Safe Shipping of Solid Bulk Cargoes

Dynamic Separation & resulting Free Slurry Surface Effect

Introduction

The shipping of solid bulk commodities is paramount to the world's development and economic prosperity. Ensuring these cargoes safely reach the end user is of most importance.

Since 2011, Rio Tinto (RT) has been deeply involved in understanding how solid bulk cargoes behave during ocean transportation, especially identifying any cargo instability due to moisture.

- The work first started with an investigation into the behaviour of iron ore fines, conducted via the Iron ore Fines Technical Working Group (IOF TWG). This work was submitted to the International Maritime Organisation (IMO) to assist with policy formulation for the carriage of iron ore fines.
- Following this work, the Australian coal industry, embarked on a study to understand the behaviour of coal during shipping, again leading to assisting the IMO with policy on the safe shipping of coal.
- Recently, bauxite has also been investigated via the Global Bauixte Working Group (GBWG) with the outcomes utilised by the IMO to develop policy to ensure the safe shipping of bauxite.

ClassNK is a ship classification society and has contributed to the Japanese IMO delegation supporting Japan's competent authority. It has held a great interest in understanding the issue of possible ship instability due to high moisture of solid bulk cargoes such as nickel ore. ClassNK and RT entered into a Collaboration Agreement in 2013 under which a joint study into the behaviour of solid bulk cargoes during shipping was undertaken. The collaboration included dynamic centrifuge physical modelling, where the impact of the ship's rolling motions and cargo properties on the stability of the solid bulk cargoes was investigated. The outcome of the joint study has contributed to IMO policy formulation for bauxite in 2017.

The cumulative knowledge developed over the course of these investigations, including the RT-ClassNK collaboration project using the dynamic centrifuge, has resulted in a better understanding of cargo instabilities due to moisture and the resulting effect on a vessel's stability. This has profound safety implications for the vessel, its Master and crew.

Dynamic Separation

The dynamic centrifuge tests showed that some cargoes do not liquefy in the classical sense; however they do exhibit an instability due to moisture whereby the cargo dynamically separates to form a drier, compact and competent solid bulk over which a free slurry surface forms.

If the cargo is fine enough, wet enough and experiences enough forces from vessel motions, the cargo will undergo dynamic separation, expelling water to the cargo surface as the cargo pile slumps. The final worst case result is the formation of a dense free slurry surface covering the full width of the vessel hold. This free slurry surface has serious implications to a vessel stability.

Cargo Before Dynamic Separation **Cargo After Dynamic Separation**

Dynamic Separation occurring in Solid Bulk Cargo when moisture and fines content are high and vessel motions are large

Free Slurry Surface Effects

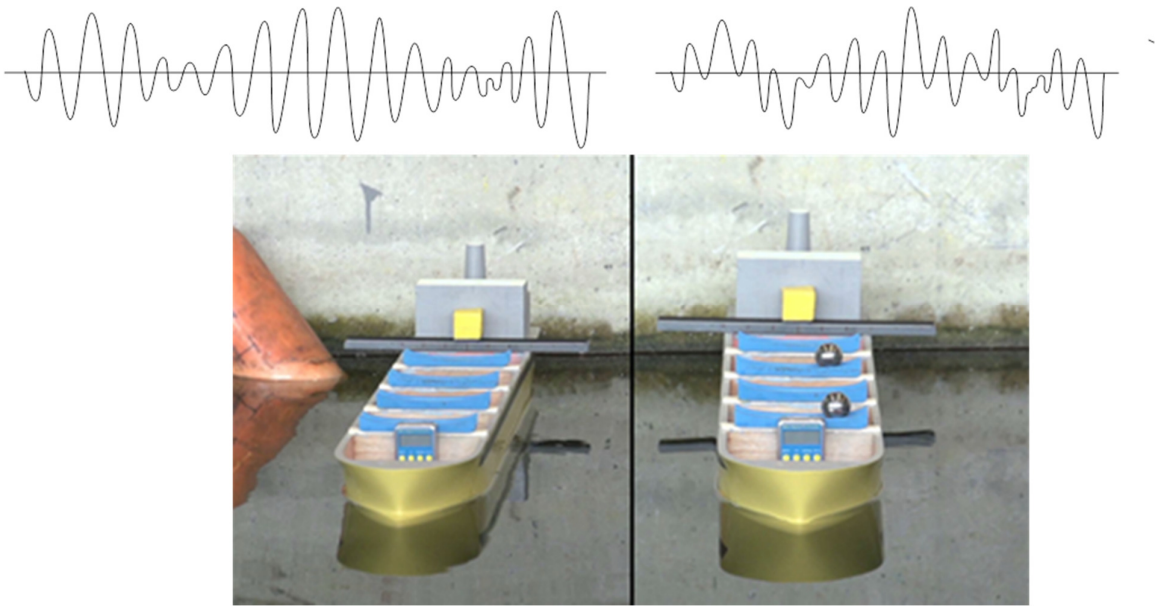
To understand the vessel's response to dynamic separation of the cargo and to be able to accurately ascribe the mechanisms leading to catastrophic failure, incidents where vessels had been lost due to cargo liquefaction where assessed, as outlined by the GBWG. Typically, it is the accounts from any surviving crew that are critical to understanding the process leading up to failure.

In most accounts,

- the first sign there was an issue was when the crew noticed the vessel's unusual response, typically its rolling behaviour.
- Soon after this, the vessel would develop a list that would progressively increase over a period of at least an hour, sometime days.
- Finally at some point when a list of 15 degrees or more had been reached, the vessel would capsize in a matter of minutes.

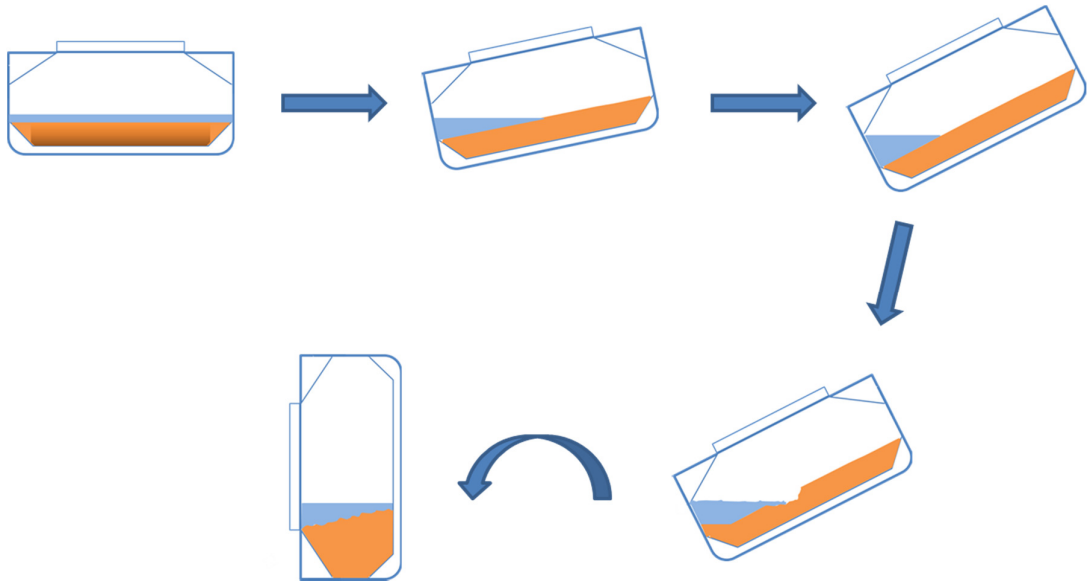
These accounts point to a two stage process of failure. The first being the steady development of a list and the second being rapid capsizing. Any cargo instability due to moisture that arises should be able to explain the vessels behaviour. Under the classical liquefaction model this is difficult to explain, as the cargo liquefies it shifts during any rolling motions causing rapid capsizing. However, the dynamic separation phenomenon with the formation of a free slurry surface can explain this two stage process leading to vessel loss.

The free slurry surface affects the static stability of a vessel by effectively reducing the vessels GM. This depends upon the density and height (amount) of the slurry formed, the width the slurry can move in the hold and the number of holds that form a free slurry surface. If one or more holds have a free slurry surface that covers the full beam of the ships hold, then the vessel's GM will be significantly reduced and an unstable state will result. In this condition the vessel may still be upright but its response to waves will be atypical and its normal rolling motions will have an overriding wobbling motion due to the free slurry surface. This is the first sign something is wrong and the crew and Master will "feel" this behaviour. As the vessel's GM approaches zero, the destabilising effect of the free slurry surface will be counter acted by the vessels righting moment (the vessel wants to be stable) and the vessel will develop a list to regain static stability. The amount of list developed depends on the slurry density, the depth of the slurry, the width of the slurry and the number of holds containing a free slurry surface.



1:185 Handymax model showing normal roll response and "wobbling" due to free slurry surface effects (ball bearings)

Once listed and still experiencing rolling motions, the free slurry surface can erode the underlying competent solid cargo, causing it to be deposited to the lower side of the cargo hold, thereby exacerbating the list. Furthermore, the exposed competent solid cargo that is on the high side can be under eroded. At this point,the high side cargo can easily avalanche as its angle of repose has been exceeded by the erosion action of the free slurry surface, causing a catastrophic cargo shift which results in the vessel quickly capsizing.



Schematic of free slurry surface effect leading to firstly a vessel list, and then to a rapid catastrophic capsizing

Key message

Under the traditional cargo liquefaction model, only by ensuring compliance before the cargo is loaded can any risks due to cargo liquefaction be mitigated. If a cargo is misdeclared and the vessel sails, the Master and crew have no advice or potential recourse, and the cargo may liquefy, causing the cargo to rapidly shift and the vessel to capsize.

Under a dynamic separation model of cargo instability, ensuring compliance before the cargo is loaded still mitigates the risk any instability occurring. However, if the cargo is misdeclared or incorrectly declared and the vessel sails, and the Master and crew are educated about the potential signs of cargo dynamic separation and its influence on the vessels behaviour, the Master and crew can now develop mitigation strategies. At the first sign of unusual vessel rolling motions, the crew now know that something is wrong with the cargo's stability.

- They can act to firstly reduce vessel motions and input forces to the cargo to prevent further cargo separation.
- The crew can get ready to abandon ship early as they know what is happening.
- They can seek refuge if possible or let others know they have issues and may need assistance.
- They could potentially start with measures to increase the vessels GM and regain stability and prevent a list from developing.

The main point is there are now a set of actions that could possibly be taken.

This new understanding of cargo instability due to moisture and how it affects the vessels stability needs to be circulated to the maritime community.

RT and ClassNK believe that this information is paramount to ensuring the safety of all mariners regardless of the cargoes declaration (Group A, B or C). If a cargo is misdeclared or incorrectly declared, and the Master and crew notice any unusual behaviour in the vessels response, urgent actions to prevent loss of life must be implemented.

The vessel and cargo may not be saved, but these can be replaced, however the irreplaceable lives of the Master and crew no longer should be lost. In the event of any future incidents, it is hoped that the Master and crew will find safety as they were aware of this information.

References

More detailed information is/will be available at the following websites:

AMSA video: https://youtu.be/zdyrQSypPBQ

ClassNK Research Institute: http://www.classnk-rd.com/

ClassNK website: http://www.classnk.or.jp/hp/en/research/rd/index.html

For further technical information please contact Dr T Evans - tim.evans@riotinto.com