Evaluating the Dynamic Motions of a Damaged Ocean Survey Vessel

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ABSTRACT

Damaged stability criteria for UK Naval Vessels include a dynamic allowance for the motion of a ship in a seaway. These allowances are applied to static damaged waterlines following Sarchin and Goldberg's SNAME paper '62. The current allowances are quasi-static, used to define the extent of watertight integrity to prevent progressive flooding into undamaged compartments. A common approach is to apply to a range of ship types and sizes, a generic fixed heave and roll allowance on each bulkhead. However, recent developments in computational power allow us to perform quasi-dynamic analyses using time-domain simulations to investigate the submergence of subdivision. This work investigates the dynamic motions of floodwater in the forward and aft regions of an Ocean Survey Vessel. The results are discussed in detail and compared with a generic dynamic roll and heave allowance.

Keywords: Dynamic V-lines, Ship Motions, Damaged Stability, Time-domain Simulation, Potential-flow

1. INTRODUCTION

It is a common practice in naval ship design to have a significant amount of watertight subdivision. Damaged stability criteria for UK Naval Warships include a prescribed quasi-static heave and roll allowance applied to the static damage waterline to account for the dynamic motions. This allowance is widely known as the V-line criteria and originates from the paper written by Sarchin and Goldberg in 1962. The approach now taken adopts a direct assessment when estimating dynamic heave and roll allowances. V-lines are derived to determine the flood water height levels on a bounding bulkhead. The water height level on a bulkhead due to flooding determines the:

- Structural requirement to design a bulkhead with the capacity to withstand the head.
- Extent of watertight integrity (penetrations).
- Which openings need to be readily shut following damage.
- Which systems (HVAC, Bilge etc.) need isolation following damage.

The Sarchin and Goldberg's V-line criteria use a prescribed heave allowance of 4ft (1.22m) to account for a vessel's motions in a seaway. Due to the lack of available numerical tools at the time of their research, the authors estimated the dynamic roll allowance as a function of the vessel displacement (see Figure 1). The roll angles describe reasonable roll motions that vessels experience in moderate seas with a significant wave height of 4ft or less.

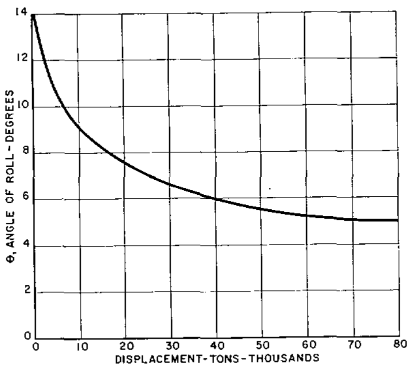


Figure 1: Angle of Roll vs. Displacement, Sarchin and Goldberg (1962)

The criteria used by UK MoD have been derived using the Sarchin and Golberg criteria. Table 1 compares UK criteria and those by Sarchin and Goldberg.

Table 1: MAP 01-024 vs Sarchin and Golberg (1962)

Allowance	Sarchin and Goldberg (1962)	UK MoD Standards
Angle of List	15 degrees of static list assumed following asymmetric damage	Worst case damage angle of heel (Limited by 20 degree list/loll Criteria)
Angle of Roll	Related to the roll vs. displacement graph in the publisted paper	15 degrees above static damaged angle of heel
Heave	4ft	1.5m

The application of the dynamic heave and roll allowances is illustrated in Figure 2.

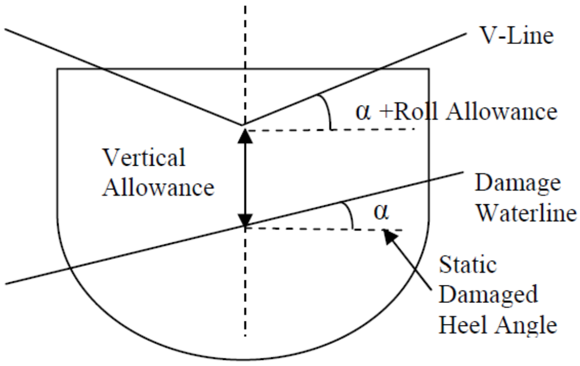


Figure 2: V-Line Definition (Heywood et.al, 2010)

The UK MoD applies a mid sea state 5 with a significant wave height of 3.25m as the basis of the Dynamic V-Lines calculations. There are two main reasons for applying sea state 5 in simulations:

- According to operational data from 1968 to 2000 Royal Navy ships spend approximately 95% of their time in sea state 5 or less (Heywood et.al, 2010)
- According to IMO 95% of ship collisions occur in sea states lower than 5.

2. SIMULATION METHODOLOGY

Time-domain simulation tool FREDYN (De Kat et.al, 2002) has been utilized to estimate nonlinear ship motions and flooding water ingress into the damaged hull in a seaway. FREDYN can implement nonlinearities related to the effect of large angles on excitation forces, rigid-body dynamics with large angles, drag forces associated with hull motions, wave orbital velocities and wind and integration of wave-induced pressure up to the free surface. Whereas the flooding module estimates the flooding water and free surface moments in a quasi-static way and integrates with the motion equations at each time step.

Simulation methodology has been discussed in detail by Peters et. al (2014). The present paper implements the probability of exceedance method to estimate the water heads on each bounding bulkhead and consecutively define the V-line profile. In the present paper, water head levels are presented at the 95th percentile (i.e. 5% exceedance) during the simulations unless it is stated otherwise. In order to calculate the water head levels at each bounding bulkhead water head sensors are located at port, centreline and starboard side locations of the bounding bulkhead. V-lines are generated by joining the water head level records obtained from sensors at the corresponding outboard and centreline water height percentiles (see Figure 3).

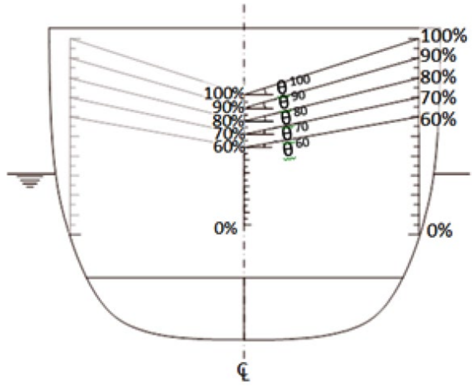


Figure 3: Lines of the probability of exceedance of water heights and the derivation of V-lines

The present study investigates a damaged naval ocean survey vessel's dynamic heave and roll allowances. The simulations were performed at mid sea state 5 at 0 and 5 kt in 8 wave headings spanning through 360 degrees. Slow forward speed is fixed at 5kts so the vessel remains manoeuvrable. Wave direction is particularly important in damaged ship simulations because a damage opening facing into or away from waves can have a significant effect on the results. Each simulation was run for 1hr duration to satisfy the ITTC Criteria which suggests a minimum of 100 wave encounters to assess vessel seakeeping behaviour under the given environmental conditions. Moreover, each wave train has been simulated 10 times with different wave seeds for each wave heading and resultant average V-Line levels were presented.

This assessment investigates a symmetric and asymmetric damage scenario applied separately on the front and aft ship location at 2 adjacent zones on an ocean survey vessel. In both scenarios, the vessel suffered minor accidental damage with an opening of dimensions of 5x5m. Damage opening is placed across the watertight bulkhead and hence there is transfer of flooding between the two main compartments as shown in Figure 4. The centre of the damage opening is defined at the centre of the damaged waterline. All results are presented for the aft, mid and fore bulkheads of the corresponding damaged zones.

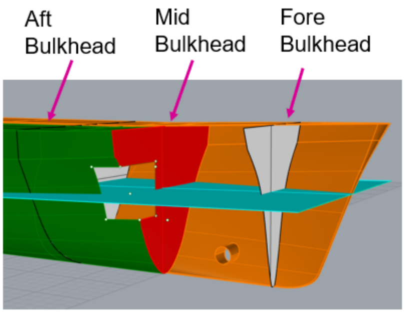


Figure 4: Symmetric damage scenario

3. SIMULATION RESULTS

Damaged V-Line Assessment

In the study symmetric damage has been investigated at fore part of the vessel whereas asymmetric damage has been applied at the aft of the vessel. Results of the symmetric fore damage has been provided below in Table 2.

Table 2: Symmetric Fore Damage V-Line levels

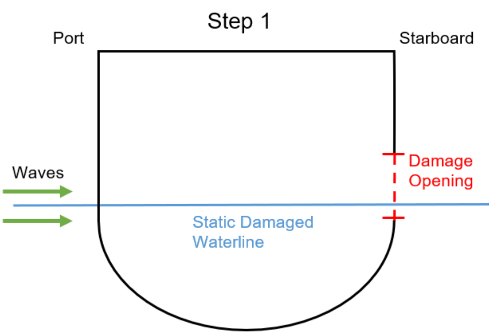
Criteria / Direct Assessment	Symmetric Damage					
	V-line Heave & Roll Allowances at 95th Percentile Water Height					
	Aft Bulkhead		Mid Bulkhead		Fore Bulkhead	
	Heave (m)	Roll (Deg)	Heave (m)	Roll (Deg)	Heave (m)	Roll (Deg)
FREDYN	1.52	3.15	1.71	1.25	2.24	0.21
MAP 01-024	1.5	35	1.5	35	1.5	35

The highest water head recording has been observed at 45° and 90° wave heading at 0kt. At 5kt the vessel experienced smaller motion responses due to higher roll damping applied at forward speed. It is observed from the results that the traditional heave allowance criteria might underestimate the actual heave allowances of a ship in a seaway. It is also observed that the heave allowance increases from the aft bulkhead to fore bulkhead. The main reason behind the phenomena is the pitch motions experienced by the vessel. Due to the pitch motions, the fore bulkhead sensors recorded higher water head levels. Also, it can be observed from Table 2 that the roll angles are very low. This can be explained in detail with the employed methodology:

- By combining the centreline and outboard water height probabilities as shown in the Figure 3, the vessel heave allowance directly impacts the roll allowance calculated.
- Maximum roll motions may occur when the depth of water in the compartment is at the lowest level. This means although the vessel is rolling significantly, the roll allowance can be only ultimately be a few degrees as the water level on the centreline is dominated by heave.
- Probabilistic V-line reflects the combined water levels on the bounding bulkhead. Traditionally the heave and roll allowance are applied independently. This work has shown this to not be the case for a real damage scenario.

The transient flooding process for the symmetric damage scenario can be simply explained in the following sequence and shown in Figure 5:

1. Wave heading is in the port side direction where the damage opening is on the starboard side. Wave forces sway and roll the vessel to the starboard side.
2. Vessel heels to the starboard and excessive amount of water ingresses to the compartments.
3. With the righting moment the vessel returns to the upright position and lolls to the portside. There is no damage opening at the port side and hence there is no water discharge.
4. Due to the wave forces, the vessel will roll to the starboard side again and ingress more water to the compartments.
5. Until the simulation reaches the steady-state response the flooding water will be accumulated in the compartments due to the water ingress rate is higher than the discharge rate.



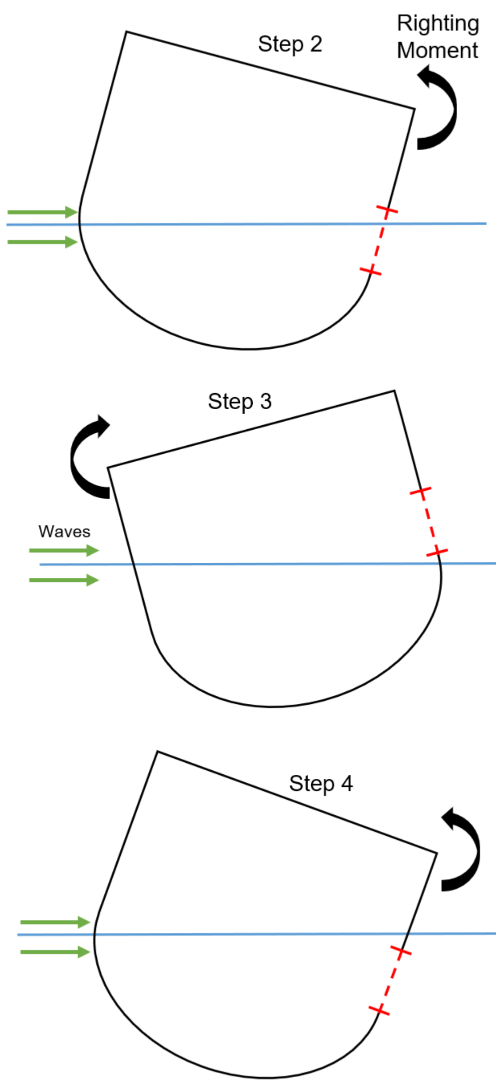


Figure 5: Transient flooding progress sequence for the symmetric damage scenario

Asymmetric damage scenario has been applied at the aft of the vessel to 2 adjacent zones separated by a bulkhead. Results of the asymmetric fore damage have been provided below in Table 3.

Table 3: Asymmetric aft damage V-Line levels

Criteria / Direct Assessment	Asymmetric Damage					
	V-line Heave & Roll Allowances at 95th Percentile Water Height					
	Aft Bulkhead		Mid Bulkhead		Fore Bulkhead	
	Heave (m)	Roll (Deg)	Heave (m)	Roll (Deg)	Heave (m)	Roll (Deg)
FREDYN	1.6	5.3	1.5	10.5	1.34	10.1
MAP 01-024	1.5	35	1.5	35	1.5	35

Again, the highest water head recording has been observed at 90° wave heading at 0kt. However, in the asymmetric damage scenario roll motion is predominant, hence larger roll allowance compared to the symmetric damage condition. In the symmetric damage scenario it is more likely to observe large heave allowances compared to the asymmetric damage scenario due to dominant heave and pitch motions.

Dynamic Heave & Roll Allowance vs Percentage Exceedance

The requirement is for, in a seaway, the dynamic damaged waterlines will not be exceeded for more than 5% of the time. The dynamic heave allowance at the centreline of the vessel on the bounding bulkhead has been investigated for the asymmetric damage scenario. This section investigates the accuracy of the 5% exceedance of water level versus the 1.5m heave allowance. In this study, the same water head recordings have been used as output from V-Line level simulation results. However, results are post-processed using different levels of percentile values. Results are shown in the Figure 6.

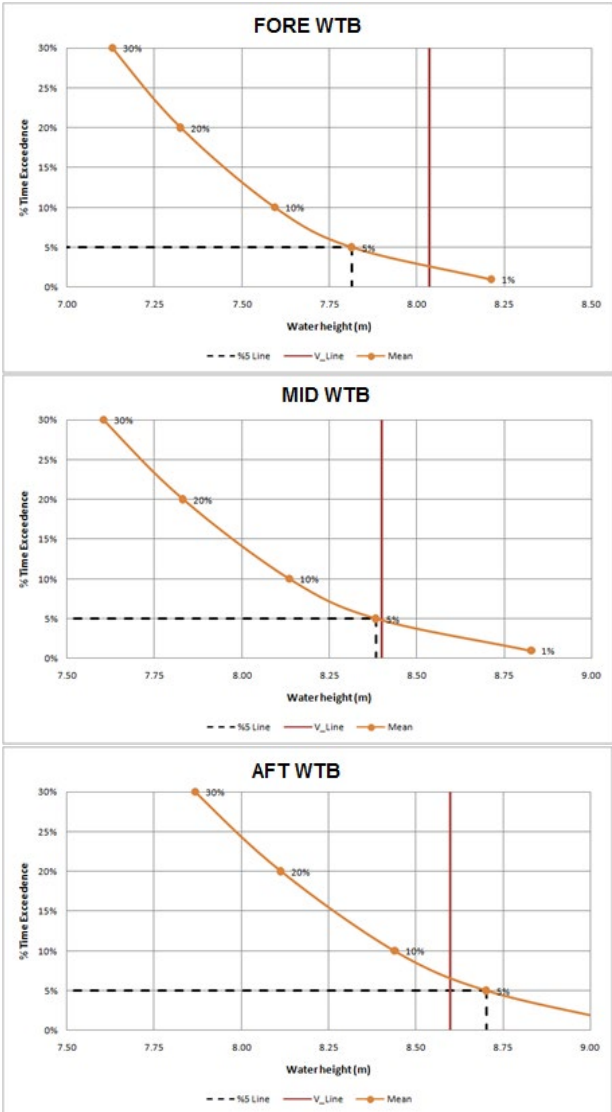


Figure 6: Percentage time exceedance and water head levels at centreline for the asymmetric damage scenario

It can be clearly observed from the Figure 4 that the 5% exceedance for the heave allowance generally stays under the 1.5m heave allowance prescribed criteria. The 5% exceedance only exceeds the criteria for the Aft Bulkhead where this can be explained as the effect of the pitch motions.

4. CONCLUSIONS

The V-Lines criteria from Sarchin and Goldberg's work in 1962 are based on frigate/destroyers. However, these criteria may overestimate the V-line results for other types of vessels. In the present study, it has been observed that V-line levels are highly dependent on whether the damage is symmetric or asymmetric.

As an outcome of the study, it appears the V-Lines criteria are over-estimating the dynamic heave and roll allowances for the investigated Ocean Survey Vessel and it is conservative up to the mid sea state 5.

The updated MAP 01-024 will adopt a direct assessment approach when calculating dynamic heave and roll allowances in a seaway. In this way, for all ship types the heave and roll allowance will be derived from the water head levels on the bounding bulkheads with a direct simulation assessment. As a conclusion, direct assessment approach may reduce the heave and roll allowances and hence this will result in reduced design and construction costs for bulkheads and open system isolations through bulkheads.

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