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Evaluation of wind loads on ships by CFD analysis

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ABSTRACT

Effect of wind loads on marine structures and ships has to be considered during design. Static and dynamic effects of wind forces and moments are incorporated into the rules and regulations of governing authorities by various means. The weather criterion of IMO, part of the mandatory requirements of 2008 IS Code, considers the effect of wind and waves on stability of ships and has been in use for a long time. The criterion is simply based on static heel angle due to pre-defined wind pressure and moment balance concept with respective roll motion. There has been a lot of criticism about the assumptions and therefore validity of the criterion especially for the standard wind pressure of 504 Pa and linear distribution of heeling arms curve irrespective of heel angles. This paper deals with these questionable issues of the weather criterion. CFD analyses have been conducted on several different type of vessels in order to predict the wind forces. The results are then compared with those mandated by various criteria.

1. Introduction

Wind forces and moments are important for all types of structures on land and on ships at sea during design. Over the years, many calculation methods have been developed to estimate these forces in the literature (Myers, 1969), (OCIMF, 1994), (Haddara and Soares, 1999), (SIGTTO, 2007).

Most of the stability criteria are based on the statical aspects of ship behavior at sea which may be considered as an unrealistic approach. Some of the criteria have been adopted, and are still in use, incorporating the dynamic effect of wind and waves in a quasi-dynamical fashion through empirical formulas. The weather criterion, adopted by the IMO Assembly Resolution A.562 in 1985, somewhat addresses dynamic aspects of ship stability problem in severe weather conditions specifically in beam seas (IMO, 2008). Chronological development and the details of the criterion are very well documented by Kobylinski and Kastner (2003). There are similar criteria that exist for the same purpose, which have been set up by navies of various countries such as the US (DDS 079), Germany (BV1030-1) and the UK (NES 109). Japan has also adopted its own weather criterion for its own fleet navigating along coastal waters of Japan (SLF 51/4/1). In the Japanese criterion, wind pressure is reduced considerably for coastal going vessels in two different categories depending upon the area of operation. For ocean going vessels, 504 Pa wind pressure is accepted as in the case of the weather criterion of IMO.

The problem of wind loads on structures on land or stationary structures in the sea need to be dealt with differently than that of the ships experiencing 6 DoF motions at sea. Apart from wind loads, associated wave excitation complicates the problem leading to excessive roll amplitudes and a possible capsize. The weather criterion of IMO has drawn a lot of criticism because of the assumptions and limitations it bears (Kobylinski and Kastner, 2003), (Syprou, 2011). Especially, the wind pressure of 504 Pa is found to be extremely high by some experts and researchers and unlikely to be come across in most parts of the world (Vassalos et al., 2003). Thus, compliance with the mandatory criteria may become more difficult especially for certain small ship types such as those having low freeboard and large superstructure. IMO has issued MSC.1/Circ.1200 “Interim Guidelines for the Alternative Assessment of the Weather Criterion” in 2006 which contains guidelines to determine relevant parameters of the weather criterion experimentally. Bulian et al. (2010) have conducted series of experiments using 3 GEOSIM models to measure roll motion in beam waves.

In this paper, wind forces and wind moments on ships have been considered. CFD applications in wind pressure calculations have intensified in the last 40 years. The existing evaluation methods, assumptions and criteria are examined thoroughly by (Owens and Palo, 1982), (Blendermann, 1996), (MCA, 2007), (SLF 46/6/8), (Brizzolara and

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Rizzuto, 2006). CFD method has been used frequently in recent years by many researchers (Janssen et al., 2017). Janssen et al. (2017) studied 3D steady RANS CFD simulations of wind loads on a container ship, validation with wind-tunnel measurements and an analysis of the impact of geometrical simplifications. Some of the research has focused on the comparison between CFD simulations and wind tunnel measurements. Wnek and Soarez (2015) dealt with wind loads on an LNG carrier with a very specific geometrical shape. They found that there is a difference in the magnitude of the forces with the experimental measurements over predicting the numerical results. They further concluded that the most probable cause of difference in the magnitude of the results was the error associated with the low wind speed which creates too small forces (Andersen, 2013). has performed wind tunnel tests on container ships. Bertaglia et al. (2004) have conducted systematic experimental tests in wind tunnel and in model basin for the IMO weather criterion requirements at the Vienna model basin. Calculation methods for wind loads are outlined in details. Three sample ships having different geometries were selected for CFD calculations. The results from CFD analysis were then compared with those from other criteria.

2. Review of existing criteria

2.1. IMO weather criterion

The stability standard known as the weather criterion, adopted by IMO as Resolution A.562, is based on a number of simplifying assumptions as described below, (IMO, 2008):

a) The ship attains a stationary angle of heel θ_0 due to side wind loading represented by a lever l_{w1}, which is the result of a 26 m/s wind,
b) Around this angle the ship is assumed to perform resonant rolling motion due to side wave action, as a result of which it reaches a momentary maximum angle θ_1 on the weather side,
c) As at this position the ship is most vulnerable in terms of weather-side excitations, it is further assumed that the ship is acted upon by a gust wind represented by a lever $l_{w2} = 1.5 \times l_{w1}$. This is translated into an increase of the wind velocity, assumed to affect the ship for a short period of time but at least equal to half of the natural roll period under the assumption of resonant ship response,
d) The requirement for stability is formulated as follows: should the ship roll freely from the off-equilibrium position θ_1 with zero angular velocity, the limiting angle θ_2 to the lee-side calculated on the basis of the condition b > a (Fig. 1) should not be exceeded during the ensuing half-cycle. This limiting angle is either the angle where significant openings are down-flooded, the vanishing angle θ_v, or the angle of 50°, which can be assumed as an explicit safety limit, whichever is the lowest. Expressed as an energy balance, the work done by the wind excitation as the ship rolls from the weather-side to the lee-side should not exceed the potential energy at the limiting angle θ_2.

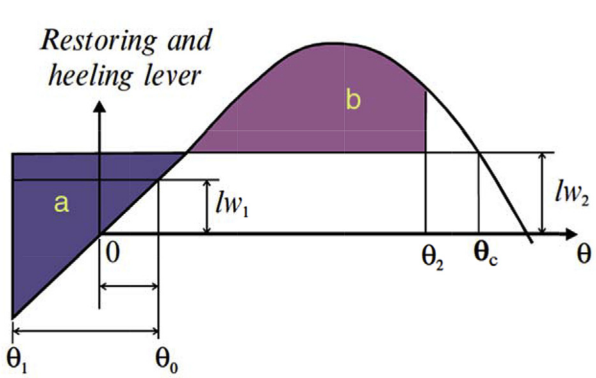

Fig. 1. IMO weather criterion (Syprou, 2011).

The heeling lever l_{w1} is calculated from the following formula:

$$l_{w1} = \frac{PAz}{1000g\Delta} \tag{1}$$

where; P: steady wind pressure [504 N/m^2], A: projected lateral area of the ship and deck cargo above the waterline [m^2], z: vertical displacement between the center of area A and the center of underwater lateral area (or approximately to a point at one half the draft) [m], Δ: ship's displacement [t], g: gravitational acceleration [m/s^2].

2.2. BV1030-1 German Navy weather criterion

The heeling lever l_V due to side wind pressure shall be calculated according to the following formula (BWB, 2001):

$$l_V = \frac{A_V(A_{VZ} - 0,5T)}{\Delta g} pV\left(0,25 + 0,75\cos^3\varnothing\right)[m] \tag{2}$$

where; Δ: displacement weight of the ship [t] A_V: area exposed to wind = freeboard lateral plan (including superstructures, masts, rigging, weapons and equipment), however without taking a possible ice layer into account [m^2]. DWL: design water level (m) A_{VZ}: height of the centroid of the area exposed to wind above DWL [m] T: draft of the ship [m] g: gravitational acceleration [m/s^2]p_V: wind pressure [kPa], to be taken as constant over the height according to Table 1

2.3. DDS 079 US Navy weather criterion

2.3.1. Effect of beam winds and rolling

Beam winds and rolling are considered simultaneously since a rough sea is to be expected when winds of high velocity exist. If the water is still, the ship will require only sufficient righting moment to overcome the heeling moment produced by the action of the wind on the ship's "sail area. When wave action is taken into account, an additional allowance of dynamic stability is required to absorb the energy imparted to the ship by the wave motion (DDS 079–1).

2.3.2. Wind velocities

Wind velocity which an intact ship is expected to withstand depends upon its service. The wind velocities used in determining whether a ship has satisfactory intact stability with respect to this hazard are given in Table 2.

2.3.3. Wind heeling arms

A general formula which is used to describe the unit pressure on a ship due to beam winds is as follows:

$$P = \frac{C\rho V^2}{2g} \tag{3}$$

where; C: dimensionless coefficient for ships, ρ : air density [lbs/ft^3], V: wind velocity [knots], g: acceleration due to gravity [ft/sec^2], There is a considerable uncertainty regarding the value of C. The variation of the

Table 1
Wind pressures by operational area.

Operational area group code	Wind speed [knots]	Wind speed [m/s]	Wind pressure [kPa]
A	90	46	1.50
	80	41	1.25
B	70	36	1.00
	60	31	0.75
C	50	26	0.50
D, F	40	21	0.30
	30	15	0.20
E	20	10	0.10

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