injection pump; high-pressure pipes are used to deliver fuel from an injection pump to an engine combustion chamber. Ships' fuel is usually stored in double-bottom tanks, deep tanks, side bunker tanks, settling tanks or service tanks. Piping between a service tank and a fuel transfer or booster pump is rated as low pressure. However, between each pumping stage, pressure increases.

It is a mistake to assume that even if a pipe's pressure is relatively low, fuel will not spray from a crack or small hole.

Pipes from fuel tanks can pass through ballast tanks and pipes serving ballast tanks can pass through fuel tanks. Because of pollution risks, classification societies have stringent rules restricting the length of any oil pipe passing through a ballast tank (and vice versa); it must be short, have increased wall thickness and stronger flanges.

The Safety of Life at Sea Convention (SOLAS) includes requirements for fire safety in engine rooms. In particular, special double-skinned pipes must be used to deliver fuel to engine combustion chambers. These are made of low carbon steel alloys and operate at high pressure, between 600 and 900 bar. Double skins are necessary because pipe fracture will cause fuel to spray in a fine aerosol. Fuel will ignite on contact with a hot surface, such as a turbocharger casing or exhaust pipe. The second skin is to guard against direct spraying. The pipe is designed so that fuel will be contained in the space between the outer skin and the main pipe, and will drain into a collecting tank fitted with a high-level alarm.

Low-pressure lubricating and fuel oil pipes passing close to a hot surface have to be secured against the possibility of oil spraying from a flange. To prevent this, the flange is usually taped. In addition, and whenever possible, the pipes are routed clear of hot surfaces. Similarly, to prevent leaking oil falling onto a hot surface, pipes should never be allowed to run above a hot surface.

Regular thermographic surveys of hot surfaces will identify those risk areas that are sufficiently hot to ignite spraying or leaking fuel. Preventive measures to be taken include additional lagging, spray or drip shields.

Fuel oil transfer pipes are usually mild steel and may corrode. The calculation for minimum wall thickness includes a small allowance for corrosion. As a pipe ages and corrodes, leakage can occur. Inspection programmes should concentrate on identifying worn or corroded pipes.

SHIPS' PIPING SYSTEMS

Engine cooling system

Water carried in pipes is used to cool machinery. The main engine is cooled by two separate but linked systems: an open system (sea-to-sea) in which water is taken from and returned to the sea (seawater cooling), and a closed system where freshwater is circulated around an engine casing (freshwater cooling). Freshwater is used to cool machinery directly, whereas seawater is used to cool freshwater passing through a heat exchanger.

The particular feature of an engine cooling system is continuous fluid flow. Fluid in motion causes abrasive corrosion and erosion. To reduce the effects of turbulent flows, seawater systems incorporate large diameter mild steel pipes, the ends of which open to the sea through sea chests where gate valves are fitted. If a seawater cooling pipe bursts, both suction and discharge valves will have to be closed to prevent engine room flooding. In order to make sure the valves operate correctly when you need them to, open and close them at regular, say monthly, intervals.

Seawater pipes are usually mild steel, but galvanised steel, copper or copper alloy are also used. Freshwater cooling pipes are generally made of mild steel.

Air and sounding pipes

Air pipes allow an enclosed space to 'breathe'. They prevent over-or under-pressure by letting air in or out of the space when liquid is pumped in or out, or when temperature changes cause air or fluids to expand or contract. Cargo holds are ventilated by air pipes passing through the weather deck and these are fitted with self-closing watertight covers (headers). This is a Load Line requirement.

Sounding pipes are small-bore mild steel pipes used to measure the quantity of fluid in a tank or a hold bilge. The pipe allows a tape or sounding rod to pass through to the bottom of a tank or hold. Deck sounding pipes pass through the weather deck and are fitted with screw-down caps. Sounding pipes for engine room double-bottom tanks are fitted with self-closing cocks. It is imperative that sounding pipe caps or cocks be kept shut. Sounding pipes are a potentially dangerous source of progressive flooding. An engine room can be flooded through an open sounding pipe if a ship's bottom is holed. A cargo hold can be flooded through an open deck sounding pipe when water is washed on deck in heavy weather. Holes in weather deck air pipes also cause hold flooding during heavy weather.

Air and sounding pipes are normally constructed of mild steel. Most of the time, these pipes do not come into contact with liquid, either inside or outside. The size of an air pipe serving a tank is determined by comparison of the pipe's cross-section area with that of the pipe that will fill or empty the tank. This determination, by the designer, is to avoid the risk of over- or under-pressure. Air and sounding pipes that pass through other compartments are a potential source of progressive flooding. It is difficult to inspect air and sounding pipes located inside cargo spaces or ballast tanks. However, the integrity of air pipes for ballast tanks can be checked by overfilling the tanks. Pipes passing through a dry cargo space must be inspected for damage caused by contact with grabs, bulldozers, etc. It is advisable to open and to inspect air pipe headers on the exposed weather deck once every five years following the first special survey. This is necessary because corrosion on the inside of an air pipe header will not be noticeable externally. Screw-down caps are fitted on the top of sounding

Image: Ventilation pipes

SHIPS' PIPING SYSTEMS

pipes. These caps should never be mislaid or replaced with wooden plugs. To extend the life of air pipe headers, they should be galvanised. The self-closing cocks on engine room sounding pipes should never be tied open.

Cargo piping – tankers

Cargo piping in tankers is usually mild steel and is protected from rusting by external painting. Most large oil tankers have a ring main system that allows increased operational flexibility but with the penalty of reduced segregation. Tankers fitted with deep-well pumps in cargo tanks have dedicated piping. Each tank will have its own pump, pipe and cargo manifold. Stainless steel piping is invariably used with stainless steel tanks. On chemical tankers, cargo pipes must be joined by welding. Flanged connections are allowed on oil tankers, as well as on chemical tankers at valve connections and for fitting portable spool pieces, which are removable short lengths of pipe used for segregation of piping. Regular pressure testing of cargo pipes is essential to detect weak points before they fail.

Hydraulic piping systems

Hydraulic pipes are high-pressure pipes. Hydraulics are used for:

- Manoeuvring the steering gear
- Actuating controllable pitch propellers and thrusters
- Control of watertight doors and valves
- Lifting appliances and deck equipment
- Opening stern, bow or side doors
- Moving mobile ramps for hatch covers
- Driving cargo and ballast pumps and for many other minor shipboard utilities.

It is a requirement that hydraulic systems for steering, pitch control and watertight doors have dedicated piping and pumps.

Some hydraulic fluids are highly flammable. As a result, hydraulic equipment and pipework must be kept clear of hot surfaces. Alternatively, hot surfaces must be protected by spray shields.

It is important to prevent the external corrosion of hydraulic piping located on deck. Hydraulic pipes operate at very high pressure and corrosion-induced weakness frequently causes hydraulic pipes to burst. A high standard of cleanliness is necessary when working with, or replacing, hydraulic piping. Check the systems regularly for leaks, corrosion or mechanical damage.

Use only good-quality and clean hydraulic fluid.

PIPE DESIGN

Classification societies publish rules for design and fabrication of ships' piping. The rules consider how the pipe will be used, the fluid conveyed, materials for construction, and welding and test procedures. Ships' piping is grouped into three categories, each of which has different technical requirements.

Class I pipes have to comply with the most stringent rules. They include fuel oil pipes operating above 16 bar pressure or above 150ºC, and steam pipes where the temperature exceeds 300ºC.

Class II pipes fall between the two rule requirements.

Class III pipes have the lowest requirements. They include fuel pipes that operate at or below 7 bar pressure and 60ºC.

During design of piping systems, fluid temperature, pressure and the type of fluid conveyed have to be considered.

Materials

Most pipes are made of mild steel. But pipes that carry dangerous chemicals or particularly corrosive fluids are manufactured from stainless steel. Some chemicals can be carried only in stainless steel cargo tanks and pipes. Some seawater pipes are copper, but plastic is often used for ballast, brine and sanitary pipes. The use of plastic pipes elsewhere in a system is restricted because of the requirement for them to pass a standard test for fire-resistance. It is not usual for plastic pipes to be constructed in a way that will enable them to pass the most stringent, level 1, fire test.

There are three levels of fire endurance test. In each case, the test procedure is the same, the difference being the duration of the test and the presence, or otherwise, of fluid inside the pipe. At level 1 testing, the endurance period is one hour with a dry pipe. It is 30 minutes with a dry pipe at level 2 and 30 minutes with a wet pipe at level 3. Passing the level 1 fire test is the highest standard. If plastic pipes are to be used, the fire-resistance rating and classification society rule requirements must be checked first.

Pipe dimensions

A pipe is sized by its internal diameter. The required diameter of a pipe depends on the minimum cross-section area necessary to permit passage of a fluid of given viscosity at a given velocity. A pipe's wall thickness depends on the pressure, the temperature of the fluid conveyed and construction materials. Pipes operating at high pressure, such as hydraulic pipes, have thick walls, while pipes that operate at low pressure, such as ballast water pipes, can be designed to classification society rule 'minimum thickness'. Pipes that connect direct to the ship's shell have thicker walls. (See table 2 on page 14)

During design calculations, an allowance for corrosion is factored into the wall thickness. However, the calculated wall thickness can never be less than rule minimum thickness. It is a mistake to believe that the corrosion allowance is enough to prevent failure from uniform corrosion before the pipe is 'design life-expired'.

Pipes passing through tanks must have thicker walls. An allowance for corrosion is added to the pipe's wall thickness to allow for possible external and internal corrosion. The allowance for corrosion is effectively doubled. (See table 3 on page 17)

PIPE DESIGN

Minimum wall thickness for steel pipes

The graph shows the classification society required minimum wall thickness for low-pressure steel pipes.

Table 2

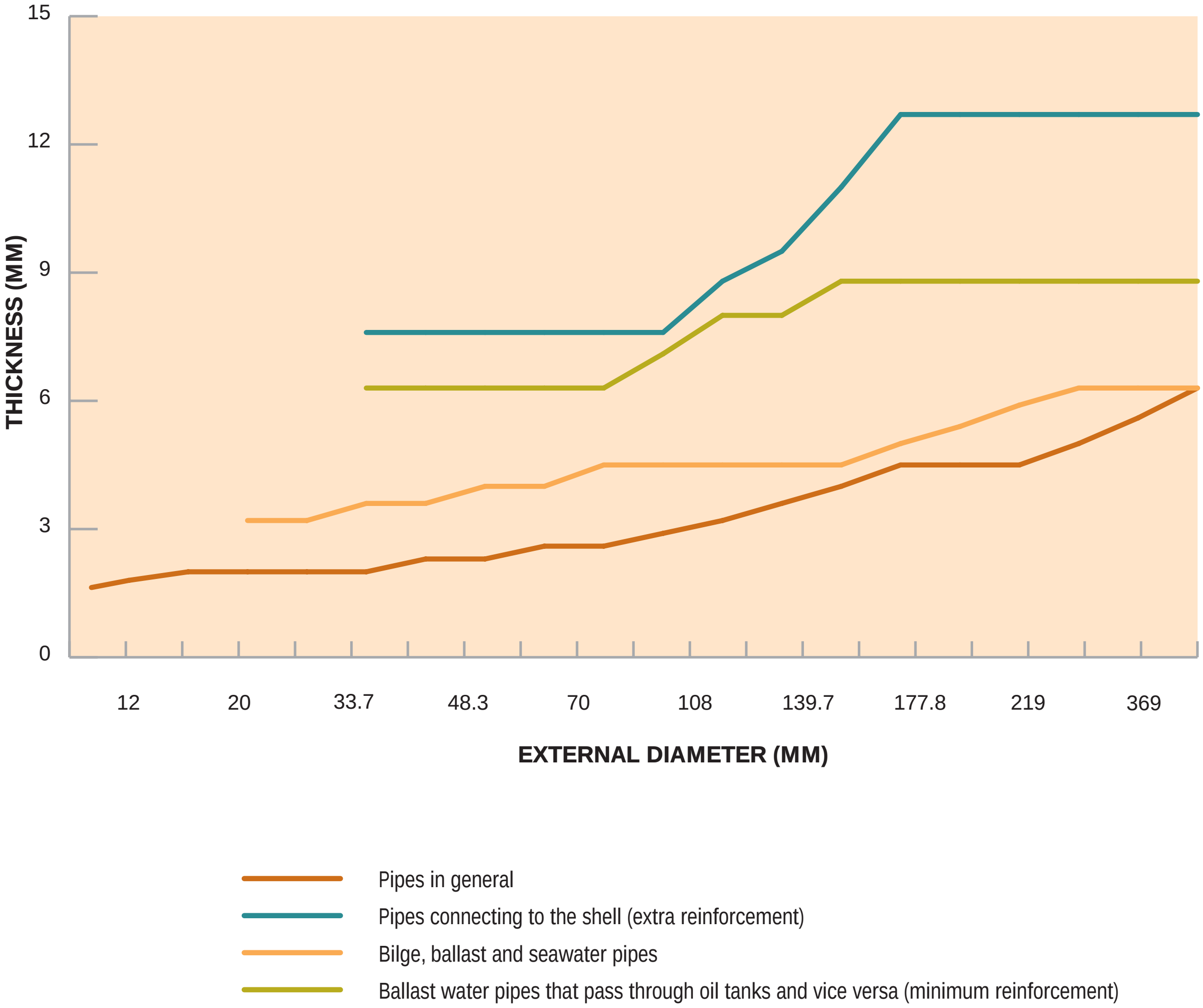

Image: Steam pipes

PIPE DESIGN

Connection to pumps

Pipes are connected to pumps by flanges. Flanges are a potential weak point in a piping system. Occasionally, and to provide the correct pressure from a pump, a calibration orifice is fitted in the delivery piping. This can result in turbulent fluid flow and cause abrasive corrosion or erosion. Welded flanges are prone to accelerated corrosion in the weld metal or in the heat-affected zone. Pipes in wet areas where corrosion is likely need to be examined at regular intervals (six-monthly).

Pipe joints

The preferred method for connecting two lengths of steel pipe, whether a straight, elbow or tee joint, is with a flange. With the possible exception of small-bore pipes in low-pressure systems, pipes are not normally connected by threaded joints. Mechanical, expansion or sliding joints are fitted in longitudinal pipes to allow the pipe to move when a ship bends and flexes, or to cater for thermal expansion. Expansion joints are not fitted where there is regularly high stress, nor are they used inside cargo holds or tanks. Expansion joints should never be used as a permanent connection for corroded pipes after a temporary repair.

Classification society rules define which piping systems to use and the positions where expansion joints can be fitted. Only approved expansion joints are allowed.

Clips and supports

Clips and supports are used to hold pipes in position and to prevent movement or vibration. A vibrating pipe can 'work harden' and fail. Pipes can fracture when there is insufficient support.

There are no hard and fast rules about the number of clips required in a length of pipe as this will depend on the pipe's diameter, length, its position and the density of fluid conveyed. The contact area at the surface of the pipe requires protection. Failures often occur as a result of mechanical wear when the clip loosens, allowing the pipe to move. Inspection procedures must be designed to ensure that all clips are checked regularly, including those hidden from sight behind insulation or under engine room floor plates. Special attention should be paid to clips in concealed places.

Valves

Valves are fitted to isolate sections of pipe and will typically be found at suction points, crossovers, feed lines, delivery lines and where pipes need to be removed. Valves connected to the shell are flanged and made of steel or other ductile material. Grey or nodular cast iron cannot be used for boiler blow-down valves, for valves fitted to fuel oil or lubricating oil tanks, or for shell valves. Shell valves should be tested regularly, on a monthly basis, by opening them. Marking valve handles with high-visibility paint will help with identification during an emergency.

Cast iron valves have a service life shorter than those made from cast steel. Consequently, they need careful examination during a special survey.

CAUSES OF PIPE FAILURE

Pipes have a hard life: they carry abrasive and corrosive fluids; they are exposed to atmospheric corrosion and to general wear and tear; they sometimes operate at extremely high temperatures. The most common cause of pipe failure is corrosion-induced weakness.

Pipes corrode internally and externally. Internally, they may be affected by erosion, uniform and abrasive corrosion, fatigue and galvanic action. Externally, corrosion is caused mainly by atmospheric conditions, but pipes can corrode locally where liquids drip onto them.

Uniform corrosion

Uniform corrosion is the most common form of attack on metal. Its aggressiveness depends on relative humidity, temperature, oxygen content and salt content. It is widespread in pipes carrying saltwater. Pipes on deck, in locations prone to wetting, in bilges and in ballast tanks, as well as pipe supports are at risk of uniform corrosion.

It is a good policy to replace a pipe when the corrosion measured is equal to or greater than the design allowance.

Accelerated corrosion can occur in steam piping fitted to the decks of tankers. If pipes are insulated, and the insulation gets and stays wet, any corrosion is accelerated. Table 3 on page 17 shows optimum corrosion allowances for various types of pipe.

Image: Colour-coding cargo pipes

Image: Pipe corrosion

CAUSES OF PIPE FAILURE

Pitting corrosion

Pitting corrosion is defined as the localised breakdown of the inert surface layer that protects metal against the formation of cavities or small diameter holes in the material. Such corrosion can occur in mild steel and stainless steel. It has a random pattern, as the formation of a pit is dependent on the breakdown of a pipe's protective film. Pitting happens more readily in a stagnant environment. The Oil Companies International Marine Forum's Guidance Manual for the Inspection and Condition Assessment of Tanker Structures contains pitting intensity diagrams for plates, and these can be used to categorise the extent of pitting. As a general rule, any badly pitted pipe needs replacing.

Abrasion and erosion

Abrasion and erosion are the wearing away of material by a fluid flow. Material that has been abrasively corroded or eroded looks pitted. To determine whether material has been lost by either abrasion or erosion, it is necessary to examine the processes involved in both.

Table 3

Corrosion allowance for steel pipes in mm	
Superheated steam systems	**0.3**
Saturated steam systems	**0.8**
Steam coil systems in cargo tanks	**2**
Feedwater for boilers in open circuit systems	**1.5**
Feedwater for boilers in closed circuit systems	**0.5**
Blow-down (for boilers) systems	**1.5**
Compressed air systems	**1**
Hydraulic oil systems	**0.3**
Lubricating oil systems	**0.3**
Fuel oil systems	**1**
Cargo systems for oil tankers	**2**
Refrigeration plants	**0.3**
Freshwater systems	**0.8**
Seawater systems in general	**3**

CAUSES OF PIPE FAILURE

Abrasion happens when solid particles, such as sand, suspended in a fluid flow scour a pipe. It is therefore a mechanical process. If the oxidised surface protecting a pipe's base metal is abraded by such flows, uniform corrosion or pitting can result. The main characteristic of abrasion is the appearance of cracking in the direction of flow. Filters are fitted in ballast and bilge lines to prevent debris from being sucked into a pipe. A slower than expected pumping rate may indicate that filters are clogged and that they need cleaning. Worn or damaged filters must be replaced.

Erosion is caused when turbulent fluid flows hit a pipe's inner surface; it is most common at points where a pipe bends and at elbows where fluid flow changes direction, or where an orifice, valve, welded joint or any other blockage impinges on fluid flow to cause turbulence. Prevention of turbulence is the key to prevention of erosion. The use of larger diameter pipes, together with a reduced pumping rate, can eliminate flow turbulence and erosion.

Fatigue damage

Fatigue damage is the rapid deterioration of metal, the results of which are cracking and collapse. It is caused by cyclical mechanical stress, or when pipes are connected to machinery or other pipes that vibrate.

Galvanic corrosion

Galvanic corrosion is the electro-chemical process between different metals. It is most common where pipes connect to equipment made from a different metal and where there is an electrically conductive path between the metals through an electrolyte.

Graphitic corrosion

Cast iron pipes and fittings are affected by graphitic corrosion that is most commonly found at bends and elbows, locations where boundary layers cause water to flow at different velocities, or where water accumulates. Graphitic corrosion attacks the inside of a pipe by oxidation and leaching of iron. It results in the formation of rust supported by graphitic flakes. The process occurs over a period of time and, if the pipe is not replaced, will continue until the pipe weakens and eventually fails, usually catastrophically.

The risk of failure through graphitic corrosion can be reduced by:

- Identifying every cast iron pipe or fitting that has a connection to the sea.
- Using ultrasonic equipment to measure the wall thickness of pipes over ten years old; this should be done annually.
- During a docking survey, removing for internal examination all iron pipes over ten years old that are located in high-risk areas likely to be affected by graphitic corrosion, such as elbows, where flow velocity changes or where water can accumulate.

Image: Misaligned air ventilation pipe

CAUSES OF PIPE FAILURE

Water hammer

Water hammer can affect any pipe but is most common in steam pipes. It is a problem in pipes where internal condensation occurs. Water hammers are impulse pressures that happen when steam enters a cold pipe containing a small amount of water. The resulting stresses, along with possible rapid expansion, can cause pipe joints to fail. Prevent water hammers by draining fluid from pipes before injecting steam gradually.

Steam systems are most prone to damage by water hammer because they operate at high temperature and pressure, and because condensed steam will remain in them, unless regularly drained.

Steam heating coils on tankers are particularly susceptible to damage by a water hammer.

Pipe alignment

Irregular stress affects pipes that are forced into alignment. If they have been weakened by corrosion, stresses caused by thermal expansion or impulse loading, the pipes will fail. Forcing pipes into alignment is bad engineering practice. Failures are most likely at flange connections or valves.

Low temperature

Very low temperatures cause water to freeze and to expand in uninsulated pipes. In cold conditions, high-viscosity or solidifying substances will become difficult to pump because of their tendency to constrict the flow in pipes. Care must be taken to avoid over-pressurising the pipe in an attempt to increase flow. It may be necessary to add anti-freeze to a pipe system, or to arrange external heating, if conditions get really cold.

Expansion

Metallic pipes expand and contract as the temperature changes. A ship’s movement will cause them to stretch and bend, and unless these stresses are absorbed by an expansion joint, pipes can fail. Bulkheads pierced by pipes present special problems. The bulkhead’s strength has to be maintained and the stresses resulting from a pipe’s movement have to be absorbed. If the bulkhead forms part of a fire zone, insulation has to be repaired or replaced to ensure that fire integrity is not compromised.

Image: Leaking fire main

DEALING WITH PIPE FAILURE

It is not always practicable to examine every pipe on a ship, which means that pipe failure is always a possibility.

If a pipe fails, the following action should be taken:

- Switch off relevant pumps; isolate the affected section of pipe by closing valves or by fitting blank flanges.
- Investigate the source of the leakage and make a temporary repair by binding or clamping. At the first opportunity, have the pipe repaired or renewed by a specialist repair shop.
- Avoid getting electrical equipment wet. If electrical equipment is wet, take care to avoid electric-shock hazards. Switch off electrical equipment.
- If there is leakage from a fuel, lubricating or hydraulic pipe, use absorbent material to soak up the loose oil. Oil is both a safety and a pollution hazard.

  Fuel spraying from a fractured pipe into an enclosed space, or on to a hot surface, is an extremely dangerous fire hazard.
- If there is leakage from a fractured steam pipe, evacuate the boiler area to avoid the risk of personal injury. This type of leakage can be extremely hazardous, especially if the steam is superheated because superheated steam is invisible and therefore difficult to detect. Test for a steam leak with a piece of cloth on the end of a pole, the cloth will flutter in the jet stream.
- If ballast piping on an oil tanker fails, exercise caution before pumping ballast into the sea because the ballast could be contaminated with oil. Check the surface of segregated ballast for oil before beginning discharge.
- If cargo or fuel pipes on a tanker fail, be very wary of pumping ballast into the sea because the fuel or cargo pipe might pass through a ballast tank. If fuel becomes contaminated with water, then pump it into a settling tank and purify it before using.
- If cargo piping failure happens on a gas carrier or on a chemical tanker, take measures to avoid vapour inhalation or skin contact. A significant escape of flammable gas from cargo piping presents an extreme explosion hazard, especially if the gas gets into the accommodation.
- Failure of a pipe that connects directly to the ship's shell can result in serious flooding, especially if the connection is located below the waterline because most ships are not able to survive engine room flooding. It is therefore essential to make sure that both suction and discharge valves can be closed, and that they are leak-free.

PIPE MAINTENANCE

Unless they are made of non-corrosive material, are galvanised or plastic-coated, the external surfaces of pipes should be painted. Generally, the maintenance of pipes should concentrate on identifying and replacing those that have weakened. It is important to identify failing pipes before leakage occurs; maintenance of piping is as much about procedural checks and pressure tests to locate weak points as it is about actual repair. The following inspection procedures are recommended:

- Inspect exposed piping and pipes in wet or damp locations at regular intervals as set down in the ship's maintenance schedule. Look for breakdown of the protective coating. Check for frictional wear at pipe clips and expansion joints.
- Inspect the inside of pipes where they connect to pumps and refrigeration equipment; this might require the removal of a length of pipe. Look for cracks caused by erosion.
- Check bends and supports for fatigue corrosion that can occur when piping is subject to vibration. If a pipe does vibrate, fit additional clips or supports.
- Check the wall thickness along the outer part of a curved pipe that forms an expansion curve. Expansion curves are usually cold bent and have reduced thickness on the outer part of the bend. Erosion inside the pipe can cause accelerated thinning of the outer wall. Measure thickness with an ultrasonic meter.
- Check a pipe's threaded connection where it is attached to a component made of different material. Look for galvanic corrosion.
- Check fixed expansion joints (bellows) for deformation. Look for distortion that can occur with overpressure. These joints are designed to withstand twice the pipe's normal working pressure. Deformed bellows must be replaced.
- Check for localised leakage as this can give rise to accelerated corrosion. Inspect glands on valves fitted in saltwater ballast lines and seawater cooling pipes. Repair all leaks, irrespective of quantity. Remember that a slight leakage is needed to lubricate the valve stem.
- Open and close line valves at scheduled intervals, especially those that are used infrequently. Pay special attention to valves that connect to the shell.
- Repair paint coatings. Fit a doubler where the pipe has suffered frictional wear as a result of chafing contact with a support clip or clamp.
- Measure a pipe's wall thickness and replace it if its corrosion allowance has been consumed.
- Remove lengths of insulation from steam pipes and check for corrosion. Repair or replace corroded pipes. When replacing insulation, refit with an external layer of waterproof material.

PIPE MAINTENANCE

- Look for pitting when checking stainless steel piping especially if it carries saltwater. This is easily identified by the presence of small rusty points on the pipe's exterior. If these are found, repair with a section of new pipe. A temporary repair can be made by chipping away the rust, cleaning the area/pipe with a stainless steel wire brush and painting it. Pitting is also likely occur on the pipe's inner surface and its presence can be detected by removing a section of pipe and checking visually.
- Co-ordinate visual examinations with pressure tests. Some operators prefer to pressure test before a visual examination. Pressure tests should be arranged after a pipe has received an impact, even if visually there is no obvious damage. When carrying out an hydraulic test, which is a pressure test using water, apply a pressure equal to 1.5 times the pipe's working pressure. Before the test, isolate ball valves to avoid accidental damage to valve seals.

  Use a pressure test to reveal small cracks, holes, and leakages at flanges or at other connections.
- Whenever accelerated corrosion or advanced thinning of a pipe is found, check all similar pipes in similar locations since they are likely to be affected, too.
- If a particular space needs regular bilge pumping, it indicates leakage. Check the space thoroughly to identify the leak.

Details of a standard pressure test are contained in Appendix 2.

Image: Manifolds, filters and valves

PIPE REPAIR

Pipes that fail are not normally repaired – they are replaced. If there is a need for local repair, then treat it as a temporary repair.

- Temporary repairs can be made by using binding and rubber, cement blocks, rings and clamps, or plastic resin. Wooden plugs in conjunction with binding are occasionally used to plug a holed pipe.
- Permanent repairs usually involve the removal and replacement of a length of piping. Welded doublers are not acceptable as a permanent repair.
- A permanent repair can only be done with classification society approved material. The society's rules require the repair to be examined and approved by its surveyor.
- After making any repairs, do a pressure test and a non-destructive test of any welded connection using the dye penetration procedure.
- After completing any repair, refit pipe supports or clips. Use additional supports if the pipe moves or vibrates.
- Replace spray shields on pipes that carry flammable liquids, especially if the pipe is located near a hot surface.
- Slag can fall inside pipes joined by welding and cause a blockage or clog valve seats. Flush the pipe before use.
- After repairing lubricating oil or hydraulic pipes, seek the equipment maker's advice on the care of oil and filters.

Image: Cargo piping arrangement

DO'S AND DON'TS

ALWAYS:

- Replace pipes that have significant corrosion, i.e., when the corrosion allowance has been used up, and check all similar pipes, replacing as necessary.
- As a pipe ages, check its wall thickness regularly, concentrating on bends, elbows, deck, bulkhead or shell penetrations.
- Arrange for regular pressure testing at 1.5 times the design pressure. As a minimum, this should be done every two years.
- Open and close shell valves at regular intervals and overboard discharges, taking care not to discharge oil accidentally.
- Refit pipe supports after maintenance and check them for erosion or mechanical damage. If pipes vibrate, fit additional supports.
- Keep pipes leak-free; paint them to prevent corrosion.
- Fit spray shields around fuel and other pipes carrying flammable substances close to hot surfaces.
- Arrange a tightness test, at design pressure, of pipes that have been accidentally hit.
- Make sure that all blank flanges have been removed on completion of a pressure test.
- Inspect pipes running near a hot surface on a regular basis.
- Ensure that insulation is maintained in good condition and is free from oil contamination.

NEVER:

- Fit wet lagging around mild steel pipes.
- Wait until a suspect pipe begins to leak before arranging repair.
- Use fire hoses to replace a failed metal pipe, except as an unavoidable emergency repair.
- Repair with a mis-match of materials, or with material of different thickness in the same piping run.
- Leave material, equipment or clothing inside a pipe after repair.
- Use stainless steel pipes in saltwater systems without washing them with freshwater after use. Static seawater will cause pitting in stainless steel.
- Force pipes into alignment.
- Use welding to repair an 'in-situ' fuel or lubricating oil pipe

Image: Ballast, air and cargo piping arrangement

APPENDIX I —
MECHANICAL JOINTS IN COMMON USE

Grip type

Provide axial resistance and can be used with pipes under medium or high pressure. The joint is achieved by an indentation in the pipe. There is an internal seal for tightness.

Machined groove type

Provide axial resistance and can be used with pipes under medium or high pressure. The joint is achieved by using a pre-deformed or machined piece of pipe. There is an internal seal for tightness.

Slip type

No axial resistance. These joints can only be used with pipes under low or medium pressure.
The seal is achieved by packing.

Swage type

These joints are pre-assembled and cannot be dismantled. They can be used with pipes under medium to high pressure. Special tools are required to assemble/fit them.

Press type

These joints are pre-assembled and cannot be dismantled. They can be used with low to medium pressure pipes. There is an internal seal which achieves joint tightness.

Byte type/compression joint

Special joints which can be used in high-pressure pipes.

Flared type

Special joints which can be used in high-pressure pipes. A flared joint is generally used in the connection of copper pipes on refrigeration systems.

Image: Pipes come in different sizes

APPENDIX II — PRESSURE TEST PROCEDURE

A hydraulic pressure test is a straightforward shipboard operation.

Follow these guidelines:

1. Isolate the area where piping is to be tested.
2. Fill piping with water, taking care to eliminate all possible air pockets that remain in the pipe before raising the pressure.
3. Increase the pressure in the pipes slowly, making sure that shock loading is avoided. Watch out for problems as the pressure increases.
4. When the maximum pressure is reached, maintain that pressure for between 15 and 30 minutes.
5. Monitor the pressure inside the pipe by using a certified manometer. Check that a reduction in pressure does not occur apart from that due to thermal variations.
6. Even if there is no significant reduction in pressure, check the pipe visually for small leaks. Before performing this check and as a safety precaution, it is advisable to slightly reduce the pressure in the pipe.

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