Modified Dynamic Stability Criteria for Offshore Vessels

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ABSTRACT

Stability has always been the biggest concern of vessels owners, operators and naval architects. Stability defines the safety and operability of a vessel, and for any activities to take place, these two points have to be fulfilled. The stability of offshore vessels has become an issue with the trend of increasing roles and unpredictable operations that one offshore vessel has throughout its lifespan.

This paper attempts to provide a ship designer's perspective on the stability issues based on our own experience and suggests a modified dynamic stability criteria more suitable for these offshore vessel operations.

KEYWORDS: *Stability of offshore vessels; Offshore operating environment; Crane operations; Towing; Anchor handling.*

1. INTRODUCTION

There is a well-known Chinese saying "Water can support the ship and it can also capsize it". Every vessel is capable of capsizing; the only question is under which conditions. The International Maritime Organization's (IMO) Maritime Safety Committee agreed in principle that *"ships are to be designed and constructed for a specific design life to be safe and environmentally friendly, when properly operated and maintained under specified operating and environmental conditions, in intact and specified damaged conditions throughout their life*" (IMO, 2009).

The IMO Criteria for stability has been developed for commercial vessels and has proven to be reasonably safe. How relevant is this criteria for other types of vessels such as offshore support vessels or workboats?

The number of Offshore Support Vessels (OSV) has increased over the years (see Fig 1). To date, approximately 30 per cent of world's oil and gas production comes from offshore. As the search for oil moves to deeper waters the challenges increase and the operating sea conditions get harsher. As a result, offshore vessels have evolved to keep pace with the ever changing demands. Today offshore vessels support a variety of duties e.g. for search and rescue, diving support, well intervention, maintenance support, hotel service etc.; either as specialist vessels or as multi-purpose vessels. Further, offshore vessels are no more limited for oil and gas industry; we see increasing use in industries such as offshore wind farms and deep sea mining.

1.1 Offshore Support Vessels Operations

There are many differences between OSVs and commercial vessels, in terms of their operating profiles, operating environment vulnerability and the risks faced. The roles of

OSVs are more diverse as compared to commercial vessels, e.g. transportation of goods and personnel, towing; diving support, search and rescue, well intervention, oceanographic surveys and deep sea mining etc (see Table 1). Unlike commercial vessels which are primarily used to carry cargo or passengers from one port to another, OSVs are built as workboats and they carry out different operations, as and when required to support the offshore industry. The duties these vessels may be asked to perform are unpredictable.

	Offshore Vessels / Workboats	**Commercial Vessels**
Types of Vessels	-Tugs -AHTS (Anchor Handling Towing Vessels) -PSV (Platform Supply Vessels) -DSV (Diving Support Vessels) -Survey -Well intervention -Fire fighting vessel -Deep sea mining	-Bulk carriers -Container ships -Tankers -Ocean liners -Cargo ships -Passenger Ships
Size	Length < 100m	Length > 100m
Characteristics	-Power horses -Very manoeuvrable -GM approx. 1m -Lower freeboards -Higher vulnerability to capsize -Unpredictable operations	-Optimised power for sailing -Do not require high manoeuvrability -GM > 2m -High freeboards -Predictable operations
Modes of Operation	-Sailing -Standby -Harbour -DP (Dynamic Positioning) -Anchor handling -Towing -Crane operations -Deck Cargo -Fire fighting	-To carry cargo, or passengers from point A to point B -Sailing -Harbour
Operating Environment	-Wind – 35 knots -Currents – 1.5 knots -Waves – 6m -Not only when sailing, but also when stationary as in DP. -As activity moved further and further offshore, harsher operating sea conditions.	-Commercial vessels can reduce speed or change course. -Operators will try to avoid seasons where the conditions of the sea are harsh; some operators may have a fixed operating months where they can predict the sea conditions

Table 1: Main difference of OSVs and Commercial Vessels

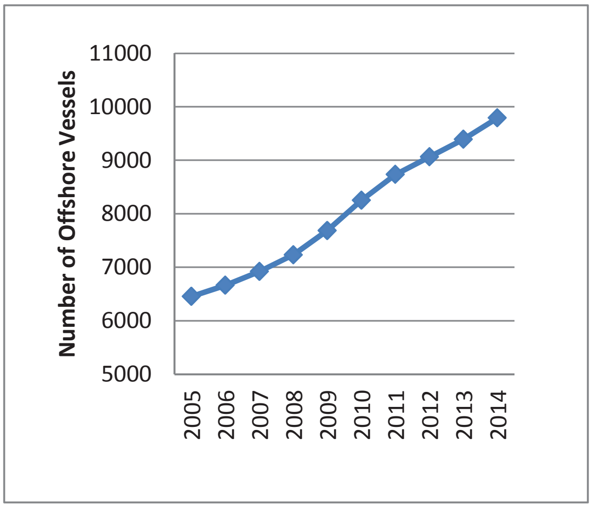


Fig 1: Number of offshore vessels by year (Clarkson Service Limited 2015)

1.2 Operating Environment

As operations move further offshore, the greater the environmental uncertainties, hence, the larger the number of safety factors that need to be applied to achieve a target level of structural adequacy and reliability. (Paik and Thayamballi 2007) The OSV is required to operate and work in this harsh environment. Anchor handling operations, Towing, Crane Operations etc. need to be carried out under these conditions. Most OSVs are required to remain in a particular position in Dynamic Positioning mode over a long period of time to support the offshore operations. For example a Diving Support Vessel (DSV) which supports diving operations need to have its position unchanged as the lives of the divers are dependent on the vessel. Therefore, unlike commercial vessels which can choose to make a detour to avoid extreme weathers, OSVs need to withstand harsh weather conditions while remaining stationary at a particular position.

1.3 Stability for Operations

As the OSV is a different form of vessel, and the operating conditions are different, the relevance of the IMO stability criteria to such operations is studied and a possible modified criterion is proposed which may more realistically take into consideration the operations as well as the operating conditions under which OSVs need to operate.

Designers know how to make ships safer but safety always comes at a cost. In practice, therefore, there is a compromise between safety and the economies of operations, and the vessel is designed to regulatory minima, because that gives the most economical solution with acceptable safety. Traditionally, regulations and stability information booklets provide limited safety guidance to the master of the ship but they do give the operator the full confidence to go to sea in the false belief that the ship is safe. It may not be safe though, particularly if it is a small vessel in big seas, and would depend on how the vessel is operated in these conditions. For OSVs which may have unpredictable operating conditions, it becomes crucial to develop a limiting envelope together with practical methods of assessing the level of safety of a ship in the range of sea states in which a ship might remain safe from capsize. Regulators have the greatest responsibility but sometimes they may be intimidated by industrial, commercial and political pressures. We should use what we learn to improve safety for all, by developing simple formulae which may offer operators means of safety assessment.

2. EVOLUTION OF IMO STABILITY REQUIREMENTS

The first IMCO (IMO) Resolutions concerning stability criteria were adopted in 1968 by Assembly resolutions A167(ES.IV) for passenger and cargo ships under 100 meters in length and in A.168(ES.IV) for fishing vessels, the Resolutions are based on the analysis of statistical data on casualties and on ships considered safe from the point of view of stability. (Kobylinski and Kastner 2003)

Recognising that the stability criteria may not be “rational” since resolution A.167 was applicable only to small ships (length of not more than 100 meters), the committee decided to develop a “weather criteria” requirement for the situation where the ship is exposed to beam wind when rolling on the wave hence aiming to improve safety against capsize. Weather criterion was then introduced and adopted by resolutions A.562(14) for passenger and cargo vessels and A.685(17) for fishing vessels and its application was not limited to ships under 100 meters in length.

In dead ship condition with severe wind and corresponding roll, the ship must comply with the “weather criterion”. The main scope of this criterion is to determine the ability of a ship to withstand severe wind and rolling from a beam sea by comparing heeling and righting moments.

However the criterion is for dead ship and still not related to the wind force that the ship may encounter, in service, while operating.

Intact Stability (IS) Code, a harmonisation of the existing stability requirements and weather criterion, was initially adopted in 1993 by resolution A.749(18). Current version of the IS Code 2008 was adopted about 15 years later by resolution MSC.267(85). IS Code preserved basic stability criteria, statistical as well as weather criterion virtually unchanged. The basic statistical criteria and weather criteria were now made compulsory by way of reference in the SOLAS Convention to part A of the IS Code 2008.

Recognising the fact that the design and normal operation of offshore supply vessels are different compared to conventional cargo ships, IMO came up with “Guidelines for the Design and Construction of Offshore Supply Vessels”, A.469(XII) adopted on November 1981 and superseded by Res.MSC.235(82). For offshore vessels, the same criteria used for merchant vessels have been passed on. Classification society have prescribed criteria for certain operating modes of OSV such as: towing; fire fighting; anchor handling; and crane operations.

In February 2015, the sub-committee for Ship Design and Construction (SDC) agreed on draft amendments pertaining to vessels that engage in anchor handling operations (SDC-2 2015). These changes to part B of the International Code on Intact Stability, 2008 (2008 IS Code) are slated for submission to MSC 95 for approval. Vulnerability criteria and standards (level 1 and 2) related to ‘parametric roll, pure loss or stability and surf-riding / broaching; and to ice accretion in timber deck cargo’ were some of the other amendments the sub-committee has agreed in principle to draft.

A correspondence group has been set up to assist with these amendments concerning towing and lifting operations. They are expected to report their findings to the next session of SDC.

3. LIMITATIONS OF PRESENT STABILITY CRITERIA

Regardless of the particular situation being evaluated, however, the conventional approach to stability evaluation still remains valid. The goal is to ensure that there is sufficient righting energy along with adequate freeboard to the downflooding points.

The criteria included currently in the IS Code is a design criteria, addressed mainly to ship designers. However, it is well known that about 80% of all casualties at sea are due to operational factors and the human factor. Resolution A.167(ES.IV) in the preamble acknowledges this, stressing the importance of good seamanship. It is to be noted that many stability casualties still happen every year, and most of these with small ships. Such accidents may not create strong reaction or public opinion as the casualties with large ships do.

Casualties for Merchant Vessels have been reducing significantly over the last 5 years. However, the casualties for OSVs do not show a similar decrease (see Fig 2).

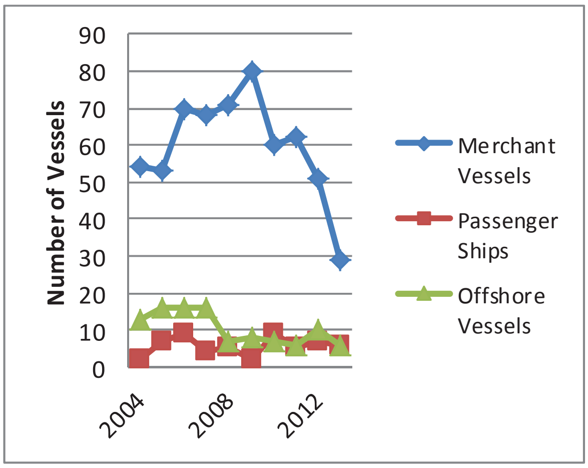


Fig 2: Losses & Casualties of Merchant Vessels, Passenger Ships & Offshore Vessels (Clarkson Services Limited 2015)

At its core, the afloat stability of the vessel is a function of:

- Adequate buoyancy and stability of the hull form;
- Preventing water from ingress into the buoyant body
- Limiting the movement of any water which does manage to enter the buoyant body

Based on the geometry and hull form, the vessels stability characteristics get fixed at the design stage, such as KM, KN etc. Each hull form being unique, the stability characteristics will be different, however for a given set of fixed dimensions, there is little room for designers to drastically improve these stability characteristics.

3.1 Watertight Integrity

The other major aspect of capsizing is the watertight integrity.

3.1.1 External Watertight Integrity

As noted earlier, one of the most important parts of ensuring adequate stability involves providing external watertight and weathertight integrity so that the hull boundary remains effective in providing buoyant force and righting energy. This is most often expressed as the location of the downflooding points into the hull. (Rousseau and Breuer, 2007)

3.1.2 Downflooding Point

“Downflooding point” is the point at which water could enter the hull envelope which was providing buoyancy and stability. From an external integrity standpoint, it is important to note that intact stability is an expression of an intermittent phenomenon, so that the vessel is presumed to incline under the effect of the environment and then return upright when that effect is removed. This has implications for the types of closures that can be considered to eliminate downflooding.

There are generally two types of downflooding points assumed in the calculation of stability: unprotected openings and weathertight openings. Openings which may be closed watertight may be ignored as downflooding points, but the types of these are limited.

3.1.3 Unprotected Openings

The most common unprotected opening is the ventilator, since provision of air to combustion machinery is necessary for operations. The possibility exists that in certain conditions, however, some of the unprotected openings may be closed such as during the preparation for severe storm or for the duration of the tow and when the hull is unmanned and not in an operational condition

Unprotected openings are important in both intact and damage stability, since water can enter the hull even during intermittent immersion of the opening.

3.1.4 Weathertight Openings

Providing weathertight closures on openings into the buoyant envelope removes them from consideration in intact stability because they are assumed to be effective in preventing the ingress of water during intermittent immersion.

There are two facts to remember regarding such closures, however: they must be manually or automatically engaged to be effective, and they will not prevent water ingress if they remain submerged, under water pressure.

In order that engagement is assured, a closure must either be automatically closing (like a ball or float check closure on a tank vent pipe) or must be specifically closed as part of a procedure such activating a screw-down ventilator closure during storm preparation.

Since they serve such a vital role in maintaining the external boundaries, it is important that closures are periodically inspected and are maintained in proper working condition.

When it is possible for an opening to be submerged for long periods, as in the case of openings below the final damage waterline, it is necessary to provide positive closure and maximum degree of confidence of the effectiveness of the closing means in preventing entry of water when subject to the same pressure head of water as the surrounding structure. In general, this involves bolted manholes or positive closing valves which are as effective as the surrounding boundary. These openings are therefore excluded from the list of downflooding points in al analyses of stability.

Penetrations in the shell for wire rope have been accepted based on a dual "pinch valve" assembly, which fails in the closed position and can be tested with applied pressure. In addition to such testing during construction of the unit, proper inspection and maintenance is also critical to ensure that the valve materials are not worn and rendered ineffective.

Ventilation closures are specifically excluded from consideration as watertight, due to the typically large size of ventilation openings and the concern over the provision of a truly watertight seal to the appropriate pressure head.

No less important than the ability to keep water outside of the buoyant envelope is the ability to limit the extent to which it can progress in the event that damage has occurred. The subdivision of a floating vessel is the means by which the final inclination or parallel sinkage is limited, which in turn helps keep the downflooding openings above the waterline, after damage.

3.1.5 Automatic Closing Openings

All tank vents and overflows are required to have automatic closures, not just the ones which might be subject to intermittent immersion.

3.2 Dynamic Positioning (DP) Mode

The present stability criteria have not dealt with such conditions of operations which take place with simultaneous wind, waves and currents. The "weather criteria" considers a dead ship or a stationary ship. However, all offshore vessels operations are carried out often under harsh sea conditions. In the DP mode, the reaction or forces from the thrusters to counter the environmental forces/moments resulting in heeling moments needed to be added in the "weather criteria", along with crane operations. In actual operations, "worst" downflooding point may need to be considered.

4. LIMITING ENVELOPE

For safe operations, a limiting envelope could be provided for the operator's guidance.

4.1 Limiting KG

The limiting KG is the maximum KG complying with prescribed and applicable set of criteria at a given draft.

4.2 Limiting Heel

This is another useful guidance for operators. The heel cycle needs to be less than the angle of which water may flood the vessel through opening left without weathertight closures.

4.3 Limiting Sea Conditions during Different Modes of Operations

Perhaps, this is the most critical guidance for the operator - limiting sea conditions i.e. the wind, wave, and current limitations.

5. CASE STUDIES

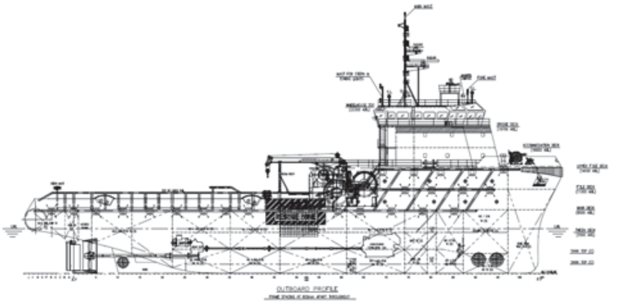
Stability investigations were carried out on existing designs of offshore vessels, in order to have a better perception of the limitations of the present stability criteria as applied to offshore vessels and then identify areas where the criteria may be modified to take better account of the actual operations.

The types of vessels investigated were as follows (see Tables 2-5):

1. Anchor Handling Tugs / Supply Vessels (AHTS) – 3 Nos.
2. Tugs – 3 Nos.
3. Platform Supply Vessels (PSV) – 3 Nos.
4. Diving Support Vessels (DSV) – 3 Nos.

Table 2: Dimensions of three unique AHTS

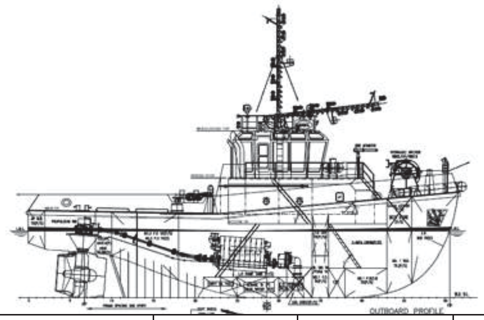
AHTS



	AHTS1	AHTS2	AHTS3
Length B.P.	44.4m	63.1m	62.5m
Beam (Mld)	12.6m	14.8m	17.0m
Depth (Mld)	5.5m	6.5m	8.5m
Design Draft	4.5m	4.8m	6m
Bollard Pull	50MT	80MT	130MT

Table 3: Dimensions of three unique Tugs

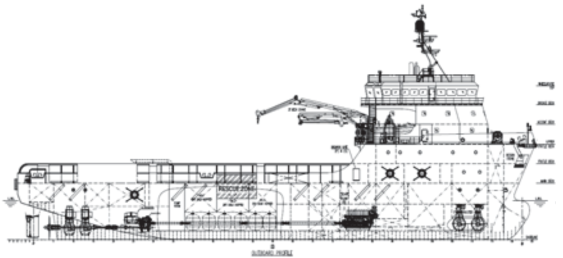
TUG



	Tug1	Tug2	Tug3
Length B.P.	25.5m	25.2m	27.0m
Beam (Mld)	10.5m	9.5m	12.0m
Depth (Mld)	4.5m	5.0m	5.3m
Design Draft	3.0m	4.0m	4.5m
Bollard Pull	35MT	40MT	50MT

Table 4: Dimensions of three unique PSV

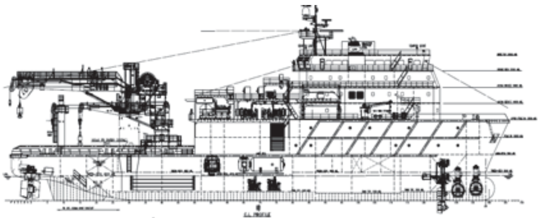
PSV



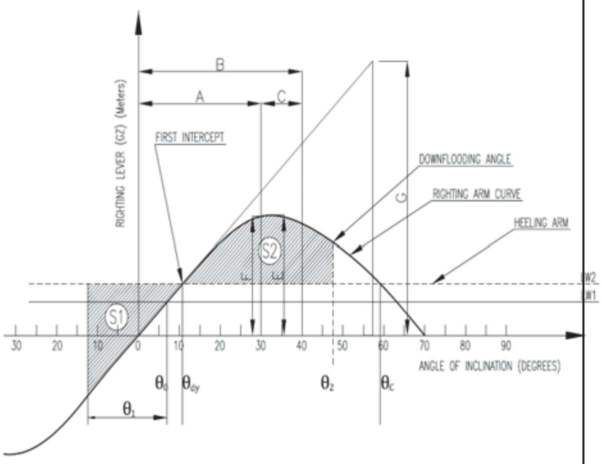
	PSV1	PSV2	PSV3
Length B.P.	73.6m	48.2m	57.4m
Beam (Mld)	17.0m	12.6m	18.0m
Depth (Mld)	8.0m	5.0m	5.0m
Design Draft	6.3m	3.5m	2.5m

Table 5: Dimensions of three unique DSV

DSV



	DSV1	DSV2	DSV3
Length B.P.	55.0m	55.2m	83.4m
Beam (Mld)	13.3m	13.8m	18.2m
Depth (Mld)	5.0m	5.0m	7.8m
Design Draft	4m	3.6m	4.2m



Intact Stability Criteria

- ‘A’ – Area under the GZ curve up to 30o ≥ 0.055 m-rad
- ‘B’ – Area under the GZ curve up to θ2 ≥ 0.090 m-rad
- ‘C’ – Area under the GZ curve between 30o and θ2 ≥ 0.030 m-rad
- ‘E’ – Max GZ to occur at an angle ≥ 25o
- ‘F’ – Max GZ ≥ 0.20 m (at angle of heel, θ ≥ 30o)
- ‘G’ – Initial GM ≥ 0.15 m

Weather Criteria

- (i) θ0 ≤ 0.80 x θde or 16° whichever is less.
- (ii) S2 ≥ S1

ABS Towing Criteria & Fire Fighting Criteria

- S2 > 0.09 m-rad

Fig 3: Intact Stability, Weather, Towing and Fire Fighting Criterion

5.1 Dominant Criteria

Limiting KG values were calculated under different draft conditions for all the criteria as defined in Figs 3-4.

1. Intact stability criteria (Fig 3)
2. Weather criteria (Fig 3)
3. Towing & Fire fighting criteria (Fig 3)
4. Crane criteria (Fig 4)

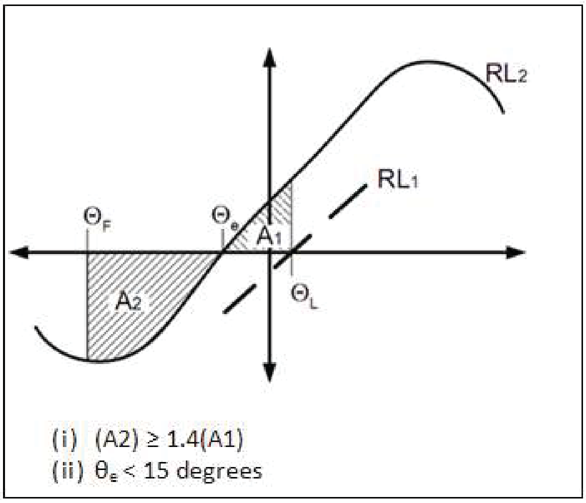


Fig 4: Stability with loss of Crane load

Investigations revealed a certain pattern in the criteria which was most dominating at different draft loading conditions (see Table 6).

Table 6: Dominant criteria under four different loading conditions

Dominant Criteria				
	AHTS	TUG	PSV	DSV
Light Draft	Weather	Towing	Weather	Weather
Light Draft - Mid Operating Draft	Towing	Towing	Weather	Crane
Mid operating draft - Normal opertaing draft	Towing	Towing	Max 92 ° angle	Crane
Normal operating - Max draft	Max 92 ° angle	Max 92 ° angle	Max 92 ° angle	Max 92 ° angle

5.2 Operational Stability

Offshore vessels provide support for the offshore industry and perform these operations under harsh sea conditions.

A series of operations to deploy and retrieve anchors for oil rigs or floating platform is called anchor handling. The AHTS should be equipped with high bollard pull, stern roller and high handling capacity winches on board.

Two accidents have already been reported in the history of this industry, and these operations are indeed considered hazardous.

The reduction of dynamic transverse stability of anchor handling vessels due to the additional overturning moment induced by the lifting anchor load is to be considered (Gunnu and Moon, 2012). Along with this the wind and wave forces can lead the vessel into capsize situation.

The present criteria provides for downflooding from unprotected openings which are normally the Engine Room Ventilator openings/louvers as it is assumed all other openings can be closed weathertight and will so be closed. However in offshore vessels and tugs, this is not the case. There may be other openings such as steering gear compartments ventilators or sometimes even doors to accommodation spaces may not be closed tight. We would rightly term this as bad seamanship or mishandling, but this makes the ship more vulnerable to capsizing. A case is made for considering such downflooding points which are not considered in the present criteria and these are termed as “worst” downflooding points.

Limiting KG curves were plotted (Fig 6 to 9) during operations for each type of vessel and for the following cases:

1. Without wind
2. With wind
3. With wind and “worst” downflooding (DF) point (see Fig 5)
4. With wind, “worst” downflooding (DF) point and aft trim 1% L

In cases of the DSV Crane Operations, the classification society Det Norske Veritas (DNV) requirement already considers the effect of wind during crane operations. However as the DSV operations are in DP mode, the additional heeling moment of the thrusters must be considered. This also has a significant impact on reducing the limiting KG (see Fig 9)

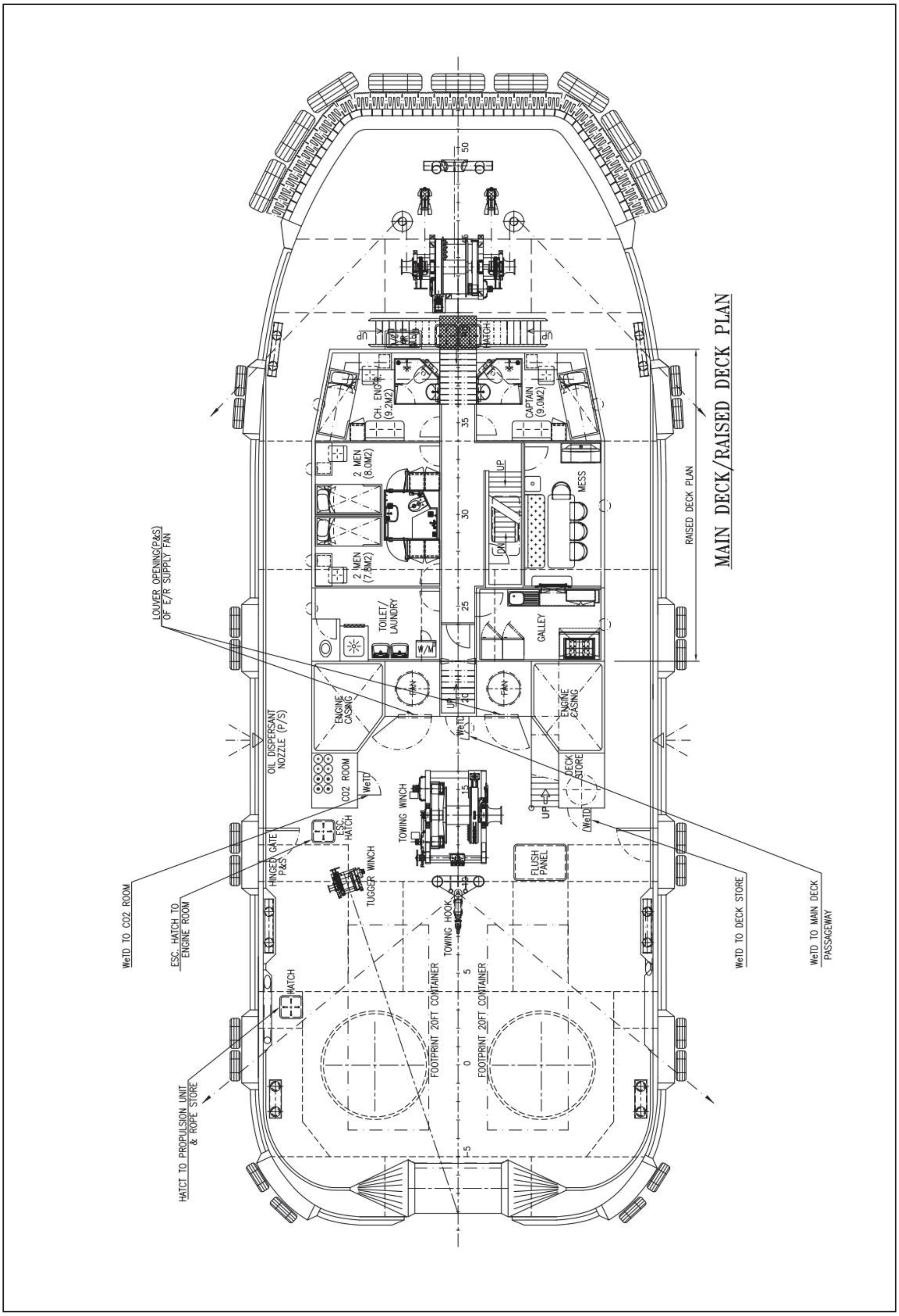


Fig 5: Downflooding Points

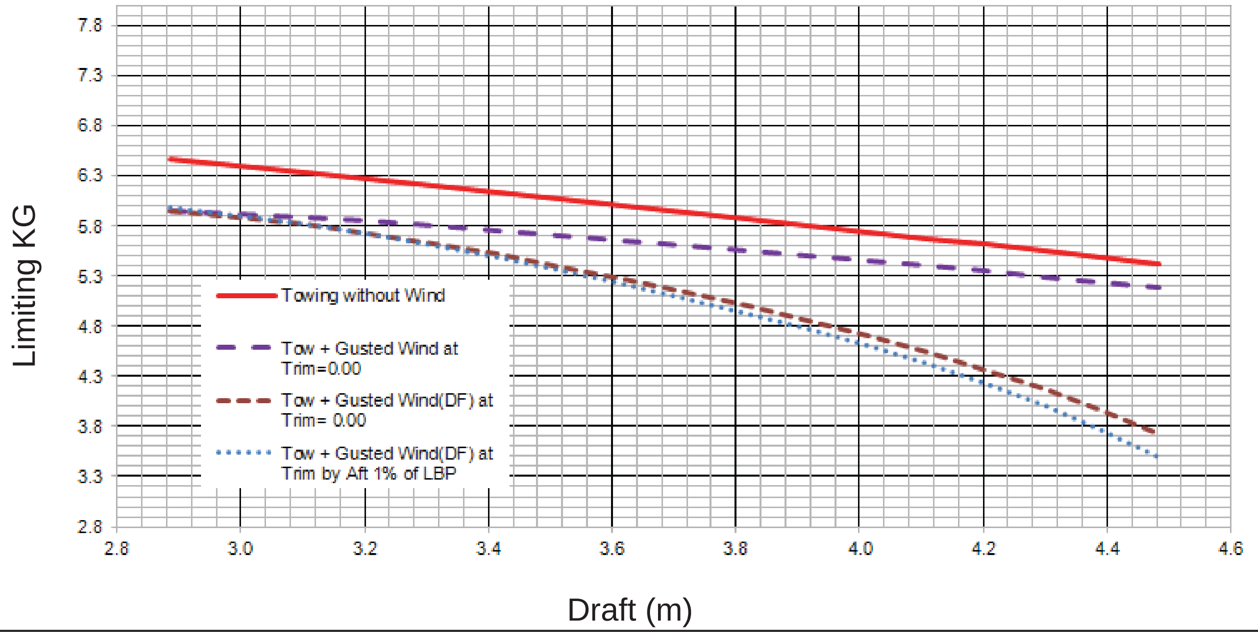


Fig 6: AHTS – Limiting KG

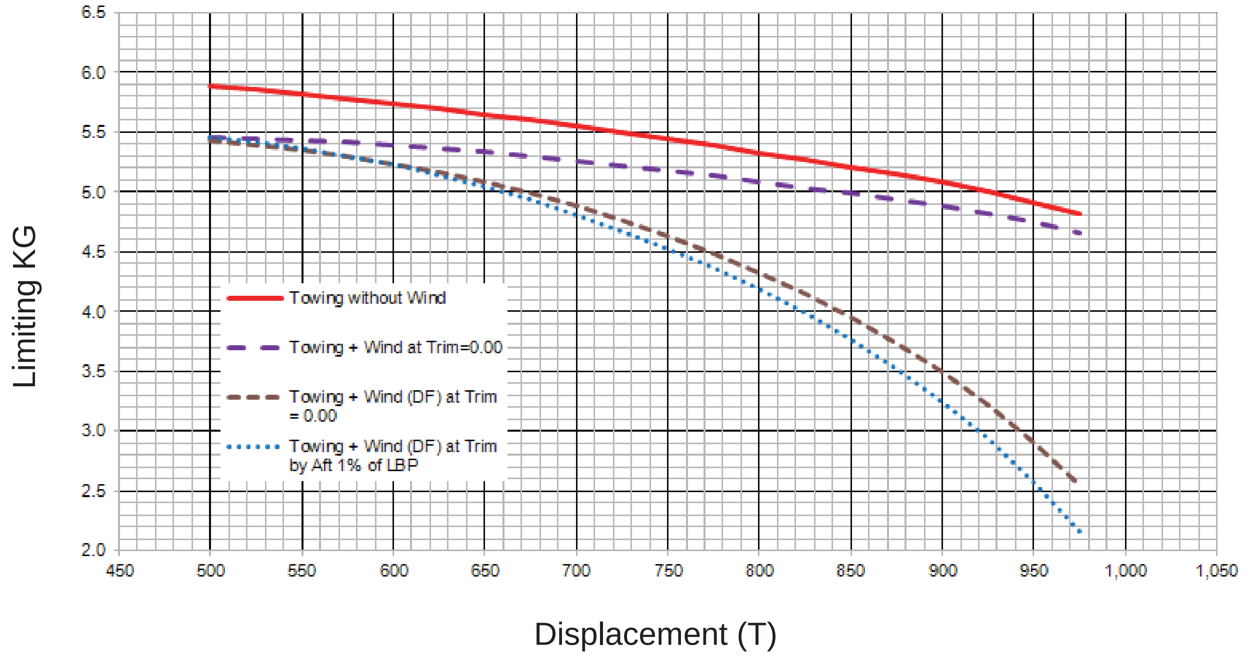


Fig 7: Tug – Limiting KG

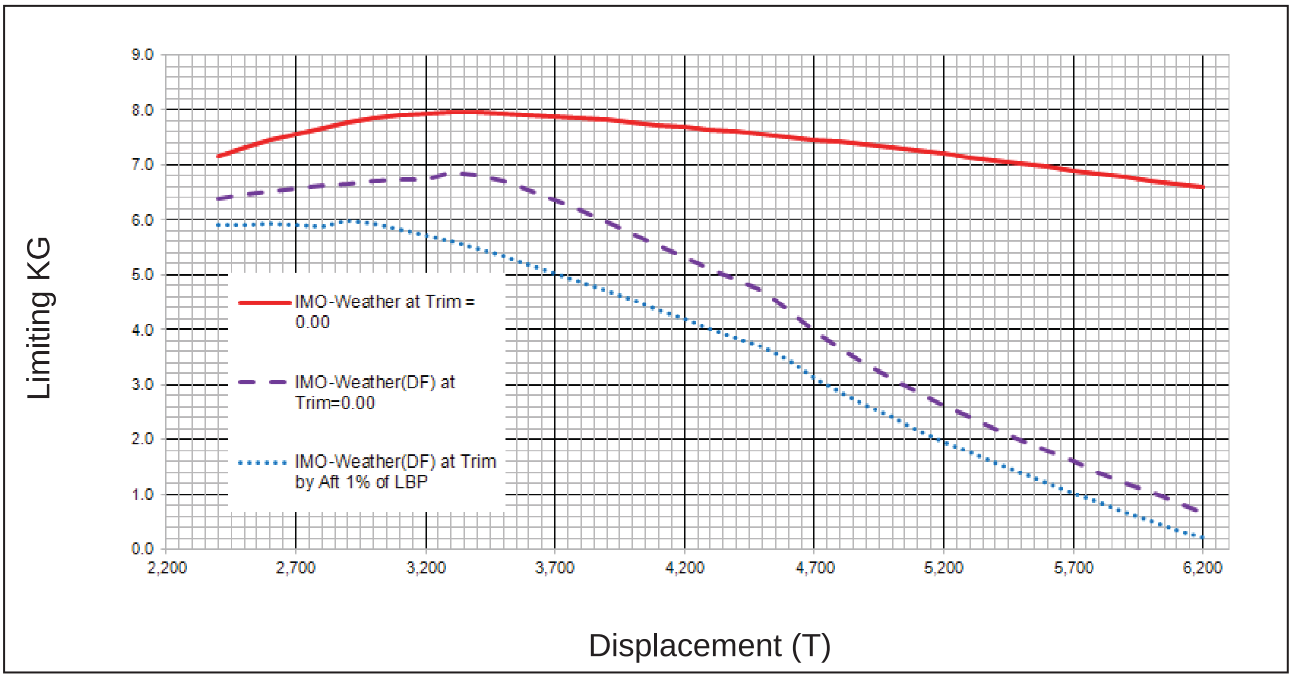


Fig 8: PSV – Limiting KG

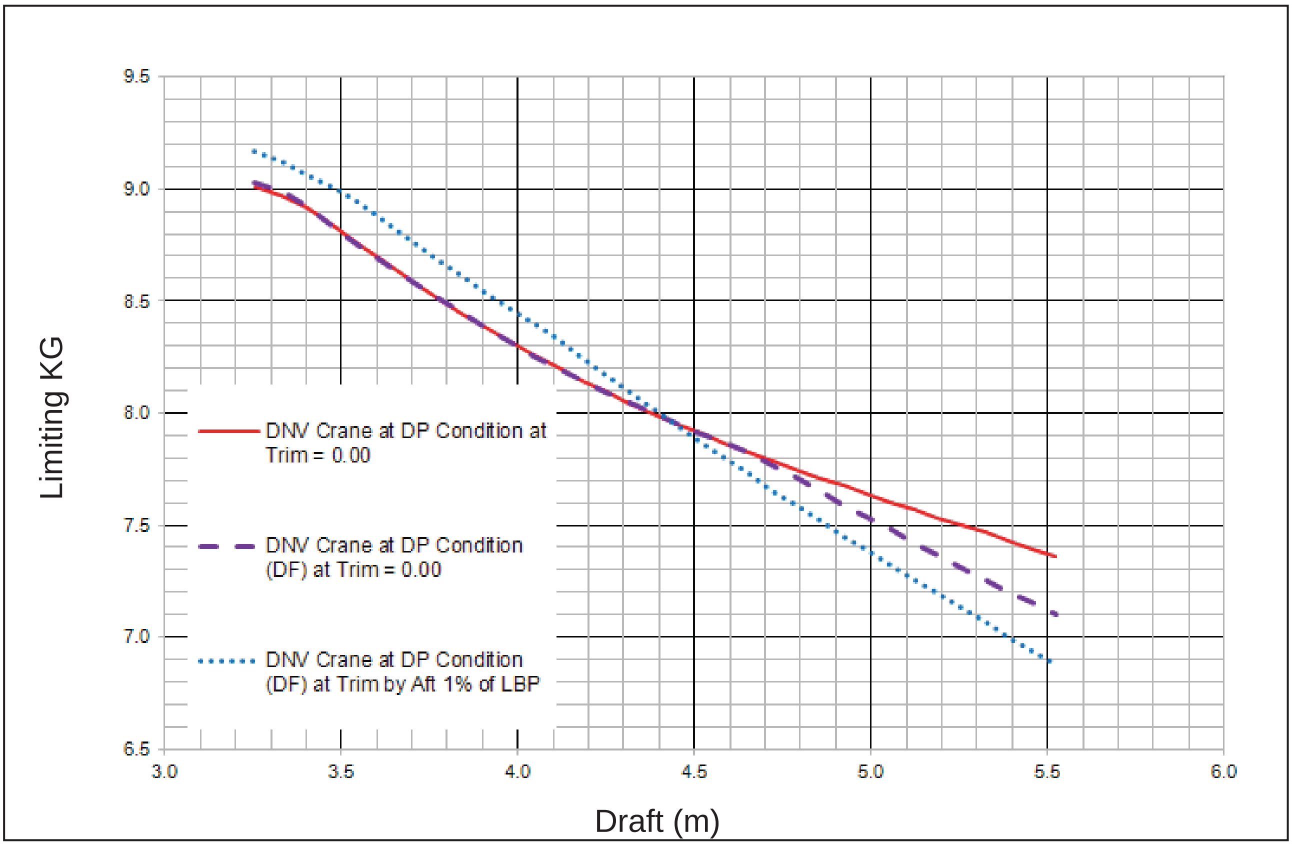


Fig 9: DSV – Limiting KG

There is a significant impact of downflooding point and aft trim on the reduction in the limiting KG. (Shown in Table 7)

Table 7: Percentage Reduction in Limiting KG

Type of Vessel	Lower Downflooding Point	With Aft Trim
AHTS	28%	4%
TUG	44%	7%
PSV	89%	7%
DSV	7%	3%

6. CONCLUSION

From the results of the case studies, there appears a strong case for modifying the existing criteria to include the following:

- Wind, wave and current forces superimposed on the existing criteria for towing, anchor handling, fire fighting operations etc.
- More fail safe means to ensure external watertight integrity
- Effect of worst downflooding point to be considered coupled with the effect of aft trim
- Effect of thruster forces to be considered as additional heeling moments during DP mode.

Presently, stability is a shared responsibility (see Table 8).

Table 8: Roles and Responsibilities (Rohr, 2003)

	Responsible	Accountable	Consulted	Informed
Design for Stability	Principal Naval Architect	Design Firm	Regulatory / Vessel Operations	Owner
Produce for Stability	Building Yard	Owner's Agent	Regulatory / Vessel Operations Master	Vessel Operations / Owner
Operate for Stability	Load Planner / Crew	Ship Master	Vessel Operations	Vessel Operations / Owner

A gradual shift of mindset is required from this shared responsibility for stability. Stability is the **sole** responsibility of the operator. It is the responsibility of the designer, regulatory bodies and other stakeholders to provide accurate and limiting envelope for operations and provide simple user friendly guidance to the operator.

Additionally, the operators deserve quality and intense training not only in "basic stability" but in "operations stability".

For operators guidance in decision making, easy to use stability advisory tools (software) should be made available with built-in limits from the limiting envelope.

Further detailed research would be required to analyse further existing designs with inputs from operators on their operational requirements and finally provide a basis to develop a modified stability criteria for offshore vessels.

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