Norwegian Petroleum Directorat

Ageing rigs

Review of major accidents
Causes and barriers

November 2003

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Ageing semi-submersibles

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1 Introduction

The present study has the general objective of forming a generic barrier diagram for major accidents with semi-submersible platforms. In order to obtain input to the generic barrier diagram (see chapter 10), specific barrier diagrams are drawn for the accidents shown in Table 1. The specific diagrams are shown in chapter 11.

Platform	Location	Year	Main cause
Transocean 3	North Sea, UK	1974	Structural failure, wedge rings
Alexander Kielland	North Sea, NO	1980	Structural failure, bracing and column lost
Ocean Ranger	Canada	1982	Ballast system, portlight
West Vanguard	North Sea, NO	1985	Gas blow-out
Ocean Odyssey	North Sea, UK	1988	Gas blow-out
Ocean Developer	West Africa	1995	Ballast system operation
P-36	Brazil	2001	Drainage operation, HC explosion, flooding

Table 1: Overview of analysed accidents.

3 categories of accidents have been treated:

- Structural failure
- Ballasting/flooding accidents
- Gas blow-out

In chapters 3 through 9 a rough sketch of the event sequence leading to each of the accidents is given. In a given accident all failures can be traced down to human errors since humans designed, built and operated the installations. However, a distinction is made between design or technical problems, organizational problems and human (judgemental) problems.

The focus is on barriers relating to the integrity of the structures and to marine operations. Therefore, evacuation and personnel safety have not been treated in any detail.

2 Barrier diagrams

Many definitions of barriers have been proposed; in ref. 1 (in Norwegian) an overview is given. One of the original ideas was that barriers are measures which separate an adverse energy source from humans or from the system they are designed to protect.

In this study a barrier is defined as any technical, operational, administrative or organizational measure which decreases the probability of adverse events or which limits the consequences of such events.

Technical barriers include systems such as valves, bracings, redundancy or life saving appliances. A barrier may also be an operational procedure which reduces the probability of committing operational errors, which again can lead to accidents. Rules and regulations can also be regarded as barriers against certain accidents.

Often barrier diagrams are drawn to be able to focus on the adequacy of the set of barriers, i.e. which barriers are available, which ones are working, which ones are not, and if additional barriers are needed. Sometimes a measure of effectiveness or reliability is assigned to the individual barrier. This is not the case for this study.

In this study barrier diagrams are used to provide an overview of the event sequence leading to the accident as well as a means of representing the barriers, which could have prevented the accident. The specific diagrams are shown in chapter 11.

The basis of a barrier diagram is the event sequence. It is shown as linked rectangular text boxes, see Figure 1 for a sample diagram. Additional causes are shown as oval text boxes.

Barriers are shown as vertical bars which are either white or shaded. Shaded barriers were available at the time of the accident. White barriers were not available at the time of the accident, but have been implemented in regulations later or integrated in later designs.

A full drawn barrier worked during the accident. A broken barrier failed during the accident, or was never activated by the crew. By convention, white barriers (not available at the time of the accident) are drawn broken.

The general principle of starting the event sequence with an energy source has - to the extent possible - been observed.

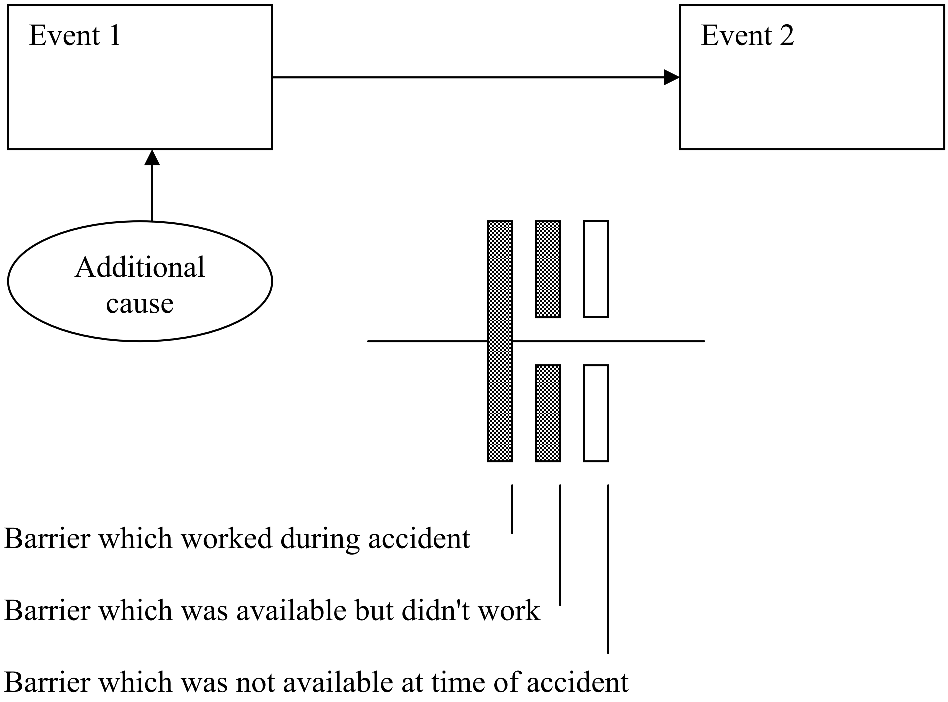


Figure 1:Sample barrier diagram.

3 Transocean 3

3.1 Facts

Structure	Semi submersible drilling rig
Location	North Sea, 100 miles east off Shetland, block 9/13
Date	1. January, 1974
Water depth	104 m
Waves	10-30 ft ~3-9 m
Wind	Force 10-11
Operational status	Anchored after tow to location
Age of rig	5 weeks
Fatalities	None

3.2 Event sequence

29. December

16.00: Movement of top wedge ring of starboard leg, later also on port leg

30. December

Morning: Slight deformation of wedges at both levels on port leg detected. The upper wedges were deforming the leg's shell plating. Shear pins were backing out and the stiffeners to the shear pin boxes were damaged. The decision to tow the structure to Stavanger for repair was made.

Attempts to jack pins into position. Attempt to reduce wedge movement: bolting of down angle retaining rings, driving in extra hardwood wedges. These attempt were unsuccessful, but decreased the rate of deterioration.

Cracks were found in the drilling derrick substructure.

1. January

14.00: CLAP 1 (Loud slamming noise).

16.30: CLAP 2.

Port leg oscillating from port to starboard.

Wedges were hitting the holding down angles outboard and inboard.

Removal of non-essential personnel to nearby platform.

Closure of watertight doors

17.55: Wedges had free movement and were banging heavily against the leg plating. Plating was being damaged only upper level. At the lower level one of the holding pins was out and another pin half way out.

18.15: Second pin was nearly out.

18.30: Evacuation of remaining men.

21.20: Port leg was tilted 3-5º outward.

23.00: Tilt has increased to 60º.

23.05: Slow capsizing to port.

Later

The rig floated upside down for some days, and sank approx. a week after the capsizing. A 50 m, 1000 t steel column from Transocean 3 drifted towards the platform West Venture. British bombers tried in vain to sink it. Later it passed the West Venture at 100 m's distance.

3.3 Design problems

Wedge arrangement inadequate: angle too large, angle rings not strong enough to properly retain the wedges, plating and wedges not designed for local load concentration.

3.4 Organizational problems

Rig operators were not aware of the significance of the wedges, i.e. the importance of keeping them in position.

3.5 Judgemental errors

Design and design check not adequate.

3.6 Barriers which are sensitive to ageing problems

Knowledge about the critical components (importance of the wedges). If descriptions of the operation mode of certain equipment or systems are missing in manuals, the transfer of knowledge about them between crews relies mainly on the individual crew member's memory and ability to communicate the essential information. The level of knowledge about the systems among the crew members will therefore deteriorate over time if appropriate training is not ensured.

4 Alexander Kielland

4.1 Facts

Structure	Semi-submersible drilling rig used for accommodation
Location	Ekofisk field, close to Edda 2/7C, Norway, North Sea
Date	27. March, 1980
Water depth	80 m
Wind	16-20 m/s
Waves	6-8 m
Visibility	About 1 km
Operational status	Anchored
Age of rig	4 years
Fatalities	123
Survivors	89

4.2 Event sequence

Platform had been in service as accommodation platform for some years.

Platform moved away from Edda 2/7C due to storm conditions. This was done by adjusting the anchor wires.

Bracing D-6 broke off due to fatigue. The fatigue crack was initiated in a low-quality fillet weld for hydrophone support. The hydrophone support was welded into a hole in the load carrying bracing. This led to stress concentration around the weld.

Failure of 5 other bracings connecting the column D and the platform. These failures were due to overload.

Loss of column D.

List (30-35 º) due to lost buoyancy from pontoon D.

Column C and E filled with water through openings such as ventilators.

Deck volumes filled.

Anchor wires prevent it from capsizing for some time.

Anchor wires break and list increases continuously.

Life boat launching was difficult to impossible due to the list.

Platform turned upside down. 89 survived, 123 died.

4.3 Design problems

Missing structural redundancy

Water tight bracings with leak detection would have offered the possibility of getting a warning before the structure fell apart.

4.4 Organizational problems

No quantitative fatigue calculations had been performed in the design phase.

Procedures for checking welds (Class and builder).

4.5 Human errors

Poor welding quality.

The initiating cracks had passed inspections undetected.

Open ventilation ducts on columns.

Anchor pattern was different from the approved pattern.

It had not been taken into account in the design that outfit was welded onto load carrying elements.

4.6 Ageing effects

Due to modification and refitting works, many parameters of the platform changes over time. As an example, weight estimation and distribution on the structure will be increasingly uncertain during the lifetime of the rig. Moreover, the impact of the modifications on basic design criteria must be evaluated, both by rig owner and by classification society.

5 Ocean Ranger

5.1 Facts

Structure	Self propelled drilling rig, semi submersible.
Location	Off New Foundland, Canada
Date	15. February, 1982
Water depth	260 ft ~ 79 m
Waves	30-40 ft ~ 10-13 m
Wind	90 knots ~ 46 m/s
Operational status	Not drilling (the drill string was cut in stead of disconnected, due to emergency (bad weather))
Age of rig	6 years
Fatalities	84
Survivors	None

5.2 Event sequence

A portlight in the ballast control room was broken by waves.

Water entered the ballast control room and caused malfunctioning of the ballast control panel.

The panel was reactivated but didn't work properly. Some ballast valves were left open, thus allowing water to enter the port pontoon.

To remedy this, ballast pumps were activated to empty the forward port tanks. The pumps were located aft, i.e. much higher than the fwd tanks. The pumps could not manage the head of water, so they were in fact unable to empty the forward tanks. Some of the valves to the aft ballast tanks were open such that they were emptied instead, leading to even more forward list.

Manual operation of up to 15 solenoid valves in the actuator system for the valves in the ballast water system. These were forced open instead of closed, such that water could gravitate forward.

Water flooded the chain lockers.

Water flooded upper deck spaces through damage to the accommodation area and to ventilators.

The crew started evacuating the rig. The 4 lifeboats were either impossible to launch or were seriously damaged during launching.

The rig capsized and personnel escaped to the sea.

The stand-by boat was 8 miles away, i.e. not in close stand-by.

All 84 men died, most from hypothermia.

5.3 Design problems

The ballast control room was located very close to the water surface (28 ft ~ 8.5 m above MWL). Therefore, the port lights should have been designed to withstand environmental forces.

The lack of a remote system for reading the draft of the rig made it necessary to keep the deadlights open all the time, also during storm.

The control panel components were neither protected against nor designed to withstand sea water.

The ballast control system was unnecessarily complicated.

The interconnection between the electrical circuits for control and monitoring aspects made the ballast control console susceptible to common faults and presentation of confusing information.

There were no covers on the chain lockers.

The down-flooding angle was low because waves had not been taken into account.

The capacity of pumps to empty the forward tanks was low.

The location of sensor tubes for tank level gauges made them imprecise in tilted condition.

A certain integrity and buoyancy of the upper hull structure was required by regulations but was not secured by design.

The evacuation system was not able to operate under the conditions at hand. Some of the boats could not be launched because of trim.

5.4 Organizational problems

No operational practice for closing the deadlights during storm.

No manual which fully described the operation of the ballast system.

No detailed drawings of the components of the system.

No training of the two operators.

No survival suits available. They were commercially available, but no regulation required survival suits at the time.

No procedure for the distance of standby boats during storm.

Complications in the SAR preparedness.

5.5 Judgemental errors

From our point of view the errors were:

- not to close the deadlights during storm given that the ballast control room was located very low.

- not to close the deadlight after the portlight had broken.

- to reactivate the control panel after the water ingress in the ballast control room. Instead, the electrical and air supplies to the control panel should have been shut off.

- to empty the aft ballast tanks instead of the forward tanks.

- to open ballast valves instead of closing them.

- that the stand-by vessel was not at close stand-by (it was 8 miles away).

5.6 Barriers which are sensitive to ageing problems

- The requirement of 2 separate systems for level measurement of ballast tanks. This barrier is prone to ageing if one of the systems is based on traditional sounding pipes, as corrosion can make them impossible to use.

- Wear of control panel. The components of the control panel have finite life time. Therefore the performance of the panel will deteriorate with time. Modern control panels have self-testing features.

- Knowledge about the systems (ballast control system and solenoid valves). If descriptions of the operation mode of certain equipment or systems are missing in manuals, the transfer of knowledge about them between crews relies mainly on the individual crew member's memory and ability to communicate the essential information. The level of knowledge about the systems among the crew members will therefore deteriorate over time.

6 West Vanguard

6.1 Facts

Structure	Semi submersible (Bingo 3000) drilling installation
Location	North Sea, Haltenbanken area, Block 6407/6, Norwe gian sector
Date	6. October, 1985
Water depth	221 m
Operational status	Exploration drilling
Age of rig	3 years
Fatalities	1

6.2 Event sequence

Exploration drilling, top hole.

20.58: Drill break due to soft sand formation with shallow gas.

Drilling halted, circulation of mud. Gas peak at 92 units. No flow check performed. No re-evaluation of depth to set 20" casing (as required in operations manual).

Prohibition of welding.

21.37: Drilling resumed.

22.18: Gas peak at 550 units. Drilling was halted to circulate mud through the well.

22.41: Drilling was resumed when gas volume reduced.

Shortly before 23.00: Strong return of mud and gas from well.

Crew connected the mud return line to the diverter system. Heavy mud was pumped down the well at full pump speed.

Gas alarm in control room. Closed air intakes in control room.

23.00: Crew ordered to muster stations.

Alarm to stand-by boat.

23.10: Alarm to main central on shore.

Bends in diverter system eroded by sand.

Noise from escaping gas made communication impossible.

It was attempted to increase the pressure on seals on telescope.

Release of sub sea wellhead connector was attempted. It was not possible to verify if it had occurred.

23.20: First explosion in drill floor area.

Fires and more explosions.

Platform manager activated release mechanism for 4 aft anchors for the fore anchors to pull the platform away from the gas plume. One of the four anchor lines was not released.

Lifeboats were launched. This was perhaps not ordered by platform manager.

Platform manager and stability supervisor climbed down forward column and swam away in survival suits.

All personnel (except for one missing person) were picked up by standby boat.

8. October

Platform towed further away from gas.

10. October

Fire extinguishing (vessel) started.

Later

The platform was towed to Kristiansund for inspection.

6.3 Technical problems

Bends in the diverter system were eroded by sand in the blow-out. This led to release of gas on the installation. The diverter pipes had varying diameter, leading to increased erosion.

Conventional diverter system was not useful. In the future the diverter systems shall not allow gas to reach the platform.

There were leaks in the mud return system on the installation.

Release of one of four anchor lines did not occur, probably due to a malfunctioning electronic control unit.

The drill string was possibly still connected after release of anchor lines. This may have continued to feed gas to the fires.

There was no effective way of moving the platform without forming sparks. DP-systems and winch systems during top hole drilling have been suggested.

One ballast tank filled with water, probably due to increased hydraulic pressure on a valve, caused by heat.

The location of the engine room air intakes was inadequate.

6.4 Organizational problems

Use of conventional diverter technology.

Inadequacies in the drilling program with regard to mud weight.

Lack of visual signals to communicate through the noise of the escaping gas and the explosions.

Lack of fire and explosion prevention measures, e.g. closing of air intakes and exhaust ducts in hazardous situations.

6.5 Judgemental errors

Misinterpretation of the situation.

Heavy mud not used early enough.

6.6 Barriers which are sensitive to ageing problems

Mechanical release mechanisms (sub sea wellhead connector, anchor release system). The moving parts become worn, lubrication deteriorates with time, friction increases, corrosion).

7 Ocean Odyssey

7.1 Facts

Structure	Semi-submersible drilling unit
Location	North Sea, 150 miles east of Aberdeen
Date	22. September, 1988
Operational status	Exploration drilling
Age of rig	5 years
Fatalities	1

7.2 Event sequence

10. September

Depth of 16160 ft was reached.

Swabbing and lost circulation.

Cementation of the well started.

12. September

Pipe became stuck.

Attempts to recover the stuck pipe and drill out the cement.

21. September

14.00: Lost circulation problems, kicks and influxes. The well was unstable, high gas levels had been encountered.

Mud was being lost at a greater rate than new mud could be manufactured, mud supplies were low.

22. September

Between 03.00 and 05.00: Barite supplies ran out.

Some influxes had been taken.

The situation was at the practical limit of safe operation.

The right thing to do would be to shut in the well, cease operations and await fresh supplies of barite and fresh mud.

05.29: Pull-out of hole operation from 16160 ft started.

Mud gains were taken for each pulled stand (4 were pulled initially).

Discussions among crew members as to what to do.

It would have been prudent to return to bottom and attempt to circulate the influx to the surface to see what it was. If that was impossible the right thing to do would have been to set a cement plug. However, it would require additional mud to get the cement in place.

Trip tank filled and was emptied 2-3 times.

09.00: Circulation re-established, 0.1 barrel per minute increase. All previous attempts had experienced mud loss. This indicated that the well was flowing.

Increase in flow rate, 10 barrel mud gain in 30 minutes.

10.00: Well shut in by using the lower annular (upper annular no longer operational). Circulation through choke line instead of riser.

No kick sheet was prepared.

Shut-in drill pipe pressure was not measured.

Too low drill pipe pressure was maintained.

A second (and continuing) influx was taken.

Wrong calculation of required no. of pump strokes to reach bottom-up.

11.00: Gas venting from derrick, smell of gas in shaker area.

11.15: First presence of gas at installation (at drill floor, rotary table).

11.30: Rise in casing pressure to 7800 psi.

Vapour coming through rotary table.

Substantial increase in mud return (very hot mud, which is opposite the normal because circulating an influx takes longer, i.e. more time for cooling).

Closure of 2 sets of rams in BOP.

Gas and steam coming from shaker area.

Evacuation of mud loggers.

Noise from choke manifold.

Mud-gas separator was venting violently.

Rapid casing pressure rise to 8320 psi.

Change of crew at drill floor.

Evacuation of living quarters.

The valve on the mud return line remained open all the time. Closure would have led the gas to the top of the derrick. Gas in shaker area led to build-up of gas on the installation.

Mud-gas separator was overloaded (mud return quantities were not controlled properly).

11.50: Stand-by vessel was called to close stand-by due to gas alert.

1159: All non-essential crew called to muster at life-boats.

12.00: Mud was pouring over the shakers, gas was coming out of the mud, some were wearing breathing apparatus.

Order to by-pass the shakers and divert the mud straight into the sand traps.

12.13: Telex from Ocean Odyssey stating: "Rig gas blow-out, all essential, non-essential personnel at lifeboat stations. Drill crew now trying to fight and control blow-out".

12.17: Telex from Ocean Odyssey stating "Blow-out controllable at present".

12.20: Pump room evacuated, gas level at shaker area at 85 % of methane explosion limit.

Evacuation of shaker area.

Flow line temperature rapidly increases to over 100º C.

Both radio operators were called back from their lifeboats, but one returned quickly to the lifeboat.

12.50: First explosion.

Release of life boats.

3 men jumped.

4 climbed down ladders.

12.56 Mayday issued by stand-by boat.

Helicopter assistance arrives.

23. September

Anchor chains were severed by the use of explosives in order to move the rig away from the flames.

24. September

Installation was boarded, the body of the radio operator was found.

Later

The flow from the well ceased (by itself)

Rig was rebuilt in Russia and Norway.

7.3 Design and operational problems

The gas vent pipe from the mud-gas separator to the derrick was 6" instead of 8" (as required by the Department of Energy).

No liquid seal on return line from the separator to the shaker area.

No pressure recording device to prevent mud-gas separators from being overloaded.

No system to monitor the contents of the mud return line.

Choke hose failed.

7.4 Organizational problems

No general practice of giving introduction training on the layout of the vessel, escape routes, safety equipment or structure of command related to safety.

The installation had a complex layout, which was difficult to get acquainted with.

Poor relationship between captain and crew.

No morning meetings between OIM and tool pusher.

The barite stocks should not have been allowed to become depleted.

No appropriate management system to ensure that the OIM was kept fully informed of actual and intended well operations and activity.

The upper annular was not repaired in time.

7.5 Judgemental errors

Decision to start pulling out of hole with very low supplies of mud and no barite to weigh up the available supplies.

It was an error to pull from an open hole instead of pulling through the closed annular or remove one single at a time.

Decision to continue pulling out of hole in spite of the continuous influx.

No kick sheet was prepared after the 10.00 h shut-in when circulation through the choke hose was commenced.

No attempt was made to close in the well completely.

The mud return quantities were not controlled properly. This led to the mud-gas separator being overloaded.

No one closed the valve on the mud return line. Closure would have led the gas to the top of the derrick instead of building it up in the installation.

The rig wasn't moved away from the flames before being abandoned.

8 Ocean Developer

Due to lack of information, no diagram is available for this accident.

8.1 Facts

Structure	Semi-submersible drilling platform
Location	Off West Africa, near Cabinda, northern Angola
Date	14. August, 1995
Water depth	3300 m
Operational status	Under tow (from Port Gentil, Gabon to Cape Town)
Age of rig	25 years
Fatalities	None

8.2 Event sequence

The ballasting system is complex to operate and someone may have "pushed the wrong button".

The rig sank during tow in open water.

The entire crew was rescued by the towing vessel.

8.3 Design problems

Complex ballasting system.

8.4 Organizational problems

Inexperienced operator of ballast system.

8.5 Judgemental errors

Someone pushed the wrong button.

9 P-36

9.1 Facts

Structure	Semi-submersible
Location	Roncador field, Campos Basin, Brazil
Date	15. March, 2001
Water depth	1360 m
Fatalities	11

9.2 Event sequence

14. March

Drainage operation of hydrocarbons from the drains storage tank in aft **port** column begins.

Operational problems in starting up the drainage pump caused reverse flow of hydrocarbons to the aft **starboard** tank. This was possible due to a damaged or partially open intake valve.

Drainage pump started. This reduced the reverse flow, but water and hydrocarbons still flowed to the aft **starboard** tank.

15. March

First explosion: Rupture of aft starboard tank due to overpressure from hydrocarbons and water.

Rupture of seawater pumping line.

Fluids from failed tank started to fill a compartment in the column at 4. level.

Doors/hatches were opened by fire crew. This allowed gas to migrate to other decks.

Gas explosion killing 11 members of the fire brigade.

The water from the ruptured sea water line flooded the column.

Failure of ventilation dampers actuators allowed water to migrate further down through the column and to the pontoon.

Platform started heeling to starboard.

Water entered the aft starboard column ballast tank and the stability box through manholes which were left open. This intensified the heel.

Ballast water was pumped to the port forward tanks to counteract the heel. This increased the draft and reduced the reserve buoyancy.

Evacuation of 138 non-essential (to emergency operations) crew members by crane and personnel transfer basket.

Remaining personnel evacuated.

Attempts to maintain the stability by injection of nitrogen and compressed air in the flooded compartments were made.

20. March

Platform sank.

9.3 Design problems

The design allowed reverse flow of hydrocarbons to the drainage tanks.

Mechanical failure of actuators to ventilation dampers.

Possible design weakness on intake valve on aft starboard drainage tank.

Design criteria for floating production units need to be revised.

The "Fail safe" position of the fire water intake was open, without possibility of closure.

There were openings between decks which allowed water to flow freely between large areas.

9.4 Organizational problems

Weaknesses in the operational management system: non-conformities with respect to operational (hydrocarbons in unclassified area) and maintenance procedures.

Need for improvement of contingency plans for large-scale accidents.

9.5 Human errors

Storage of hydrocarbons in unclassified area.

Failure to close the intake valve of the aft starboard drainage tank or failure to maintain it properly.

Failure to maintain the actuators of ventilation dampers.

Decision to increase the draft by ballasting down the forward port column.

Leaving too many man-holes open in stability box.

Failure to observe the water tightness and integrity in stability-critical areas (containment of water).

Failure to dewater the flooded areas before abandonment.

Defective bilge pumps.

9.6 Barriers which are sensitive to ageing problems

Barriers which rely on mechanical equipment such as ventilation dampers and valves will deteriorate with time, especially if maintenance is inadequate.

The bilge system was defective. This may be due to an ageing problem.

Knowledge about design preconditions (hydrocarbons in unclassified area).

10 Generic barrier diagram

10.1 General

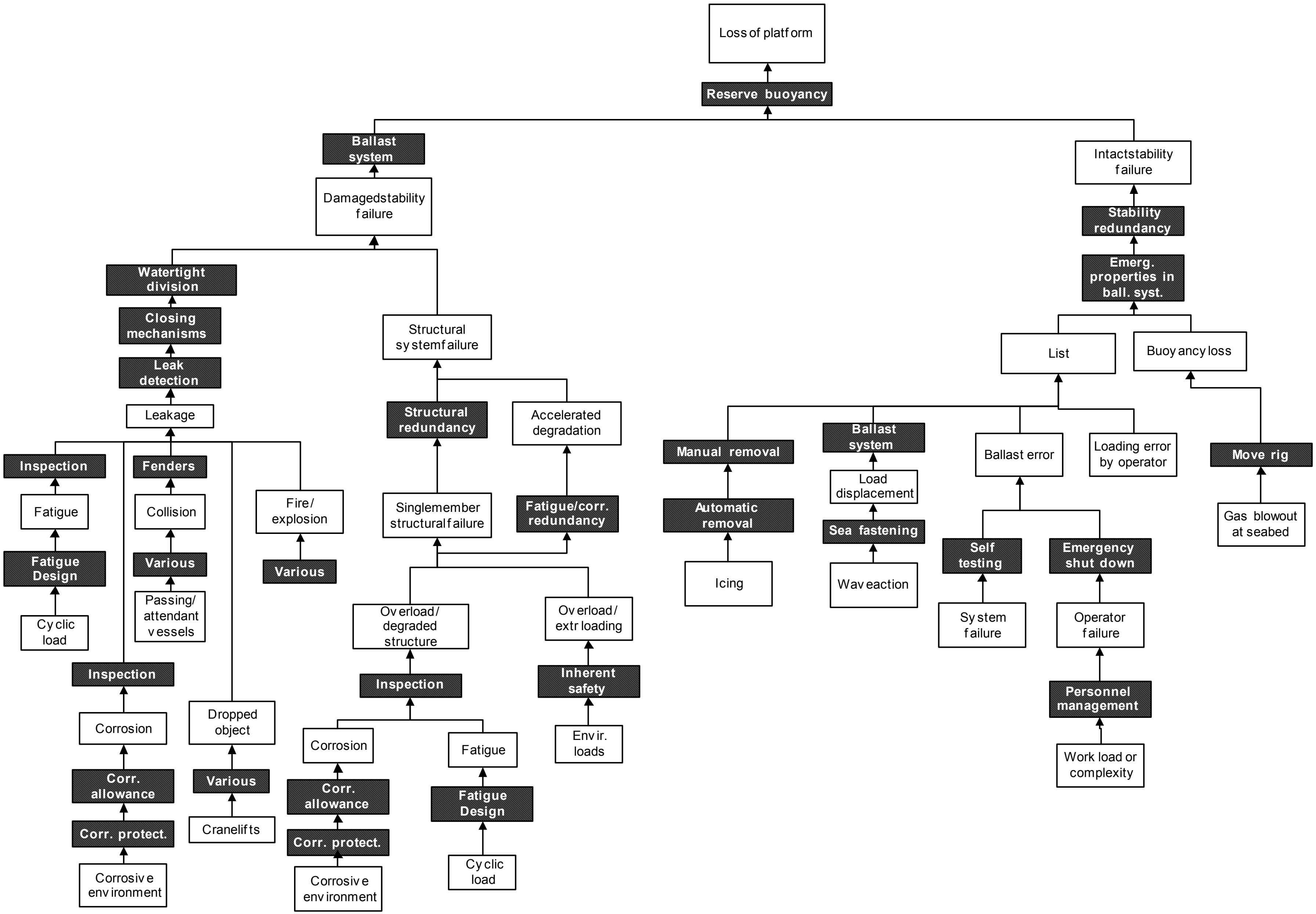
On the basis of the detailed diagrams of chapter 11, the generic barrier diagram shown on the next page has been formed. It focuses on structural and marine operational aspects for semi submersibles. Personnel safety and fire/explosion events have not been included in any detail.

The events leading to loss of platform have been divided into two branches; one for intact stability failure, and one for damaged stability failure. In the intact mode, loss of vessel occurs mainly due to human error, (e.g. in loading or ballasting) or from failure of the ballast system. In the damaged mode, leakage or flooding may occur due to a wide range of causes, e.g. fatigue cracks, corrosion or overload.

In section 10.2 the individual generic barriers are exemplified and explained. The list is not complete but is meant as a catalogue of possibilities for comparison to rig owners' statements.

Many of the barriers found in the detailed diagrams (such as training, design QA, classification procedures, system description in operational manuals and maintenance procedures) belong in practically all of the branches of the generic diagram. However, in order to enhance the overview, they have to a large extent been left out.

In section 10.3 an aggregate list of barriers which are sensitive to ageing problems is given.


Loss of platform
Reserve buoyancy
Ballast system
Damagedstability failure
Intactstability failure
Stability redundancy
Emerg. properties in ball. syst.
List
Buoyancy loss
Watertight division
Closing mechanisms
Leak detection
Leakage
Structural systemfailure
Structural redundancy
Accelerated degradation
Inspection
Fatigue
Fatigue Design
Cyclic load
Fenders
Collision
Various
Passing/ attendant vessels
Fire/ explosion
Various
Inspection
Corrosion
Corr. allowance
Corr. protect.
Corrosive environment
Dropped object
Various
Cranelifts
Singlemember structuralfailure
Fatigue/corr. redundancy
Overload/ degraded structure
Overload/ extr loading
Inspection
Inherent safety
Envir. loads
Corrosion
Corr. allowance
Corr. protect.
Corrosive environment
Fatigue
Fatigue Design
Cyclic load
Manual removal
Automatic removal
Icing
Ballast system
Load displacement
Sea fastening
Waveaction
Ballast error
Self testing
System failure
Emergency shut down
Operator failure
Personnel management
Work load or complexity
Loading error by operator
Move rig
Gas blowout at seabed

10.2 Description of generic barriers

The following list exemplifies and explains the barriers shown in the generic barrier diagram.

1. Fatigue design is the task of ensuring that the design has adequate capacity against fatigue loads. Special attention should be paid to material choice for joints.

2. Corrosion protection can be surface protection (paint or coating) or cathodic protection.

3. Corrosion allowance is additional material thickness to account for corrosion.

4. Inspection with respect to corrosion and fatigue includes visual inspection as well as various NDT methods for crack detection and plate thickness measurement.

5. Various barriers against collision from passing or attendant vessels include diversion of shipping routes, charting, buoyage and design measures such as distance between platform elements and normal position of attendant vessels. Moreover, radar surveillance and general operational procedures for attendant vessels can be mentioned.

6. Fenders protect the structure against ship impact loads.

7. Various barriers against dropped objects are procedures to avoid lifting heavy loads over sensitive equipment. In addition, restricted operational zones for the individual cranes can be counted in this category.

8. Various barriers against fire and explosion include all measures to ensure well control, prevent gas leaks, reduce ignition sources and limit the oxygen supply.

9. Leak detection system requires a system of sensors or other types of measuring methods for leakage in critical members. The presence of a leak detection system (usually not present in water filled members), the functionality of the measuring system (e.g. corroded tubes or wires) and other defects may be critical for the effectiveness of this barrier.

10. Closing mechanisms include all types of valves, air intakes etc. that are operated automatically or from the control room. ESD systems often include fail safe position of ballast valves. This barrier category also includes manual closure of e.g. manholes.

11. Watertight division is a barrier that contains a leak in certain compartments.

12. Inherent safety is the conservatism in design, safety factors, etc.

13. Fatigue/corrosion redundancy is the structures robustness in fatigue and corrosion for a single member failure. If e.g. fatigue and corrosion are highly correlated, or if load redistribution due to a single failure leads to increased fatigue in nearby elements, the barrier cannot be regarded as effective. In such cases the structures robustness due to single failure is not correctly represented by the overload after damage check.

14. Structural redundancy ensures that a single member structural failure does not lead to system failure. In other words the structure is able to survive even if one element is lost. These issues are addressed in regulations.

15. In the damaged condition the ballast system can be used as a means to keep the structure at even trim (to prevent the situation from escalating) or to counteract a leak to gain time for evacuation.

16. Automatic removal of icing is provided by heat coils on sensitive equipment.

17. Manual removal of ice is usually done with clubs.

18. Sea fastening is the task of ensuring that all items are securely fastened such that they don't displace or drop due to wave motion.

19. The ballast system can be used to counteract a load displacement to get the rig back on even trim.

20. Self testing features of systems are gaining importance. They reduce the probability that system errors remain undetected until they become critical.

21. Personnel management includes manning plans, training of operators and operational procedures.

22. Emergency shut down (following operator failure) can be activated on various levels. Valves will return to their fail safe position.

23. Moving the rig away from the gas plume counteracts buoyancy problems (and reduces the concentration of gas on the installation, but this has nothing to do with buoyancy loss). This can be done by anchor winches, release mechanisms or DP-systems.

24. Emergency properties in the ballast system are "fail safe" position of valves, or freezing the current position of valves. Possibilities of manual operation of valves also belong to this category of barriers.

25. Stability redundancy is provided by design due to regulations, so even if buoyancy is lost for some compartments, reserve stability is available.

26. Reserve buoyancy can be provided by e.g. buoyant deck.

10.3 Barriers sensitive to ageing

10.3.1 General

In the following an aggregate list of barriers which are sensitive to ageing is given. It is based on the lists established for the individual accidents.

10.3.2 Technical barriers

- All types of barriers which rely on mechanical equipment will be prone to degradation over time. Examples are mechanical release mechanisms (sub sea wellhead connector, anchor release system), closing mechanisms (ventilation and ballast valves). The moving parts become worn, lubrication deteriorates with time, friction increases, corrosion. Proper maintenance remedies these effects.

- Sacrificial corrosion protection degrades with time and must be renewed to ensure continuous protection.

- All types of electronic equipment (control panels, sensor systems) consist of components with a finite life time. Therefore the performance of equipment will degrade with time. Usually defective electronic components cannot be repaired but have to be replaced. Some systems (such as modern control panels) have self-testing features.

- The requirement of 2 separate systems for level measurement of ballast tanks. This barrier is prone to ageing if one of the systems is based on traditional sounding pipes, as corrosion can make them impossible to use.

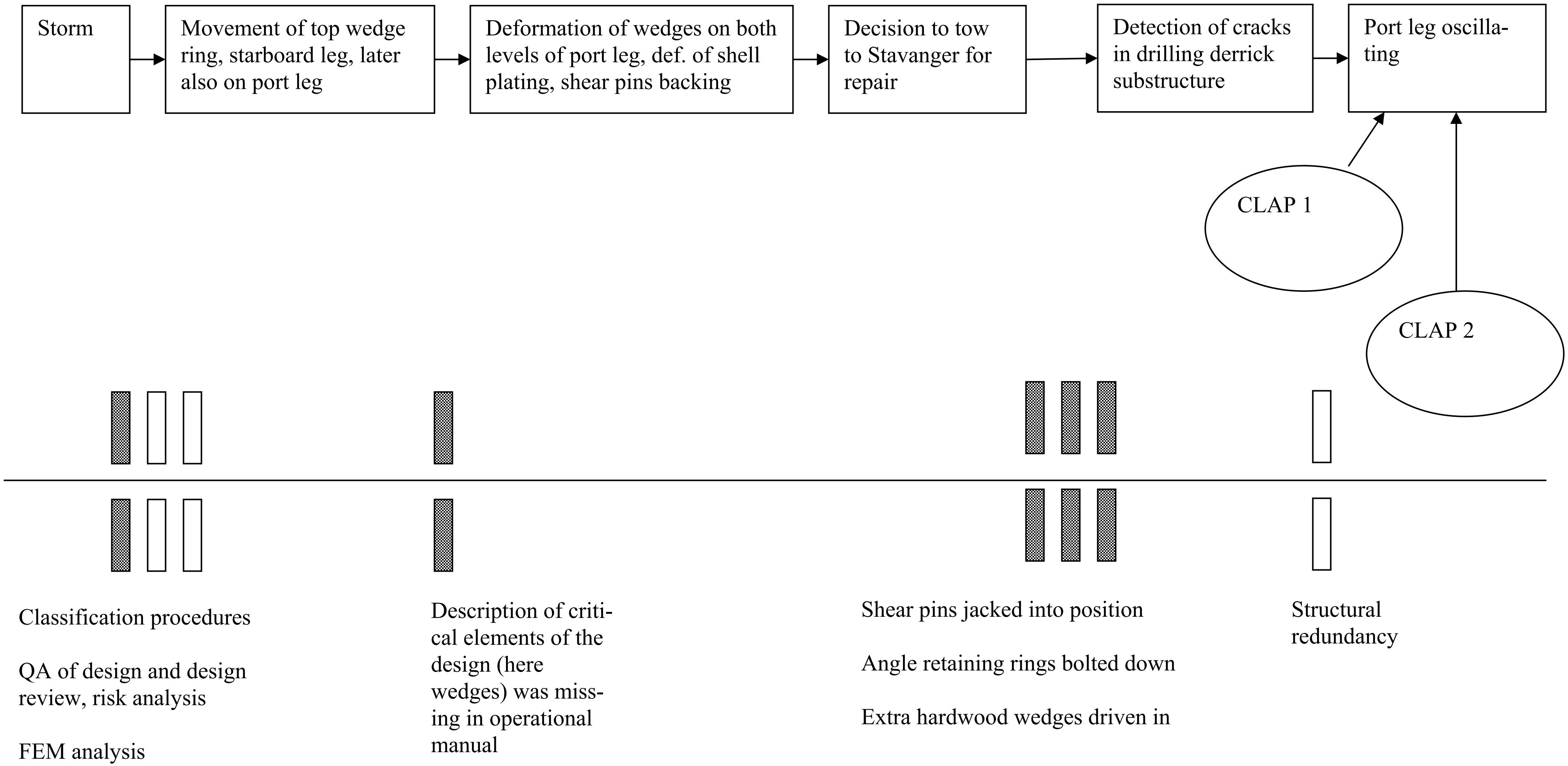
10.3.3 Organizational barriers

- Knowledge about the critical components, systems and design preconditions. If descriptions of the operation mode and criticality of certain equipment or systems are missing in manuals, the transfer of knowledge about them between crews relies mainly on the individual crew member's memory and ability to communicate the essential information. The level of knowledge about the systems among the crew members will therefore degrade over time if appropriate training is not ensured.

- Due to modification and refitting works, many parameters of the platform change over time. As an example, weight estimation and distribution on the structure will be increasingly uncertain during the lifetime of the rig. Therefore the stability condition as well as the structural load on particular members may be different from the design preconditions. Therefore, the impact of the modifications on basic design preconditions must be evaluated, both by rig owner and by classification society.

11 Specific barrier diagrams

11.1 Trans Ocean III

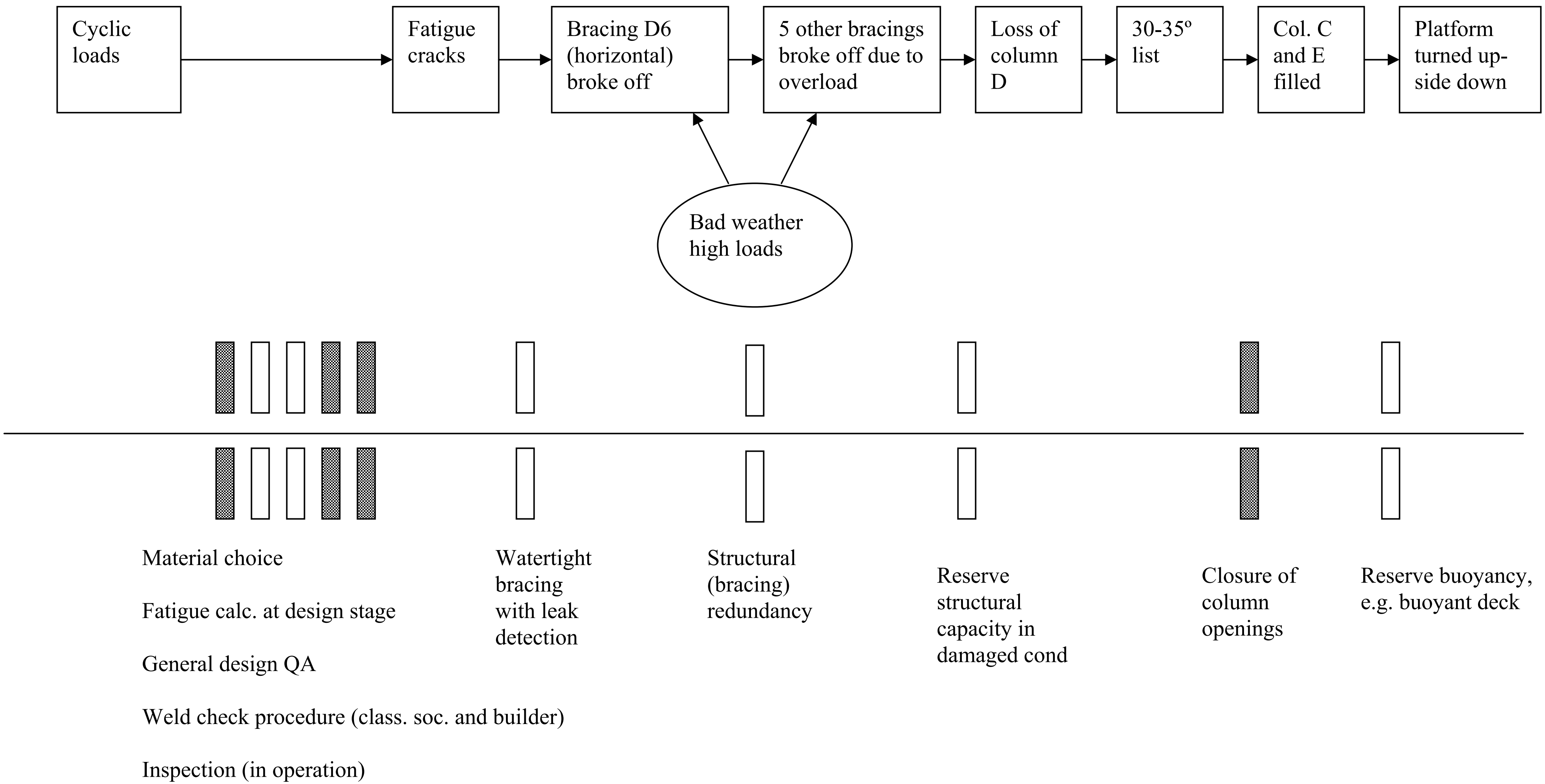


Wedges hitting holding down angles → Removal of non-essential personnel → Wedges in free movement damaging shell plating of upper level, one holding pin out → Second holding pin nearly out → Evacuation of remaining personnel → Port leg tilted outward → Capsizing to port

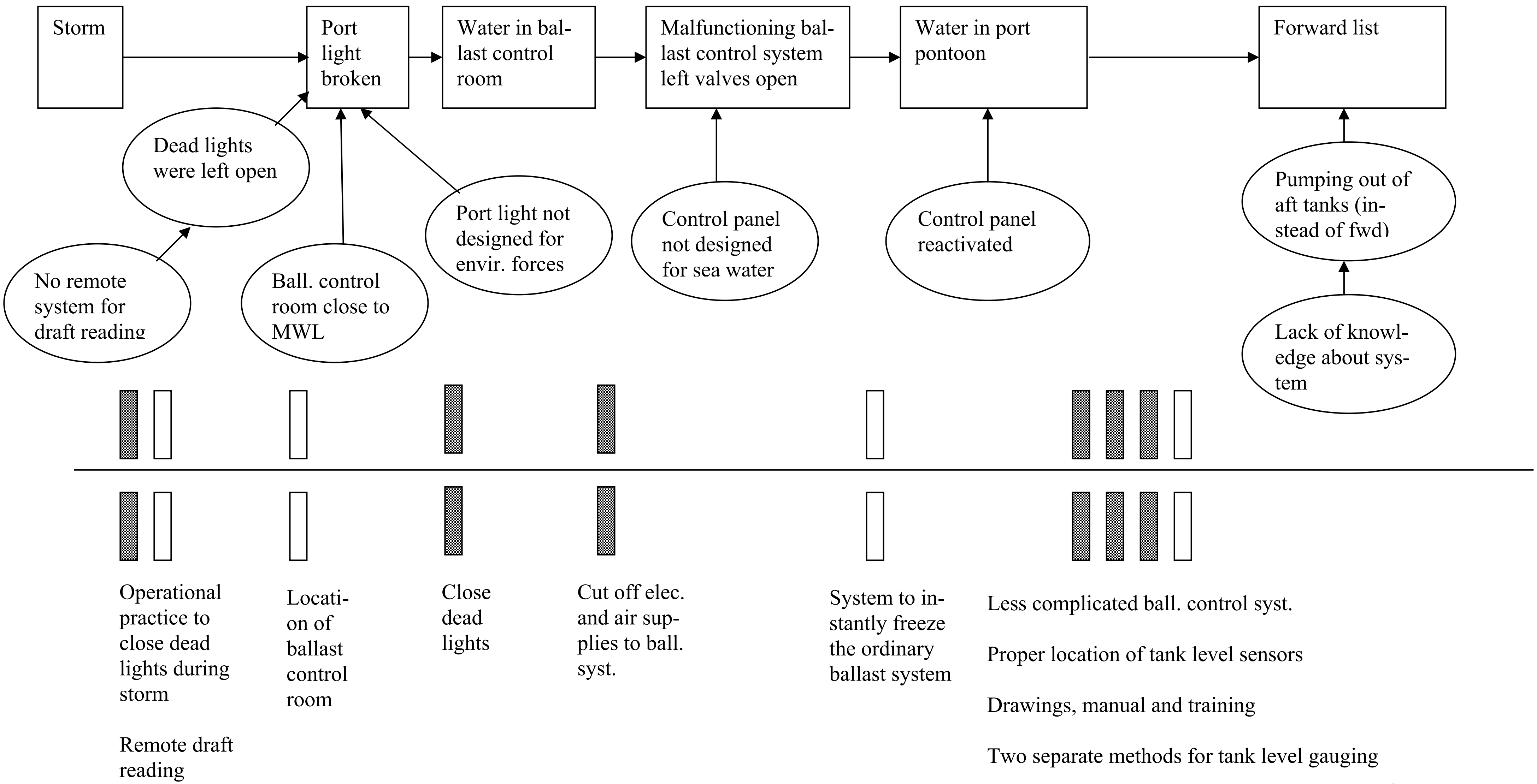
Closure of water tight doors in main hull

Redundant buoyancy

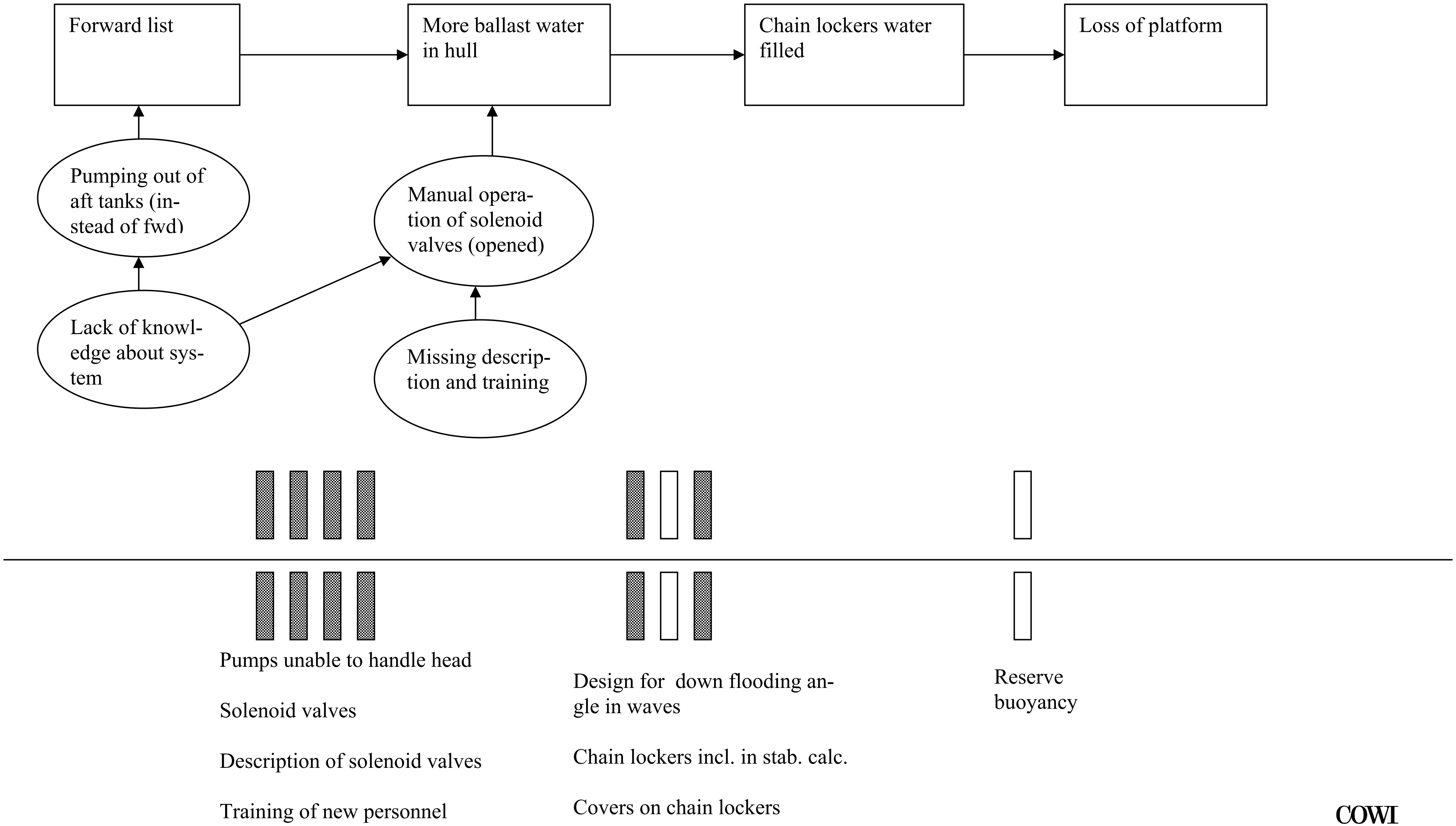
11.2 Alexander Kielland



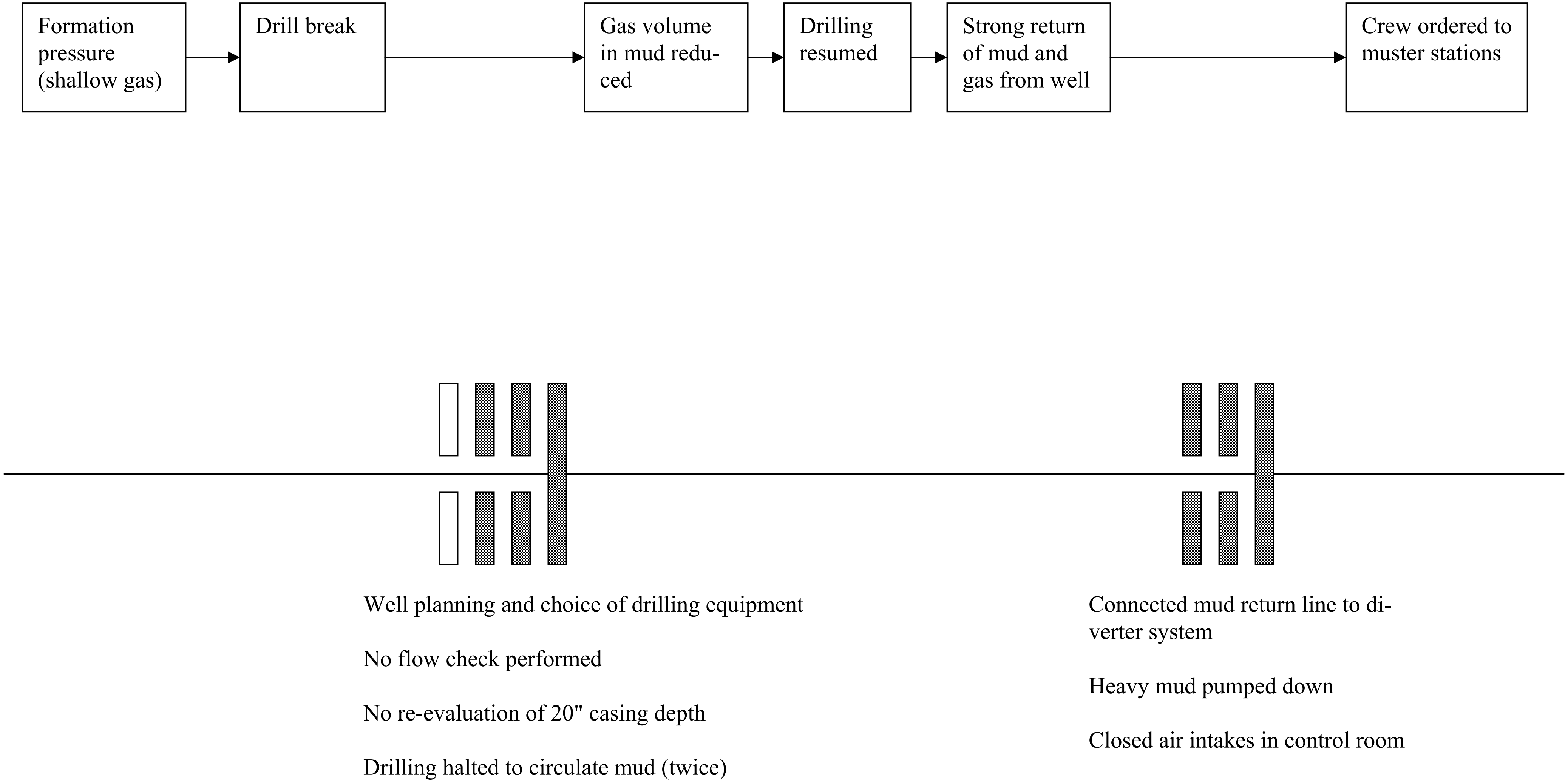
11.3 Ocean Ranger



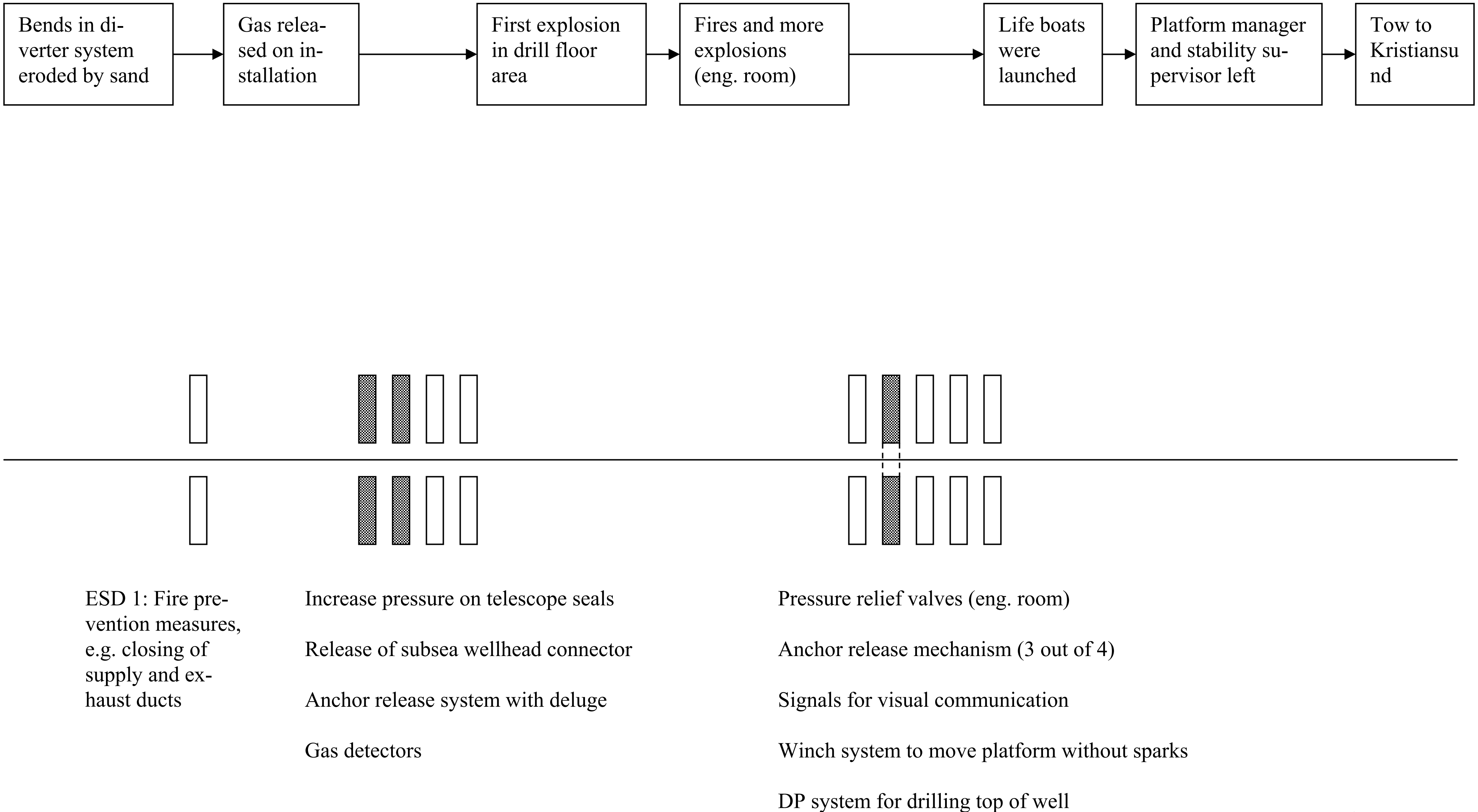
Ocean ranger 2/2



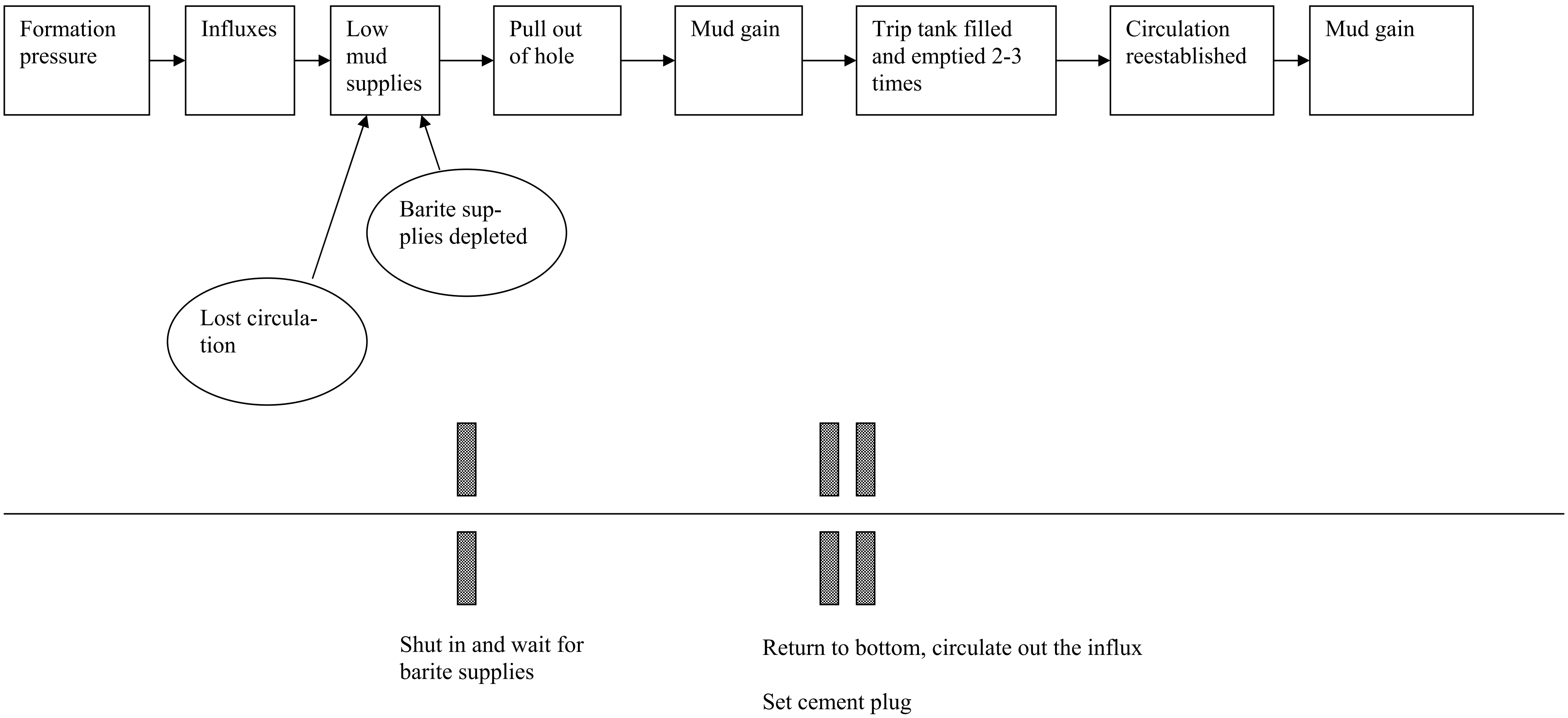
11.4 West Vanguard



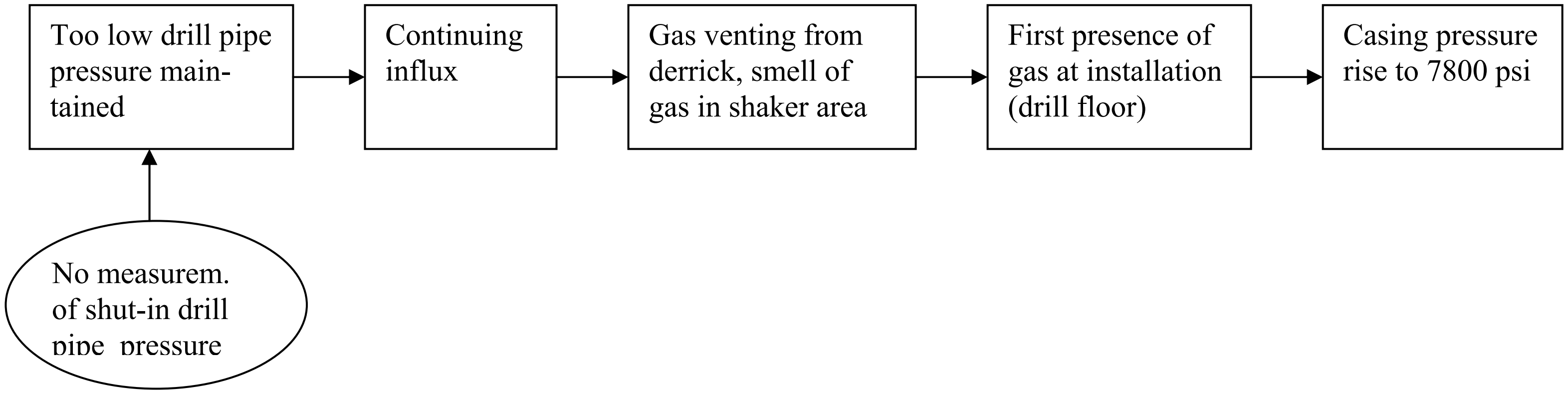
West Vanguard 2/2

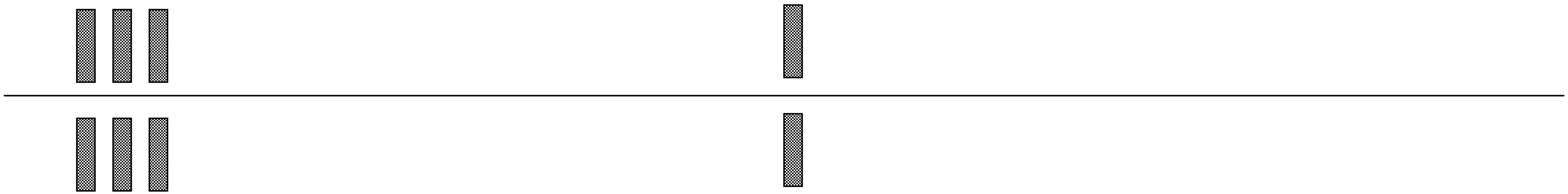


11.5 Ocean Odyssey



Ocean Odyssey 2/5



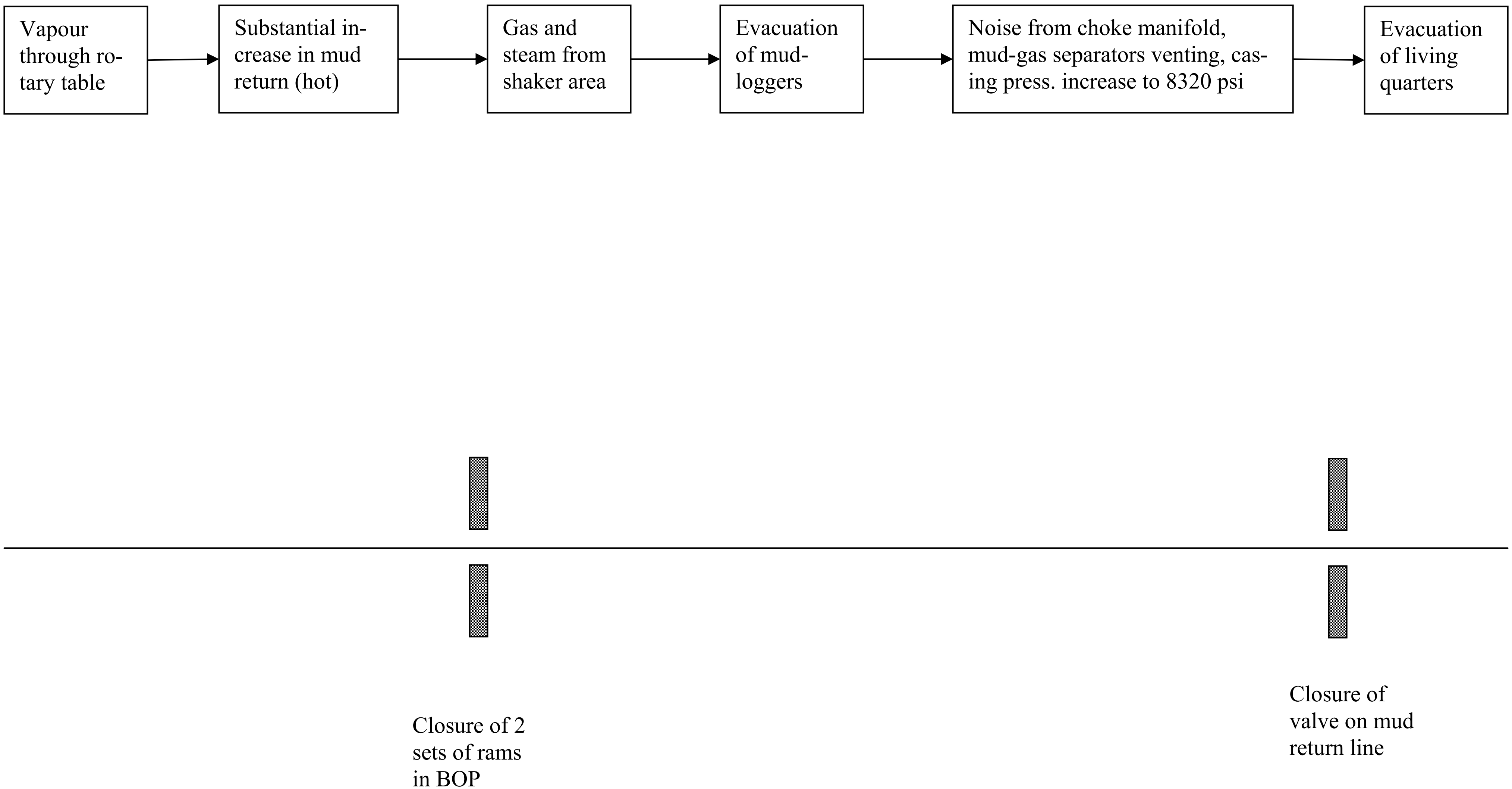


Shut-in, lower annular, circ. through choke line

Preparation of kick-sheet

Measurement of shut-in drill pipe pressure

Calc. of required no. of pump strokes


Vapour through rotary table
Substantial increase in mud return (hot)
Gas and steam from shaker area
Evacuation of mud-loggers
Noise from choke manifold, mud-gas separators venting, casing press. increase to 8320 psi
Evacuation of living quarters
Closure of 2 sets of rams in BOP
Closure of valve on mud return line

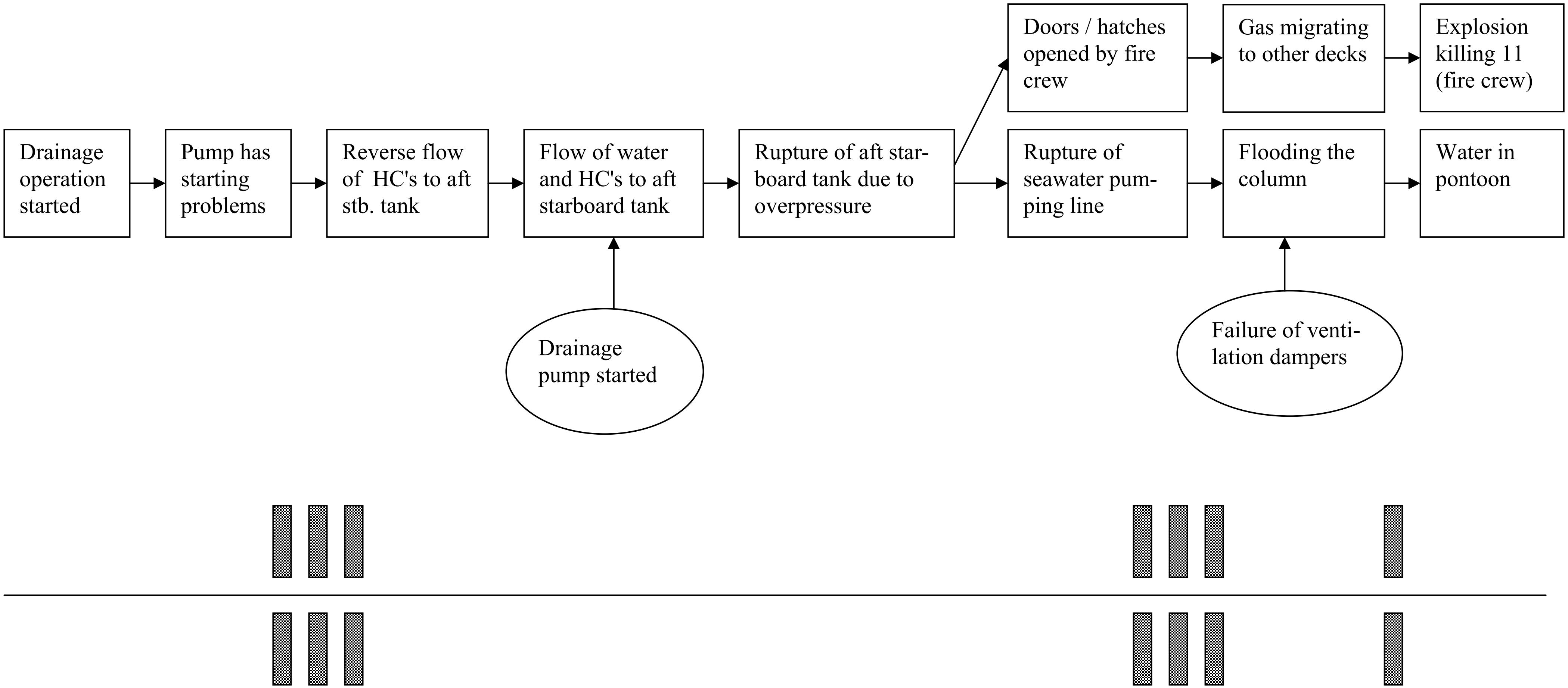
Gas alert, Stand-by boat on close stand-by → Mud pouring over shakers, gas coming out of mud → Evacuation of pump room, gas level in shaker area close to expl. limit → Evacuation of shaker area → Flow-line temp. increases to over 100º C → First explosion → Release of life-boats

Ocean Odyssey 5/5

3 men jumped, 4 men climbed down → Mayday issued by standby boat → Helicopter arrives → Flow from well ceased by itself → Rig was rebuilt in Russia and Norway

Anchor chains severed to move rig away from flames

11.6 P-36 1/2



Storage of HC's in unclassified area (oper. management syst)

Design against reverse flow

Failure to close or maintain intake valve of aft stb. drain. tank (not fail safe)

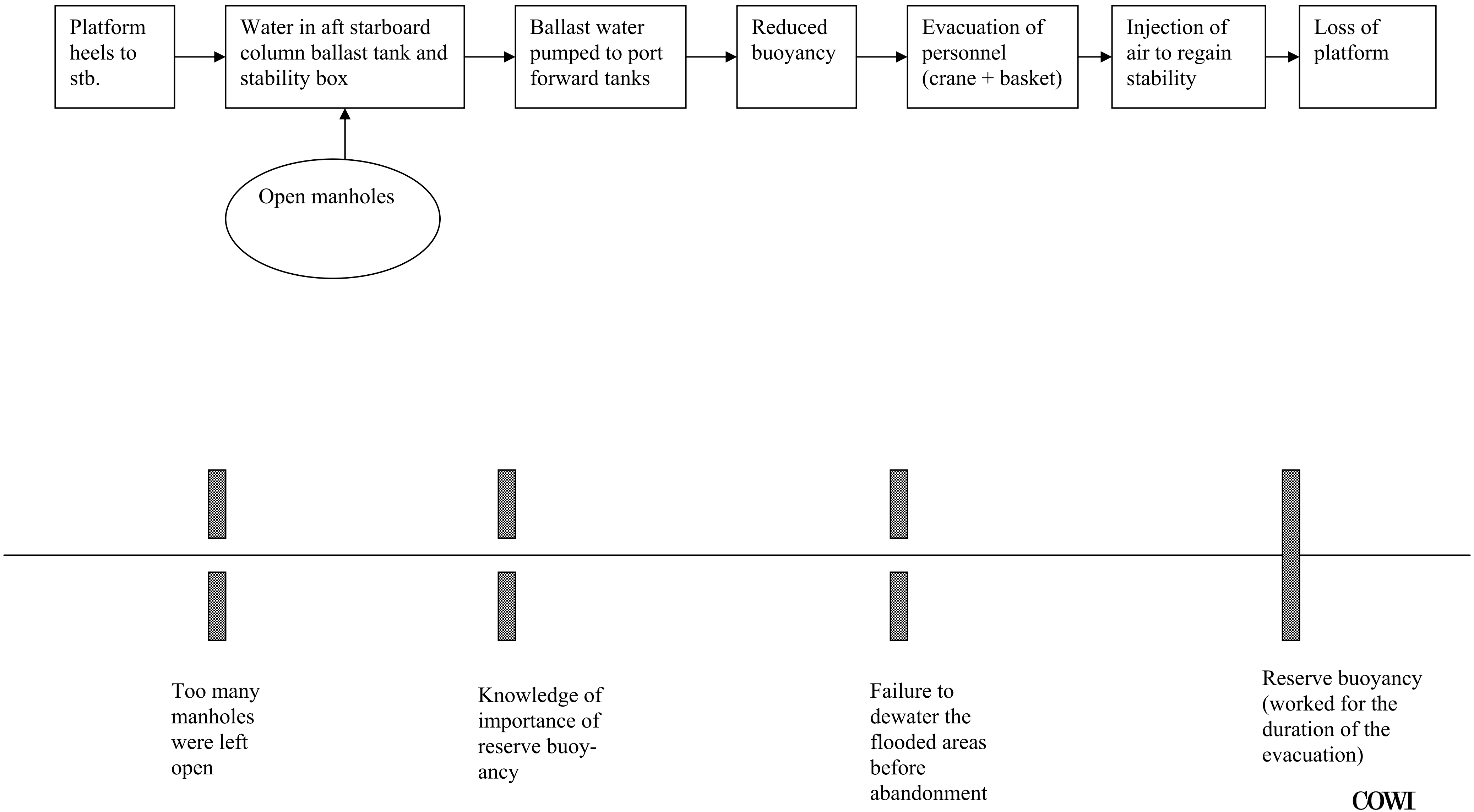
Failure to maintain the actuators of vent. dampers

Closure of "fail safe" fire water valve

Failure to contain the water

Bilge system defective

P-36 2/2


Platform heels to stb.
Water in aft starboard column ballast tank and stability box
Ballast water pumped to port forward tanks
Reduced buoyancy
Evacuation of personnel (crane + basket)
Injection of air to regain stability
Loss of platform
Open manholes
Too many manholes were left open
Knowledge of importance of reserve buoy-ancy
Failure to dewater the flooded areas before abandonment
Reserve buoyancy (worked for the duration of the evacuation)

12 References

Ref. 1 Diskusjon av barrierebegrepet, SINTEF Teknologiledelse, prosjektnr. 384540, 2003-02-14