

Yacht keel design and construction: what can we learn from the capsizing of *Finistere*?

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RINA WA 28th June 2022

Presentation

- How often do keels break?
- The failure conditions
- Summary of *Finistere* incident
- DoT technical findings

Guided discussion

- Are the technical findings accurate?
- What can be done to stop this happening again?
 - Naval architects
 - Builders
 - Owners

How often do keels break?

1984 - 2013

Cause of failure	Number
Undefined	40
Welded fin failures	11
Grounding or collision	8
Hull/internal structure	8
Keel bolts	3
Keel cant system	2
Total	72

24 fatalities

Source: ISAF, in MAIB 08/2015

i.e. 3 per year

Prodigy 2 2017

- Keelbolt washers designed too small
- Low laminate quality



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MarineTraffic.com

Photograph 1. "Prodigy 2" yacht

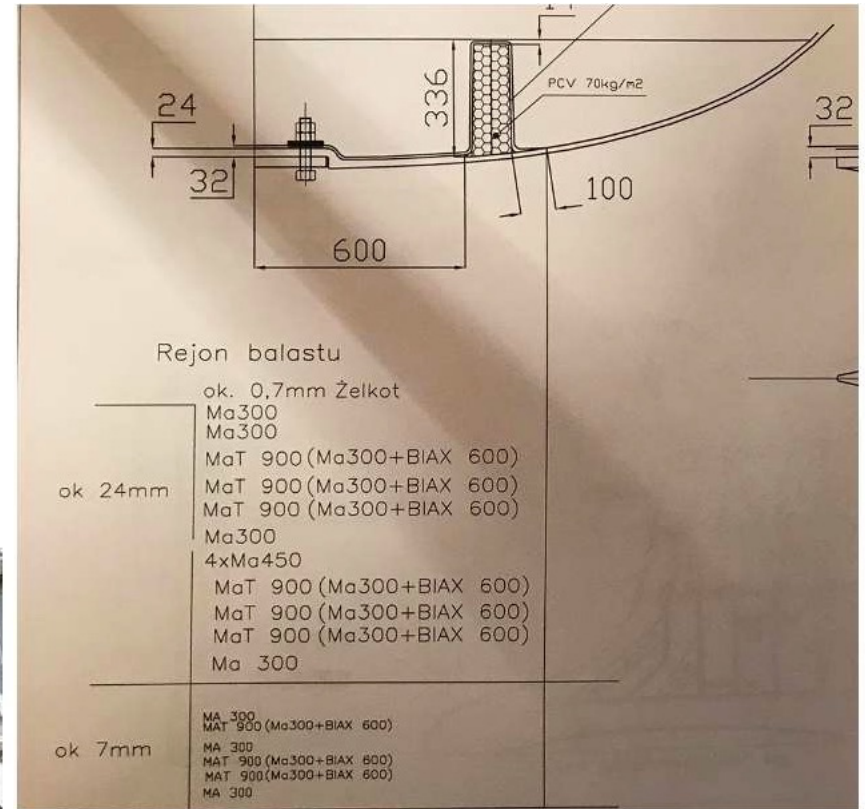
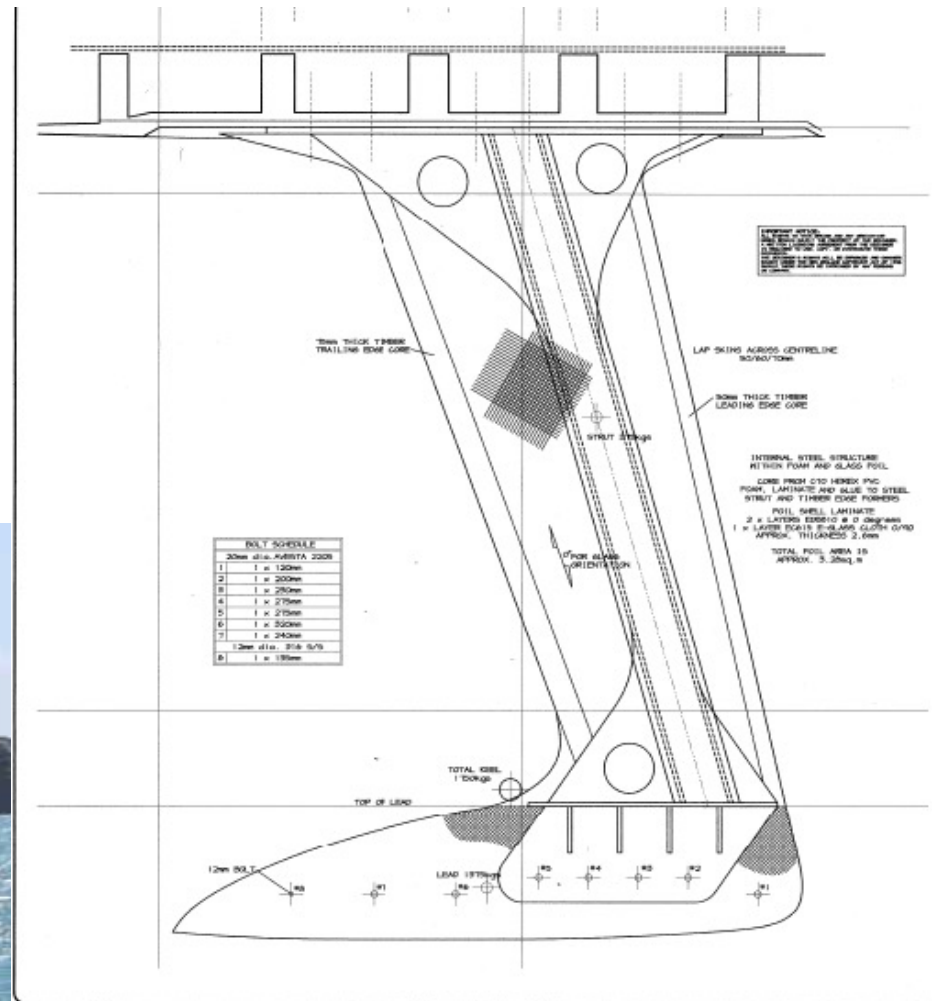


Fig 1 Fragment of drawing 09/16 Kalif 58 by CORS

Time to Burn 2008

- Inappropriate design
- Inappropriate welding



Cheeki Rafiki 2014

Beneteau First 40.7



Cheeki Rafiki



“It is possible that some of *Cheeki Rafiki*'s reported 'light' groundings could have significantly affected the integrity of the matrix attachment in way of the keel.
It is also possible that the keel bolts had deteriorated.”

Hooligan V 2007

Max Fun 35



Hooligan V 2007

- Independent analysis of the “original” design calculations confirmed that they did not achieve the required Safety Factor.
- Further analysis of the keel design, as built, showed this failed to achieve the required safety factor by an even larger margin and
- that the subsequent addition of extra bulb weight in 2005 had exacerbated the situation.

Finistere



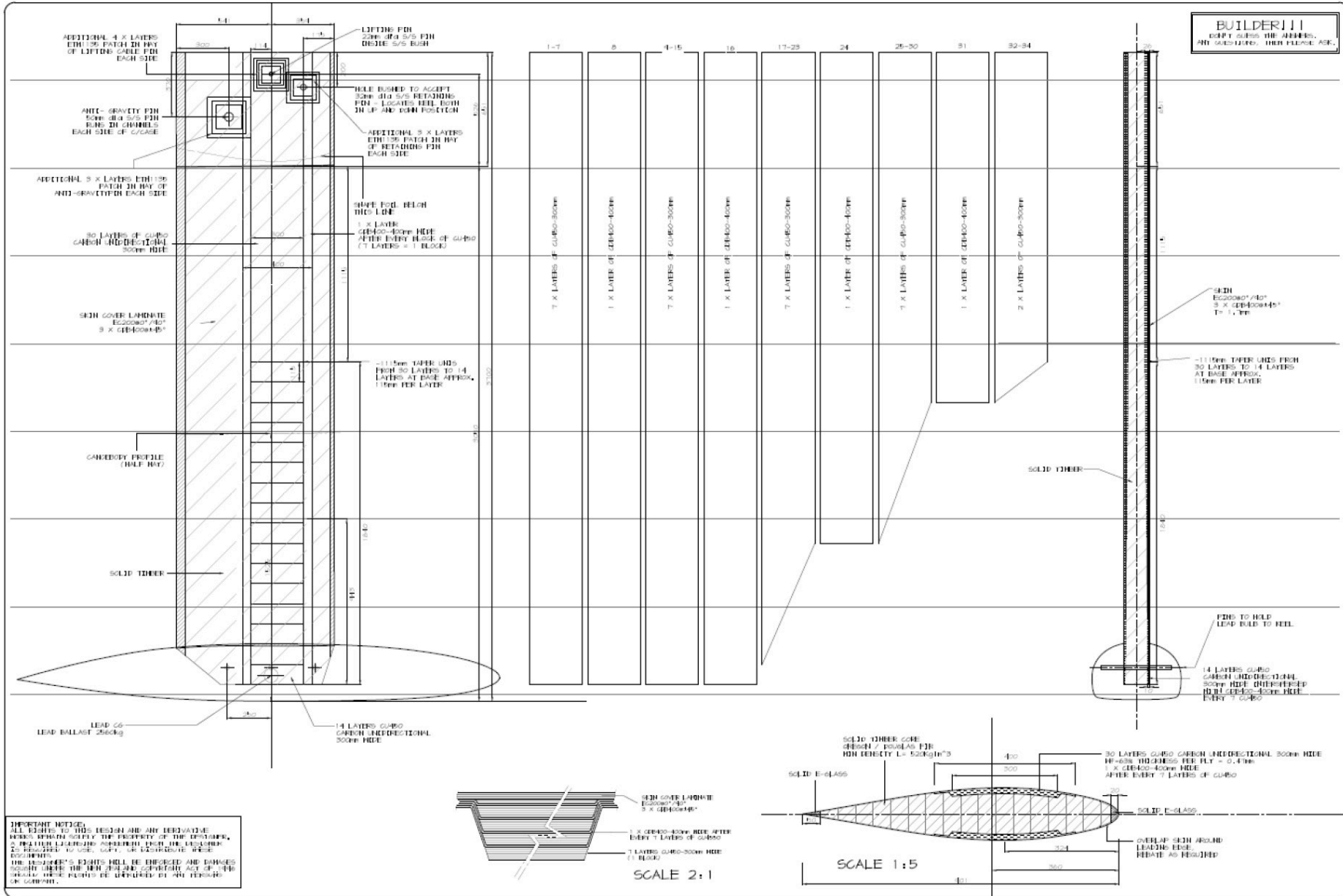
WA Newspapers

Finistere timeline

- Davidson 50 built 1990 with fixed keel.
- Changed to lifting keel before 2002; composite oregon core, sheathed in carbon fibre.
- Keel delaminated in 2009, replacement keel installed “rebuilt as per the original drawings and specifications”.
- Locating pins that were at the height of the waterline, were modified and raised in 2012.
- Passed AS Cat 3 audit requirements Sept 2017.
- Vessel had grounded several times, including during the race prior to the capsized race.
- Capsized Feb 2018.

Finistere keel drawing "June 2011"

(June 2011? Compare with dates in previous slide!)

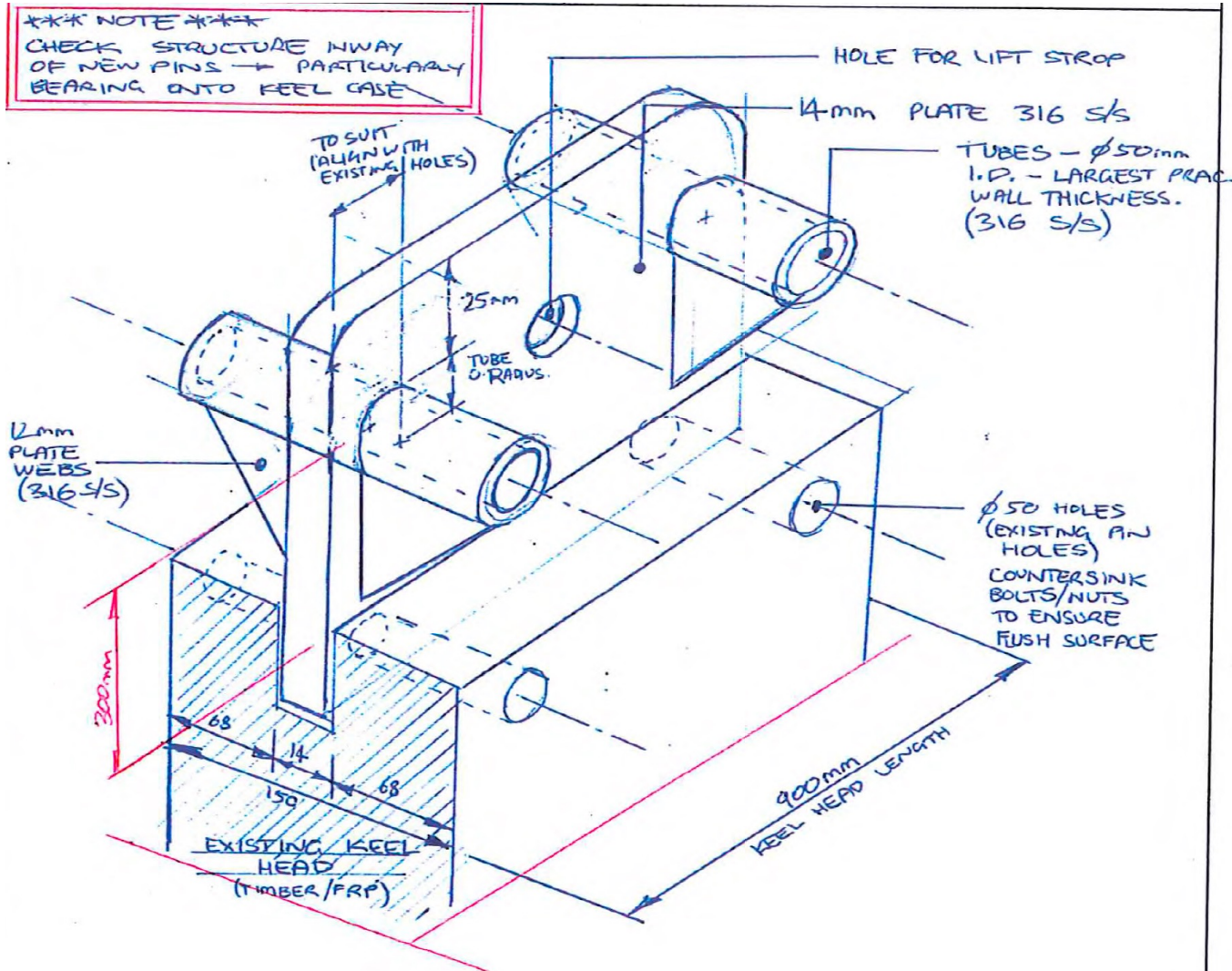


RETROFIT BALLAST KEEL FOR MR. ROBERT THOMAS PERTH WA.

AMENDMENTS	
DATE	REV. DESCRIPTION

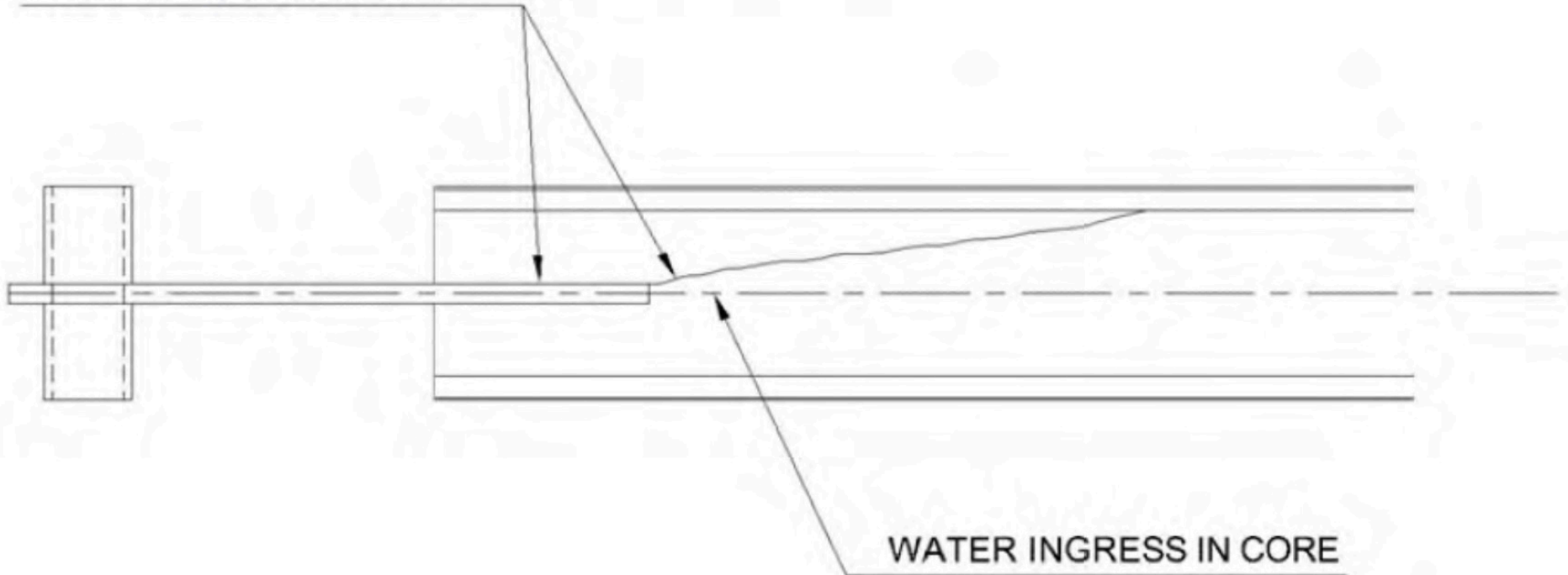
KEEL FIN STRUCTURE			FIG#
			0900
DESIGN. BY	DATE: Jun-11	SCALE: 1:100(A)	
CHKD:	ISSUED:		REF: 0912

Locating pin mods 2012





POINT OF SHEAR FAILURE



WATER INGRESS IN CORE

Post-incident inspection

- Areas of friction between keel and keel case.
- Resulting wear over time had exposed wooden core, hidden from view.
- Extensive water damage of wooden core at modified locating pin locations, original pin locations and area “below the steel plate”
- Pin did not pass through both sides of keel; slumped down on port side.
- Failure of bond between locating pin steel structure and wood core
- Port skin separated from core and slumped.
- *“ Evidence suggests that the factors identified as causing the failure of the keel are associated with the modifications undertaken to raise the locking pins”.*
- *“ the design parameter for the mods were appropriate and did not cause the failure”*
- The keel mod drawings had no details on the bonding and sealing between the steel plate and the original keel.

Report conclusion

“A combination of mistakes during the modification process, age wear, damage from minor groundings <either separately or in combination> are the likely causes of the slow deterioration of the upper portion of the keel”

Report recommendations (paraphrased)

- Modifications and repairs should be undertaken in accordance with best industry practice.
- Vessel owners should consider thorough inspection of keel (incl. inside keel case) if vessel grounded, and annually.
- When competing in an event the organisers must be informed of mods, repairs etc. so that they can determine if required safety standards are met.
- (plus three vessel operational safety recommendations)

Safety changes made 1 January 2022

AS Offshore Special reg 3.02.4, for Cat 0 to Cat 3 inclusive.

- Consult the owner's manual for any instructions for keel bolt checking and re-tightening.
- The following inspection to be conducted by a qualified person externally with the boat out of the water. Check that there are no visible stress cracks particularly around the keel, hull/keel attachment, hull appendages and other stress points, inside the hull, backing plates, bolting arrangements and keel floors.
- *Lifting and swing keels: In addition to above, check there are no significant stress cracks in structure around pins supporting the keel. Check for extensive corrosion on pins, cylinders and supporting metal structure.*

But.....

Safety changes made 15 Feb 2022:

Decision has been made by WS Special Regs sub-committee to exempt Cat 3 from annual inspection by a qualified person.

Effective 1 January 2023, at a haul-out within two years prior to the event, *the owner or his/her representative shall inspect* the integrity of the keel and rudder following the recommendations in Appendix L < the previous slide>.

Finistere capsized during a Cat 3 race.

Besides, all these regs only apply to racing yachts, not cruising yachts i.e. *fewer than 10% of yachts with keels have to comply!*

Discussion

- Are the technical findings accurate?
- What can be done to stop this happening again?
 - Naval architects
 - Builders
 - Owners

Some possible solutions

- Design problem- better plan approval?
- Build problem – in-build inspection?
- Modifications – plan approval, inspection?
- Maintenance – annual inspections?
- Age – limited design life for a keel? (fatigue)
- Educate owners – share information about incidents?

Why do DoT/AMSA publish incident reports for commercial vessels but not for recreational vessels? It happens in USA and UK, so why not here?

DoT Marine Safety

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The purpose of the Marine Safety Business Unit (MSBU) is to provide and enable safe, accessible and sustainable use of navigable waters for the economic and social prosperity of Western Australia.

MSBU ***responsibilities*** are:

To provide and enable the safe, accessible and sustainable use of navigable waters through the provision of an integrated policy and waterways safety management approach to ***promote the safe and sustainable use of navigable waters, including those activities related to education,*** navigational safety, compliance and investigation.