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Next Generation Performance-Linked Tug Stability

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SYNOPSIS

There is a general consensus that the present IMO stability criteria are not adequate for tugs and other workboats. Having established the limitations of present IMO stability criteria, there is an urgent need to raise the bar and develop better guidance for the tug master and operators. This paper introduces a limiting operability envelope approach to tug stability, together with practical methods of assessing and monitoring stability during operations.

The following parameters have been identified that can be readily measured, and which also lend themselves to the judgmental perception of safety by the operators for each mode of operation: heel angle, ship speed, rudder or azimuth angle, and wind speed and direction. Limits for these parameters are obtained from the modified IMO criteria, and these can be monitored onboard. In this paper, a case study is used to illustrate the performance-based stability approach.

INTRODUCTION

For workboat designers, one of the crucial components of safety has always been the vessel's stability. Guaranteeing a sufficient level of safety, and complying with the standard regulations, has typically been considered to be a matter of design. However, it is not possible to ensure safety only by design, as it also depends on how the vessel is operated and on the prevailing operating conditions.

Furthermore, safety itself is a matter of personal perception. What may be safe to one person may be unsafe for another. This brings the human factor into the safety equation. For a more proactive response to safety, vessels must therefore be designed for their intended operations, comply with regulations, be operated safely and have a safety management system onboard for human operators, taking into consideration not only their skills and experience but also their attitudes and behaviours.

Standards for safety are set traditionally by regulations. It was only recently, in November 2016, that IMO MSC 97 included the consolidation and adoption of agreed amendments to IS Code 2008 to include stability criteria for towing operations. These will replace the criteria presently stipulated by classification societies, and the code is expected to enter into force on 1 January 2020.

The new IMO stability criteria are welcome. However, more needs to be done to reduce the gaps between actual operation and the theoretical or empirical basis of the new criteria. A *limiting operability envelope* approach to tug stability is required, wherein the designer provides adequate guidance to the operator to allow the operator to assess the situation in real-time and take the correct decisions.

THE NEW IMO TOWING STABILITY CRITERIA

The new IMO towing stability criteria are applicable to ships of 24m in length and above when engaged in harbour, coastal or ocean-going towing operations and escort operations. As part of these requirements, the vessel engaged in towing operations should also be provided with means for quick release of the towline for winches. It may be noted that the new criteria are non-mandatory, as they come under Part B of the IS Code 2008, and thus remain a recommendation and guideline.

A *ship engaged in harbour towing* is defined as a vessel engaged in an operation intended for assisting ships or other floating structures within sheltered waters, normally while entering or leaving port and during berthing or unberthing operations.

A *ship engaged in coastal or ocean-going towing* is defined as a vessel engaged in an operation intended for assisting ships or other floating structures outside sheltered waters in which the forces associated with towing are often a function of the ship's bollard pull.

The criteria for ships engaged in towing operations require the calculation of the self-tripping and tow-

tripping heeling levers as a function of heel, based on the propulsion and towing arrangement, by using semi-empirical formulas *(see Figure 1)*.

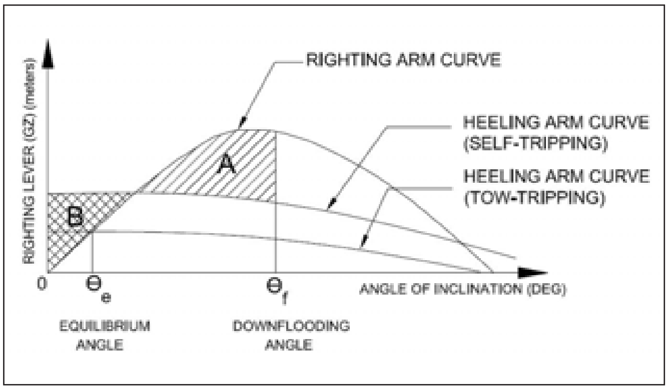

Figure 1: IMO towing criteria

Self-tripping is the tendency of a towing vessel to overturn itself under the influence of the heeling couple created by the opposing towline pull and propeller forces (in the figure above, A > B).

Tow tripping is tendency for the tow to veer off and create an unexpectedly large transverse component of force on the tug with a large upsetting moment resulting ($\theta_e < \theta_f$).

The new criteria are also based on the energy balance principle, where the angle of heel results from the equalisation of the work of the heeling and righting moments. The concept of energy balance is that the righting energy must be more than the capsizing or overturning energy. For ships engaged in harbour, coastal or ocean-going towing operations, the static heeling angle resulted by the towing moment should always be less than the angle of down-flooding.

A comparison of the maximum allowable vertical centre of gravity (KG) and corresponding equilibrium heel angle is shown in *Figure 2*. It is interesting to see that for the cases studied the new criteria are more conservative at lower displacements, but allow a higher KG at higher displacements.

SOME LIMITATIONS OF THE NEW IMO TOWING CRITERIA

The publication of new criteria is a welcome step in the right direction. Finally, there are uniform guidelines that apply to all tugs.

However, this approach is still based on a static energy balance model, and the towing operation is considered without superimposing the prevalent wind and environmental forces. The calculations are carried out for the maximum bollard pull acting at 90 degrees to the ship's centreline. This is a scenario which may only rarely occur. Most of the time, the tow rope pull would be much lower than the maximum bollard pull, and, in such cases, the operator should be allowed to operate with a higher KG, say, as it would still be safe. It is also more logical to have higher requirements for coastal and ocean towing, compared to harbour towing, which is undertaken under more sheltered conditions.

Though the new amendment does specify openings to spaces below main deck to be protected within enclosed superstructures, it still allows other openings, such as emergency escapes, vent openings, etc, on main deck. These become potential downflooding points.

There is also a lack of clarity on bow and stern towing operations. In fact, bow towing would only be expected for ship-handling operations. For such operations, the towline angles to the tug's centreline are restricted to, say, 45 degrees, and never go to 90 degrees as included in the new criteria.

The IS Code 2008, which has been developed for commercial ships, requires the full load departure

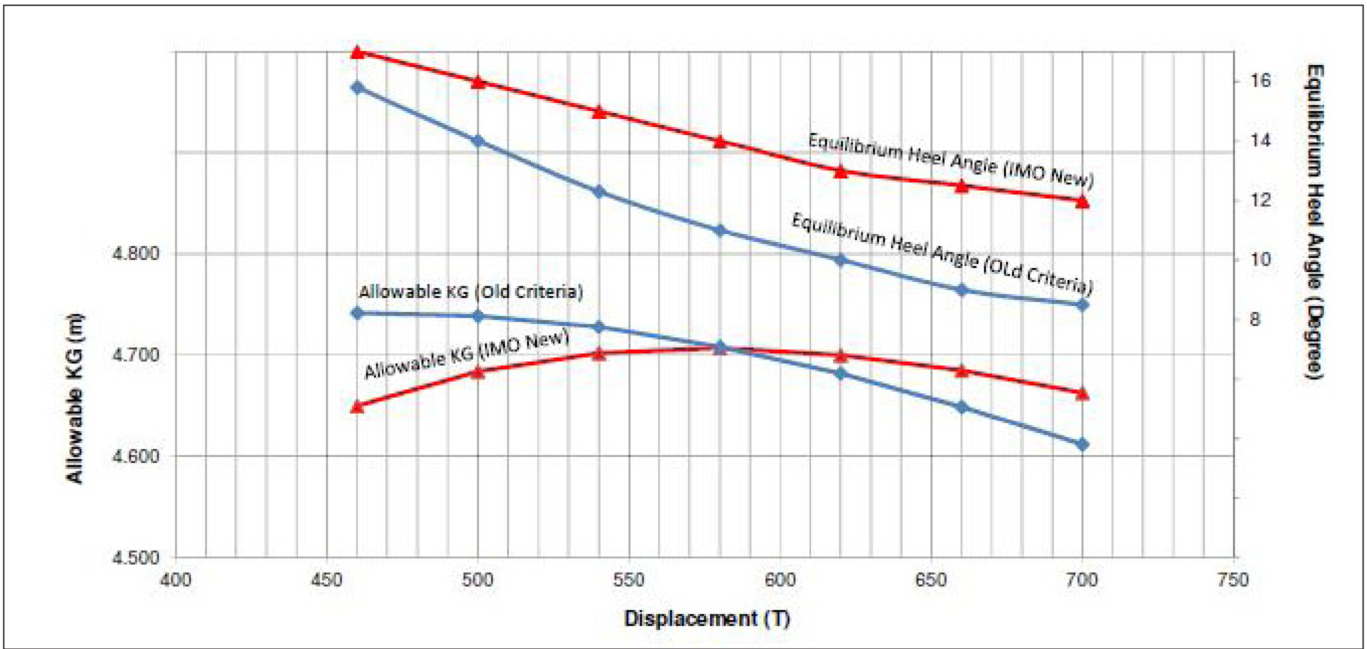

Figure 2: Comparison of new and old IMO criteria

condition with 100 per cent fuel and freshwater (consumables). However, harbour tug operations are different to those of commercial ships. Larger fuel oil and freshwater capacities may be required for transit, but for harbour operations such capacities are not required. In some cases, larger capacities are provided for trim control, and if the 100 per cent consumables condition were demanded by the flag administration, the loadline would be submerged. These loading conditions do not apply to tugs and workboats. As the tug is an operational workboat, it should have an operating manual onboard which details the safety procedures to be followed, instead of the theoretical prescriptive fully loaded departure and arrival conditions.

PERFORMANCE-LINKED STABILITY

Watertight integrity

One of the crucial means of ensuring adequate stability involves providing external watertight integrity, so that the hull boundary remains effective in providing buoyant force and righting energy.

The *downflooding angle (see Figure 3)* is the angle at which water could enter the hull when the vessel heels due to an external overturning moment.

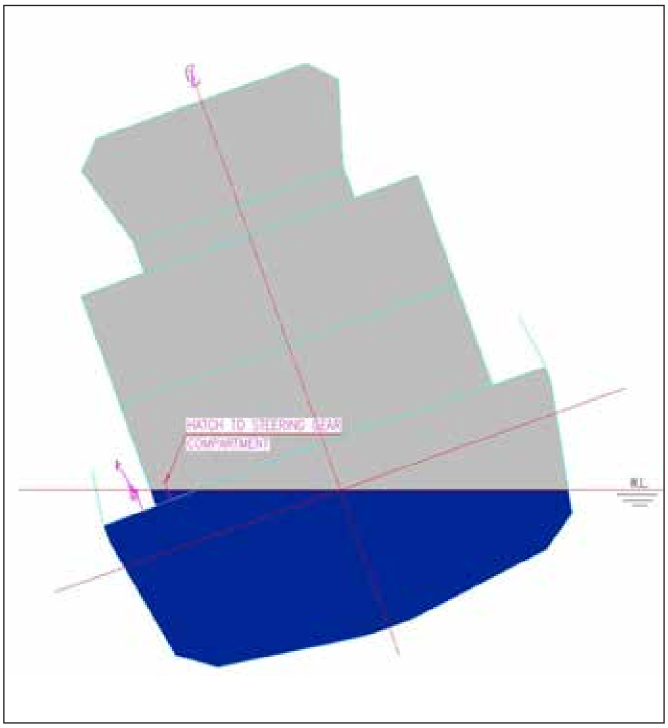

Figure 3: Downflooding angle

Apart from the stability criteria, the new amendments to the 2008 IS Code also include design precautions and operational procedures against capsizing. For example, the access to the machinery space (other than emergency and removal hatches) should, if possible, be arranged within the forecastle, while any access to the machinery space from the exposed cargo deck should be provided with two watertight closures, if practicable.

For tugs, real-time monitoring of the downflooding points, and the ability to close the openings, is crucial to make the vessel 'fail safe' – or even safe after failing (ie, heeled beyond the downflooding angle). It should be possible to force-close the downflooding points instantaneously.

In case of fire in the engine room, the regulations stipulate the closing of all air inlets to the engine room. In the same way, in the case of unusual extended moments, the downflooding points must be force-closed weathertight, thus preventing the flooding of the hull and leading to capsize.

External heeling moments

Different tug operations take place with simultaneous wind, wave and current effects superimposed. The environmental forces and moments, resulting in additional heeling moments, need to be added, along with towing or manoeuvring operations undertaken by the tug, in order to properly reflect dynamic operations *(see Figure 4)*.

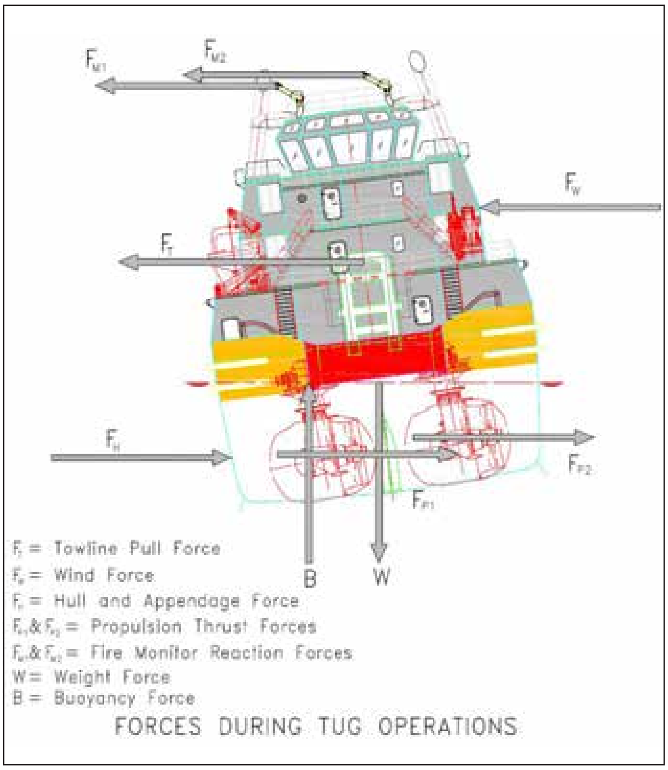

Figure 4: External forces and heeling moment during tug operations

In addition to towing operations, which are usually performed at slow speeds, on some occasions the tug may also undertake high-speed operations, such as turning and similar manoeuvres. If the azimuth thrusters are turned, say, 90 degrees, this will result in the full thrust athwartship, causing a very large heeling moment *(see Figure 5)*.

Escorting is another high speed operation, in both direct and indirect modes. There is adequate awareness of escort operations safety within the industry, and the classification societies and the new IMO stability criteria have laid down adequate stability guidelines and criteria for escort tugs.

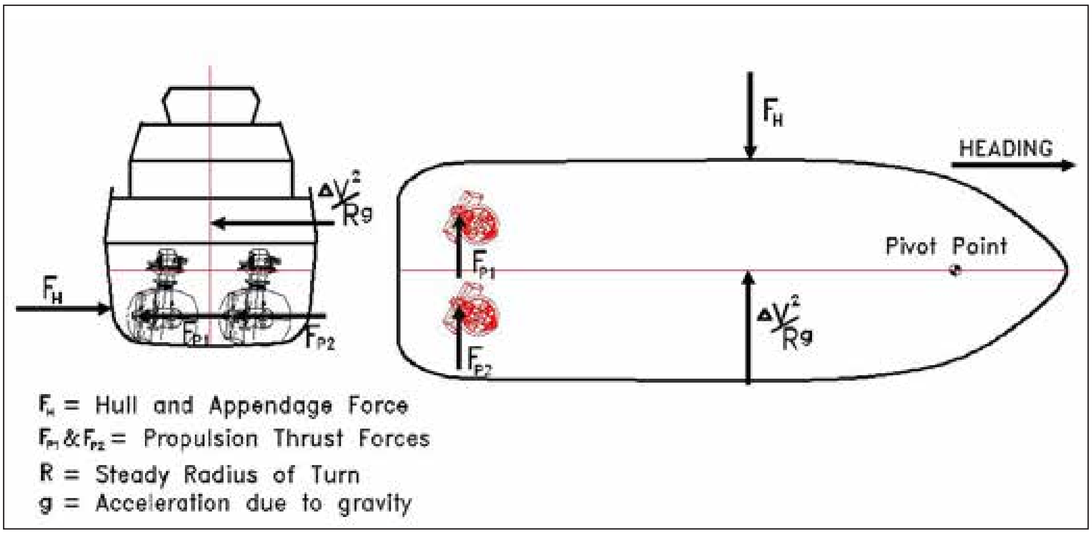

Figure 5: High speed operations – turning

Real-time external forces including tow rope tension, wind, waves, current and thruster forces need to be monitored onboard to simulate dynamic phenomena during tug operations.

Vessel motions

The stability characteristics of the tug during operations are subject to dynamic phenomena and cannot be fully evaluated by using static energy balance and metacentric height methods only. Vessel motions are the direct results of these external dynamic forces. Real-time roll period, heeling angles, heave and pitch motions, interaction effects, vessel drafts etc, can be determined and related to tug stability characteristics along with real-time external forces. Real operational scenarios need to be simulated using time domain and CFD tools validated with model tests. Ultimately, the tools should be passed on to the operators to monitor stability onboard.

Operability envelope

For safe operations, a limiting or operability envelope is to be provided to the operator in each mode of operation. Such an envelope will provide the following limits, which operators may monitor closely, and have built-in alarms to forewarn the operators as well as provide enough guidance for decision-making.

Limiting heel

The stability criteria are related to the vessel's heel angle, and the limiting KG is converted to a limiting heel. This is more useful guidance for operators. For towing operation, the heel must be less than the angle at which water may flood the vessel through openings left without weathertight closures.

For turning operations, the heel needs to be less than deck immersion or, say, 10 degrees, whichever is less (the 10-degree heel has been suggested based on feedback from operators on a reasonable value).

Limiting speed

For higher speed operations, it is essential to advise the operator on the limit speed for safe operations.

Limiting rudder angle/turning diameter

Turning diameters of 1.3 LOA and 1.8 LOA have been taken as the limits.

Limiting wind speed

This is perhaps the most critical point of guidance for the operator. Limiting sea conditions, such as the wind, wave and current limitations, dictate where different operations may be carried out.

CASE STUDIES

Investigations were carried out on existing tug designs *(see Figure 6)* in order to develop an operability envelope taking account of the actual operating conditions. The parameters of these three tugs are shown in *Table 1*.

Table 1: Principal dimensions of the tugboats

	LOA	LBP	Beam (mld)	Depth (mld)	Design Draft	Bollard Pull
	(m)	(m)	(m)	(m)	(m)	MT
Tug 1	25.80	21.91	9.50	5.00	4.00	40
Tug 2	32.50	24.83	10.50	4.90	3.90	45
Tug 3	33.00	27.64	11.60	5.60	4.40	65

Figure 6: The 25.8m tug used in the case studies

DOMINANT CRITERIA

Limiting KG values were calculated under four different draft conditions for all the following criteria:

- General stability
- Weather criteria
- Towing and fire-fighting operations
- Towing operations with a steady wind of 25 knots and 35 knots

Criteria for turning operations were as follows: equilibrium heel on a turn of <10 degrees, or deck immersion. Investigations revealed a certain pattern in the criteria, which were most dominant in different draft loading conditions *(Table 2)*.

●●●	Turning + steady wind
▬	Towing
◆◆◆	Towing + steady wind
▲▲▲	IMO General

Draft	Light	Mid	Normal	Max
Tug 1	●●●	●●●	●●●	●●●
Tug 2	◆◆◆	◆◆◆	◆◆◆	◆◆◆
Tug 3	◆◆◆	◆◆◆	●●●	●●●

Table 2: Dominant criteria of tugs under four different loading conditions

LIMITING KG CURVES

As seen in *Table 2*, the following two criteria are dominant: towing + steady wind, and turning + steady wind. For turning criteria, Tug 1 was selected, as it had this as the dominant criterion for all the four draft conditions. For towing criteria, Tug 2 was selected, as it had this as the dominant criterion for all the four draft conditions. Limiting curves were then plotted *(see Figures 7 and 8)* for the following cases:

- Without wind
- With steady wind (25 knots)
- With steady wind (35 knots)
- Without wind and 'worst' downflooding (DF) point *(Figure 8, overleaf)*
- Without wind, forward trim 1 per cent of LBP and aft trim 1 per cent of LBP *(Figure 8)*

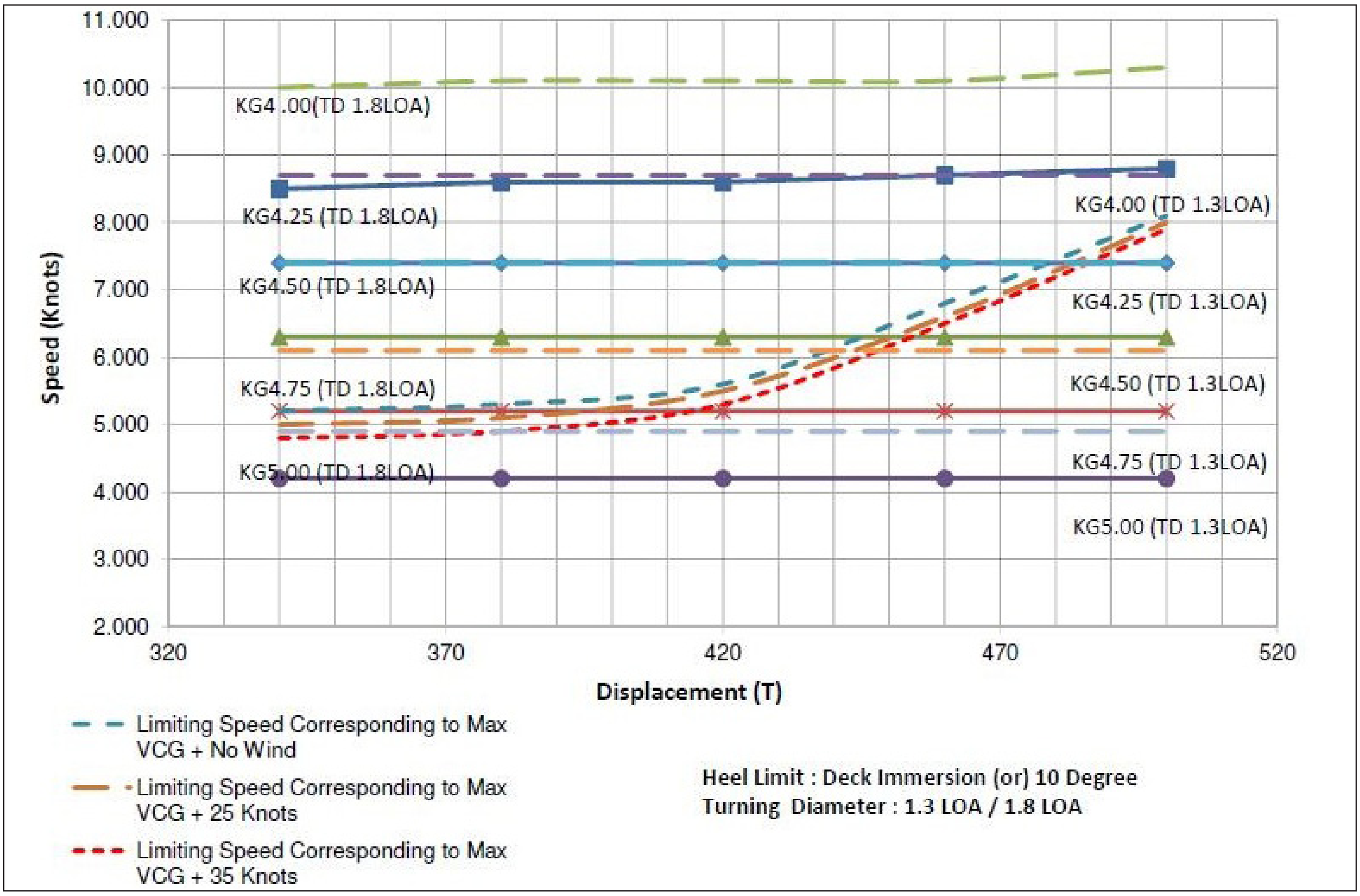

Figure 7: Speed limit for turning

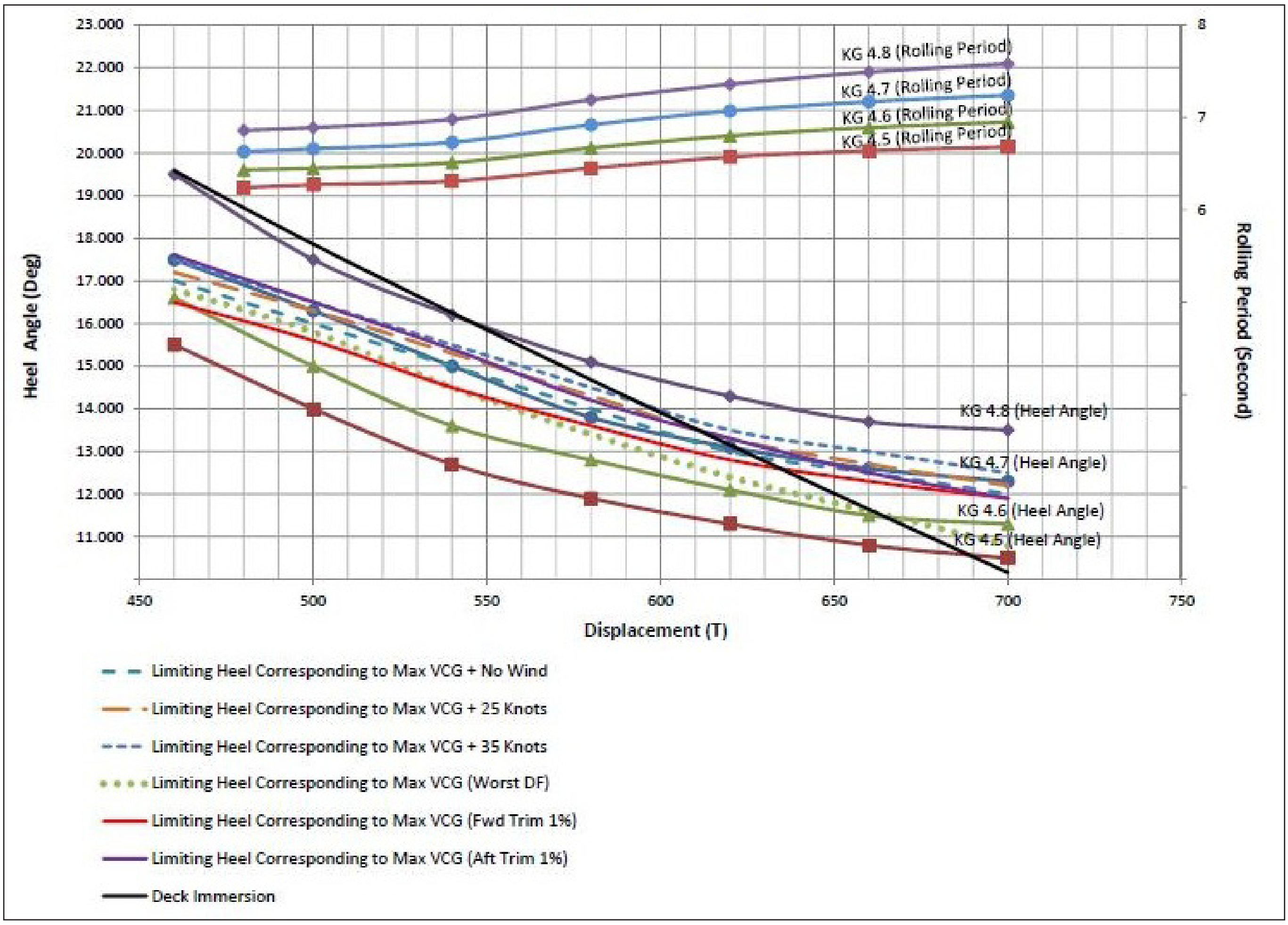

Figure 8: Heeling angle limit for towing

Limiting curves were plotted as follows:

- For turning operations, the heel angle limit was defined as the deck immersion angle or absolute 10 degrees, whichever was less. The speed limit for each case was plotted *(see Figure 7)*.
- For towing operations, the equilibrium heel angle limit and rolling period for each case was plotted *(see Figure 8)*.

CONCLUSION

Publication of the new IMO towing stability criteria is a step in the right direction. The next step would be to move towards an operability envelope. There is no constant or fixed operation for a tug, and the operator needs a real-time stability assessment.

For operators' guidance in decision-making, the following step is to develop easy to use stability advisory tools (software) with built-in limits from the limiting envelope. The operator will be provided with clear instructions on limiting operating parameters by the real-time stability alarm and monitoring system.

Further detailed research and collaboration with other stakeholders would be required to analyse a larger sample of existing designs, with inputs from operators on their operational requirements, in order to finally provide a basis to develop modified stability criteria relevant for workboats.

Finally, it would be more effective if naval architects were to have more direct access to the relevant IMO committees, along with other stakeholders, to provide the designer's perspective and ensure that the safety and stability requirements regulated are realistic and suitable for intended operations. We must not wait for another tragedy to raise safety standards.

FURTHER READING

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