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Seaways

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Multitasking
Focus and distraction in port **p10**

When to abandon?
Stability criteria and safety **p12**

Bring back the clerk!
Cutting the bureaucratic burden **p16**

Beyond human error
Preventing accidents at source **p21**

Navigational competence

Supporting and developing Generation Y – Command seminar report p5

The Nautical Institute

When to abandon

A better understanding of factors affecting stability would save many lives

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The sinking and abandonment of the *Costa Concordia*, followed earlier this year by the loss of the South Korean ferry *Sewol*, has put the competence of Masters in handling emergencies under the spotlight. In particular, it has raised issues about how and when Masters should give the command to abandon ship.

Besides my professional interest in the subject, this also has a personal connotation. In 1992, a fellow student from the Naval Academy died in the sinking of the *MV Guantanamo*. He was the second mate. More recently in 2011, another fellow student and friend also died when he sank with the ship under his command, the *MV Helga*.

All four cases (see box) are different but they all share a common factor: a wrong assessment of the situation and/or a hesitation in giving the order to abandon ship.

Before discussing when is the right time to abandon the ship and how the Master can best assess this, there are two facts to consider: firstly, not all ships founder in the same way and secondly even the way in which a given ship founders will depend on the conditions. Even so, the Master is expected to have an idea of how his own ship will founder in each condition.

I use the word founder, rather than sink, as a generic term, to refer to the loss of the ship either by sinking or capsizing. In the following discussion, I will divide the causes of possible loss into two: loss of buoyancy and loss of stability.

Loss of buoyancy

This refers to the loss of buoyancy beyond the maximum applicable load line, compromising the floatability of the ship.

For this event to happen there has to be ingress of water. Excess of water in one or several compartments will increase the ship's displacement and will reduce the freeboard expected for the season/navigation zone. The water is taking the ship's reserve of buoyancy.

At that stage, if one of the compartments is totally flooded, the ship might be expected to survive afloat. Damaged stability criteria call for ships to stand the flooding of any single compartment, including the foremost cargo hold.

When the ingress of water sets in, the first thing to assess is where the point of ingress is located: forward, centre or aft. If the lost buoyancy is forward, it will result in a change of trim. If as a result of this the water

Guantanamo On 10/03/1995, the *Guantanamo* was bound for Santander loaded with a shipment of scrap or mill scale. While passing some 500 miles south of Azores with heavy seas, the cargo shifted and the vessel developed a substantial list. Eventually the ship sank with the crew still at the embarkation deck awaiting the order to abandon. A sole survivor, the electrician, at some point decided not to wait any longer and put a life raft afloat. According to his declarations – subsequent to the accident and his rescue after more than 20 days at sea – the ship was listing over 30 degrees. Of 26 crewmembers, 25 died.

Costa Concordia On 13/01/2012, the cruise ship deviated from its route while on passage in the Tyrrehenian sea, hitting the rocks at night in calm seas on her port side. The ship turned and headed or drifted toward shallower waters where she ran aground, developing a massive list and sinking the accommodation on starboard side. The Master allegedly abandoned the ship without leading the evacuation. Of 3,229 passengers and 1,023 crewmembers, 32 died.

MV Helga Sailed Mexico on 19/03/2011 with a shipment of salt bound for Honduras. Shortly after departure, it was apparent she had hit the bottom and there was ingress of water. The Master assessed that the ship could reach Honduras as the water ingress seemed to be contained to the double bottom tank and continued the passage. Just when passing Belize, the ship lost buoyancy and sank, only three miles away from an island. The crew was effectively evacuated, but the Master, chief engineer and a helmsman didn't make it out. The last time the Master was sighted, he was carrying the passports and ready to abandon last. Of 11 crewmembers, three died.

Sewol On 16/04/2014, the passenger ferry *Sewol* sailed from Incheon bound for Jeju with cargo consisting of containers and probably cars too. The ship had been subject to modifications altering its stability. According to news reports, the ship was overloaded and the cargo poorly lashed. In order to take the extra cargo, the ship carried only some 580 out of the 2,030 tons of ballast recommended. After a sharp turn, apparently in calm seas, the cargo shifted and the ship developed a large list and started taking water in. The Master allegedly asked the passengers to remain in their cabins reportedly to avoid contact with the frigid water which was about 12 degrees. Hundreds of people were trapped in the lower decks unable to evacuate due to the excessive inclination. Fatalities: out of 476 passengers and crewmembers, 300 died.

line exceeds the bulkhead deck, the water pressure in the damaged compartment could force the hatches off – even when the water is restricted to a certain volume. This would extend the flooding to adjacent compartments, leading to the eventual loss of the ship. Accordingly, flooding of foremost compartments should be regarded as more critical and dangerous than that of centred compartments.

The amount of water admitted to a compartment not only depends on the volume but also on the permeability. This is the ratio between the volume that is floodable and the total volume (from 0 to 1). Knowing the content of the compartment flooded (cargo, liquid, stores, and accommodation stuff) will give an idea of the possible extent of water ingress.

When flooding is not symmetrical, because of the existence of a longitudinal bulkhead that has not been compromised, cross flooding is recommended (flooding an opposite compartment symmetrical to it). While this method is recommended for flooding to avoid large angles of heel, sacrificing buoyancy for the sake of stability, it is not recommended when cargo shifting occurs, as this could shift back to the opposite side with the added heeling moment of the flooded compartment.

When the loss of buoyancy occurs without loss of balance or stability, the ship might rest afloat for a considerable amount of time before sinking. This would be true if in addition to keeping an adequate transversal stability condition, the loss of longitudinal balance (excessive trim) is not a factor.

In this case, the ship is indeed the best lifeboat and it is best to remain on it for as long as possible. However, when deciding how long to remain, attention should be paid to two aspects:

- Given the location and rate of ingress of the water, the number of subdivisions and the general design of the ship, how long can the vessel stay afloat?
- If the ingress of water is due to possible structural failure, how reliable is the ship – and how fast can the failure propagate?
- How much time can we count on to deploy the lifesaving appliances?

Floatability by ship type: ro-ro

In a ro-ro ship, the cargo space or garage is above the bulkhead deck, and lacks the subdivisions that are in place below it. The freeboard, which runs to the bulkhead deck, is rather low and close to the water line. The vast amount of enclosed spaces without subdivisions poses challenges both to floatability and to preventing the spread of fire, which could disable many of the safety features such as monitoring systems, flooding alarms, and even door integrities that are critical to these ships.

In terms of floatability, the biggest challenge for ro-ro ships is the volume of the cargo space – the ro-ro deck – and the access to it. If the access doors to the cargo space were to be opened or damaged, a massive amount of water could invade these spaces, compromising the seaworthiness in terms of reduction of buoyancy, and loss of stability. The loss of stability will be seen further ahead with loss of balance, and

> “When a ship sustains structural damage resulting in cracks it is not possible to ascertain if the crack has already reached the critical length”

the implications of large inclinations and free surface, but the loss of buoyancy alone would pose a threat to the ship.

Accidents like *Herald of Free Enterprise*, *European Gateway* and *Estonia* prompted a number of investigations, research and SOLAS amendments that improved safety on Ro-Ro ships. The paper *IMO and Ro-Ro Safety*, dated January 1997, is very explicit and detailed. Some of the amendments proposed were: a second line of defence or an inner door, increasing drainage, better lashing and securing, audible alarms for doors, etc. Despite these safety measures, however, ro-ro ships by their very nature are more vulnerable to massive ingress of water and a rapid loss of buoyancy than others when the integrity of the hull is breached. The *Estonia* sank in just a few minutes, with the loss of more than 900 lives.

Structural damage and failure

Limited ingress of water can result from structural damage when encountering severe weather. If the cargo hatches were not battened down and secured properly or the acting cleats not regulated, the watertightness would be affected to a varying degree, with the eventual ingress of water. Even if a whole panel is misplaced and massive amounts of water gain access to the hold, the water would still be confined to a certain space between watertight subdivisions (the transversal bulkhead) and the ship would be able to survive the damage.

However, another cause of structural damage leading to ingress of water – and more severe – would be cracks on the hull resulting from impact (collision, grounding). The science of Fracture Mechanics studies the causes, origin and propagation of cracks, fatigue, and fatigue life. For the sake of brevity, I will only point out a few facts.

Crack propagation

Commercial steels used in the naval industry possess a number of qualities such as ductibility, toughness, etc to stand loads for a large number of cycles. At the same time, defects are inherent to such materials and further defects arise in the process of shipbuilding.

Even in extreme weather conditions, the ship is designed to maintain its structural integrity, despite the flooding of any single compartment. Despite this, cracks may appear. According to research on the origin and propagation of cracks, by the time a crack is visible, the structure has already used most of its fatigue life. Structural designs are also oriented to stop or slow the propagation of small cracks through geometries serving as crack arrestors. However, massive structural deformations and changes in geometries would affect the stress concentration and accelerate the crack propagation. Moreover, crack arrestors are ineffective in preventing the propagation of fatigue or fast running cracks.

There are mathematical tools for calculating rates of crack growth and stability, but it is not feasible to carry out these calculations onboard ship, let alone in an emergency situation. When a ship sustains structural damage resulting in cracks it is not possible to ascertain whether the crack has already reached the critical length and the possibilities of crack propagation and failure.

Most cases involving structural damage and large cracks, such as grounding or collisions, involve damage to the hull plating with ingress of water resulting in substantial stress. In such cases consideration should be given to the possibility of crack propagation and massive failure, even the splitting of the ship, not only to the rate and quantity of water ingress.

Loss of balance and stability

The loss of stability deserves a different analysis, whether or not loss of buoyancy is also involved.

The physics of loss of balance and stability are well known. Inclinations due to rolling after events such as waves or wind gusts start with a shifting of the centre of buoyancy, which by not being in the same vertical of the centre of gravity creates a moment – uprighting moment with GZ as the arm. This moment, which is opposite to the upsetting moment, will bring both centres back to the same vertical.

Inclinations due to shifting of weight are different. They start with the shifting of the centre of gravity causing the ship to incline. The inclination causes a change in the submerged volume and shifting of the centre of buoyancy. The inclination will stop when the centre of buoyancy is in the same vertical as the centre of gravity. The ship will remain in this position.

> “When time and circumstances permit, abandonment should not be seen as a single step process, but a series of steps, some of which can be taken before the actual abandonment”

While the first is a temporary phenomenon, the second is permanent as long as the weight doesn't continue to shift or doesn't increase.

In both cases the angle of inclination resulting will depend on parameters such as displacement and metacentric height GM and by extension, the vertical position of the centre of gravity of the vessel. In the first case, the more displacement and GM – at lower angles of inclination – the more upthrust force and uprighting arm GZ, therefore more uprighting moment. In the second case, the more displacement, the less transversal shifting of the centre of gravity of the vessel resulting from the same weight being shifted (GG1 = (m x d)/Disp), and the less KG and more GM, the less the angle of inclination for the same shifting of the centre of gravity GG1.

Several scenarios may apply:

1. Large inclination due to ingress of water, resulting in loss of stability.
In this case, water has gained access to one or various compartments. If the ship had a previous list, the list will increase as the centre of gravity of the mass of water off centred will create an extra heeling moment. The massive free surface in the cargo hold will have the same effect as a vertical shifting of the centre of gravity, resulting in less GZ and therefore less uprighting moment. If the inclination reaches the flooding angle, the ship will be lost either by sinking or capsizing. Mariners might experience a similar situation when ballasting a cargo hold. If the weights on board are not well balanced, a list will start to develop and increase when the amount of water in the ballast hold increases. Ballast operations must be stopped immediately because this has an exponential effect: the more water, the more free surface moment, less stability, more inclination, more transversal shifting of the centre of gravity and more inclination.

2. Large inclination due to shifting of weight (cargo).
In this case, typical transversal shifting of the centre of gravity has the problem that after the shifting of the weight the ship might not rest on that angle. At such an angle further shifting might occur, either from faulty lashing of break bulk (cargo units) as a result of transversal accelerations or in the case of bulk cargo as a result of exceeding the angle of repose when it is non-cohesive. If no ingress of water is involved, the degree of inclination will depend on the amount of cargo units breaking loose. In the case of non-cohesive cargo, it will depend on the dynamic angle of repose.

3. A combination of the two above.
Ingress of water causing inclination and shifting of cargo or a shifting of cargo causing inclination and ingress of water. In both cases the two effects aggravate each other.

In the case of a ro-ro ship, this effect has even worse consequences, as the lack of subdivision in the cargo spaces could trigger a global breaking of the cargo unit lashings and shifting. In addition, the size of the cargo space creates a massive free surface.

The effect of the free surface on the loss of stability can never be underestimated, as the inertia of a compartment depends on its size. On a typical Laker, the moment of inertia of a centre hold can go up to over 30000 m^4; at about 50% it would be some 18000 m^4, which if not at full displacement, say about 30,000 MT, could increase the KG and reduce GM by 0.6 meters, double the min 0.3 required by SOLAS and the International Code on Intact Stability.

4. One extreme but possible scenario.
The cargo starts breaking loose and shifting, causing a moderate angle of inclination and rupture of the ship's hull or faulty hatch covers. Water starts gaining access in the cargo hold, increasing the weight. As there was already an inclination, the water will form a wedge, adding its own heeling moment. In addition to that, the free surface effect starts taking place. This results in more inclination. More inclination results in greater transversal accelerations causing more cargo to break loose, to shift, to cause the ship to incline even more, more water coming in, and the process repeating until the ship sinks or capsizes.

When assessing the effects of the list, it is vital to take into account the possibility that the inclination will increase.

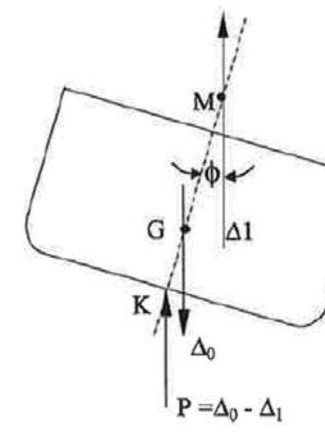
Both SOLAS and the International Grain Code state that if a cargo of grain shifts, the angle of heel after the shift should never exceed 12 degrees. This suggests that any angle of heel or list exceeding 10 to 15 degrees should be deemed as rendering the ship unseaworthy.

Loss of stability during grounding

A grounding (intentional or unintentional) will affect both the metacentric height and the righting moment. When the ship rests partially or totally on the bottom, there will be a loss of buoyancy. While the force of gravity acting on the centre of gravity equals the initial displacement, the buoyancy upthrust acting on the centre of buoyancy and through the transverse metacentre M will be equivalent to the displacement at the new draught.

These two opposite forces will create a couple, forcing the ship to right up. But now the couple is not the same as the uprighting moment or as large as the heeling moment. On the other hand, at the resting point, a new uprighting force equal to the difference between the initial and new displacement P= Δ0 - Δ1 will act, but opposite to the uprighting force as it will act in the opposite side of the righting moment and gravity force couple (P on keel centre K, Δ0 on centre of gravity G and Δ1 on metacentre M), reducing the righting moment even more.

Accordingly, a grounding will result in loss of stability, and unless the ship is perfectly balanced and the bottom is perfectly and horizontally



flat, this will result in inclinations. This is very well known to Masters and officers: before going to drydock, the ship's staff will seek to have a positive and substantial GM and no residual list.

All the above demonstrates that assessing the urgency of the situation and the best course of action is a complex process. The actions to be taken will depend on the situation. Given the subdivisions on the ship, a passenger ship might be better off sinking slowly in the open sea, in calm waters, rather than approaching shallow waters with the risk of running aground, losing stability and inclining. The Master of a ro-ro vessel may wish to proceed with the evacuation of personnel without delay, given the history of previous accidents on ro-ro ships. Masters of cargo vessels should be aware that after a certain angle of list there is nothing to do but to take the crew to safety. In case of a grounding where the ship is still afloat, it may be better to stop and seek refuge to assess the extent of the damages before continuing the passage.

The wishful thinking lag

It is inevitable that a Master will wish to save the ship and avoid abandonment. But we have to learn from previous incidents. In the wake of the *Sewol* incident, Michael Grey FNI asked some tough questions about how to prepare for the unthinkable in his newsletter *Great Expectations*. "Just as happened on the *Concordia*, it seems there is 'wishful thinking' lag – a delay in which the Master hopes against all hope that the situation can be saved," he concluded.

This 'wishful thinking lag' might be due to reluctance on a subconscious level to accept the unavoidable. At a conscious level, it might also be due to a poor assessment of the situation and the notion that announcing and preparing for the abandonment is the very last resource, the point of non-return.

I fully agree with Mr Grey when he suggests that the reason why so many hesitate to give the ultimate order at sea is 'hope' – hope that the vessel can be saved. Anyone who has ever had to launch or embark on a lifeboat even in moderate seas knows how difficult and risky this can be, let alone at night in stormy seas. Even more, though, it is because as seafarers we are trained to protect the ship and the crew. Believing the ship will be saved means believing the crew on it can be saved too – and that their best chance is to remain with the ship.

Bearing all this in mind, when is it right to abandon the ship? When is it too early, or too late? If attempting the abandonment one second too late could have consequences for the safety of the lives of the crew and passengers, we could infer that it is never too early.

The process of abandonment

As long as we keep thinking of abandonment as the last resort while the extent of the damages and the gravity of the situation are still unclear, human losses will continue. We will continue to wait for clearer signals that the ship cannot be saved. The paradox is that by the time the signals are clear, it might be very difficult if not impossible to abandon. What are those signals after all? A massive list which render the boats on the davits useless, or the ship capsizing, or the ship splitting in two. By this time it is already too late.

When time and circumstances permit, abandonment should not be seen as a single step process, but a series of steps, some of which can be taken before the actual abandonment.

The **first step** when the danger and the urgency of the situation are apparent is to *bring the personnel to the embarkation decks and to make the lifesaving appliances ready to receive them*. While the process of sinking can take several hours, in many cases the situation can turn dramatically in a matter of seconds: such as the onset of larger, exponential inclinations until capsizing or sudden split of the vessel.

There is no question in my mind that the place to be would be anywhere other than an enclosed space in the lower decks. In case of capsizing or flooding, interiors could easily trap people in places with no chance of escape.

The lifesaving appliances should be made ready because once large inclinations set on, they are difficult if not impossible to deploy. This is particularly urgent in the case of passenger ships and those commercial ships that still rely on davits rather than freefall boats.

As a **second step**, if the situation continues to deteriorate – the list develops, the ingress of water increases or the buoyancy reduces despite efforts to revert the situation – and there are still doubts of the outcome, *non-essential crew should be evacuated* using the lifesaving appliances already deployed or made ready to deploy. This, in addition to buying time, will allow the crew to rescue the staff still on the ship should the situation turn to the worst or vice versa.

It may sound controversial to deploy lifesaving devices in perhaps rough seas when it is still uncertain the ship has to be abandoned. But the alternative is having people lose their lives because they didn't have enough time to abandon when the situation turned critical. During this operation, there could be heavy damages to the boats, or life rafts. If the situation can be turned around, recovery of boats or rafts – though not personnel – may be difficult or impossible. But again, it is a better alternative than waiting until it is too late. The electrician of the *MV Guantanamo* who deployed and embarked a life raft on his own in the middle of a storm while his comrades awaited the orders to abandon, lived to prove it.

Finally, **the third step**. As the situation develops, it will be clear whether the situation can be corrected and the non-essential crew and lifesaving appliances retrieved, or whether the *crew remaining on board should also abandon*.

I see the abandoning of the ship as a phased process, rather than a stay or leave kind of decision. It is not possible to establish guidelines. Calm assessment of the situation and sound judgment is essential, but I strongly believe that as long as we turn to the lifeboats only when the water is up our knees, lives will continue to be lost.

As human beings we are bound to err. But a debate on this and other issues where human errors result in loss of life and property will bring collective intelligence and experience together to minimise them.

This article is a tribute to Capt Arturo Edreira Cuza, who perished at sea while trying to save his crew and being the last to abandon.

Editor's note: This article has been edited for length. A full version is available on request from editor@nautinst.org