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RESEARCH ARTICLE

***An ethical committee approval and/or legal/special permission has not been required within the scope of this study.**

ASSESSMENT OF PURE LOSS OF STABILITY FOR A TURKISH NAVY TANKER*

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ABSTRACT

The second generation intact stability criteria (SGISC) have been developed by the International Maritime Organization's (IMO) Sub-committee on Ship Design and Construction (SDC). The SGISC involve improving the current intact stability criteria by including dynamic movements of ships in waves. The criteria are structured around five failure modes, pure loss of stability being one of these. This paper presents sample calculations regarding the assessment of pure loss of stability for a Turkish navy tanker. The calculations involve two steps that this study explains: Level 1 and Level 2. In addition, Option A and Option B are used as solution methods for both levels. Minimum metacentric heights (GM_{min}*) are calculated at the lowest draft (Option A) and at different wave crest locations alongside the ship (Option B) for Level 1. Values for the angle of vanishing stability, angle of loll, angle of stable equilibrium and maximum righting lever have been calculated from the GZ curves for Level 2. As a result, the subject ship was found not to be vulnerable to pure loss of stability. Level 1 results for both options are inconsistent due to Level 2 results being consistent.*

Keywords: *Second Generation Intact Stability Criteria, Pure Loss of Stability, Level 1, Level 2, Navy Tanker.*

BİR TÜRK DONANMA TANKERİ İÇİN TOPLAM STABİLİTE KAYBININ DEĞERLENDİRİLMESİ

ÖZET

İkinci nesil hasarsız stabilite kriterleri, Uluslararası Denizcilik Örgütü'ne (IMO) bağlı olan Gemi Tasarımı ve İnşası Alt Komitesi (SDC) tarafından geliştirilmiştir. İkinci nesil hasarsız stabilite kriterleri, geminin dalgaların etkisi ile yaptığı dinamik hareketlerini inceleyerek mevcut hasarsız stabilite kriterlerinin iyileştirilmesi hakkındadır. İkinci nesil hasarsız stabilite kriterleri, beş zafiyet modu üzerinde yapılandırılmıştır. Dalga tepesinde toplam stabilite kaybı, beş zafiyet modundan biridir. Bu makalede, Türk donanmasına ait bir tanker için dalga tepesinde toplam stabilite kaybı zafiyet durumunun değerlendirmesi hakkında örnek hesaplamalar sunulmaktadır. Hesaplamalar Seviye 1 ve Seviye 2 olmak üzere iki aşamada incelenmiştir. Ayrıca Opsiyon A ve Opsiyon B çözüm yöntemleri kullanılmıştır. Seviye 1 hesaplamaları için minimum metasentır yükseklikleri (GM_{min}), en düşük draft drumunda (Opsiyon A) ve gemi boyunca 11 farklı dalga tepesi konumu arasından (Opsiyon B) hesaplanmıştır. Devrilme açısı, bayılma açısı, dengeye gelme açısı ve maksimum doğrultucu kol değerleri, Level 2 için GZ eğrilerinden hesaplanmıştır. Hesaplamalar sonucunda, seçilen geminin dalga tepesinde toplam stabilite kaybı açısından güvenli olduğu tespit edilmiştir. Her iki opsiyon için yapılan Seviye 1 hesaplama sonuçları tutarsızlık gösterirken, Seviye 2 sonuçları tutarlılık göstermiştir.

Keywords: *İkinci Nesil Hasarsız Stabilite Kriterleri, Dalga Tepesinde Toplam Stabilite Kaybı, Seviye 1, Seviye 2, Askeri Tanker.*

1. INTRODUCTION

Despite complying with the International Code on Intact Stability 2008 (IS Code 2008), many ships (e.g., APL China, Chicago Express, JRS Canis) have been involved in stability-related accidents (Petacco, 2019). These accidents show the insufficiency of the current intact stability criteria. As a result, IMO has started work on the Second Generation Intact Stability Criteria (SGISC) to identify the new intact stability criteria regarding the dynamic stability of ships in waves.

SGISC have been under development through IMO's sub-committee on Ship Design and Construction (SDC) since 2005. SGISC are intended to improve the current intact stability rules by adding safety in waves. SGISC are gathered under the following five stability failure modes: pure loss of stability, parametric roll, dead ship condition, surf-riding/broaching and excessive acceleration (IMO-SDC, 2019).

SGISC have many different aspects apart from the current stability rules that make up 2008 IS Code. 2008 IS Code involves the following basic parameters: righting lever arm (GZ) and initial metacentric height (GM) as calculated for a ship in calm water. These parameters are strictly related to the vertical position of the ship's centre of gravity (KG). Meanwhile, SGISC generally focus on wave-based dynamic forces using a probabilistic approach. SGISC have three assessment levels in each failure mode. Level 1 concerns the GM_{min} calculation based on a simplified physical and deterministic approach. Level 2 is based on a probabilistic approach that requires calculations on hydrostatics in waves (GZ). Level 3 uses a direct assessment method and consists of experiments or numerical simulations of the ship's behaviour in waves.

In the last 15 years, SGISC development has been one of the most important topics for SDC. At the beginning of 2020, SDC 7th session finalized SGISC after a long and demanding process. SGISC are expected to come into force as recommendations; nevertheless, IMO endorses their application for assessing their consistency and validity (Petacco and Gualeni, 2020). Therefore many studies have been carried out for different ship types by the committee members during the development of the new criteria. Some of these studies have focused on pure loss of stability. For example, Chorab carried out sample calculations for pure loss of stability on a fishing vessel. Pure loss of stability mainly affects ships with small hulls, which is why a fishing vessel was chosen (Chorab, 2014). Grinnaert et al. studied both pure loss of stability and parametric roll phenomena. Level 1 and Level 2 assessment steps were applied for three naval ships of different sizes (helicopter carrier, destroyer, offshore patrol vessel) (Grinnaert, 2016). Chouliaras presented information about SGISC failure modes apart from the dead ship condition and applied them to a post-Panamax container ship (Chouliaras, 2015). Panagiotellis applied SCISC to a series of RoRo Passenger (RoPax) and RoRo Cargo Ships (Panagiotellis, 2018). Grinnaert carried out SGISC calculations for a variety of civilian and naval ships (Grinnaert, 2017).

This study concerns sample calculations regarding the failure mode of pure loss of stability. The following chapters present theoretical calculation procedures and the physical background of proposed criteria for pure loss of stability. A Turkish navy tanker is used as the sample ship. Both Level 1 and Level 2 calculations have been carried using the option A and option B solution methods. All calculation steps are presented in detail and the results have been presented for the subject ship.

2. SECOND GENERATION INTACT STABILITY CRITERIA

2.1. Pure Loss of Stability

Pure loss of stability is the reduction of stability due to wave passage when a ship is sailing in longitudinal waves. As can be seen in Figures 1 and 2, the waterline area undergoes a significant change in waves, which also leads to a change in the righting lever arm (GZ) curve. If the waterline area decreases, the area under the righting lever arm (GZ) curve decreases. As a result, the stability of the ship decreases and the failure mode of pure loss of stability may occur.

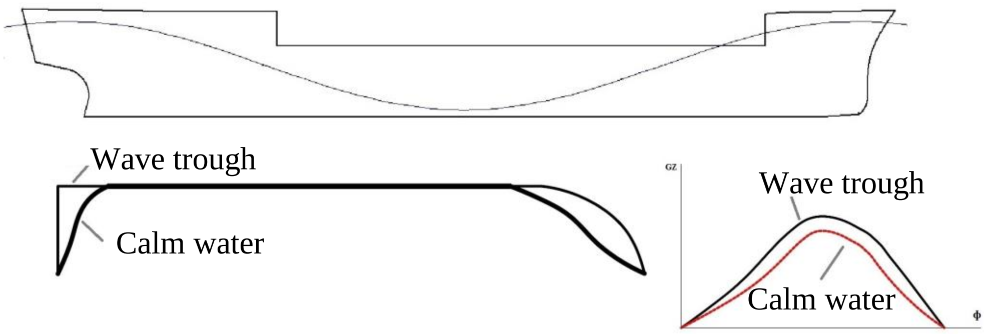

Figure 1. Changes in waterplane and GZ curve when a wave trough is amidships.

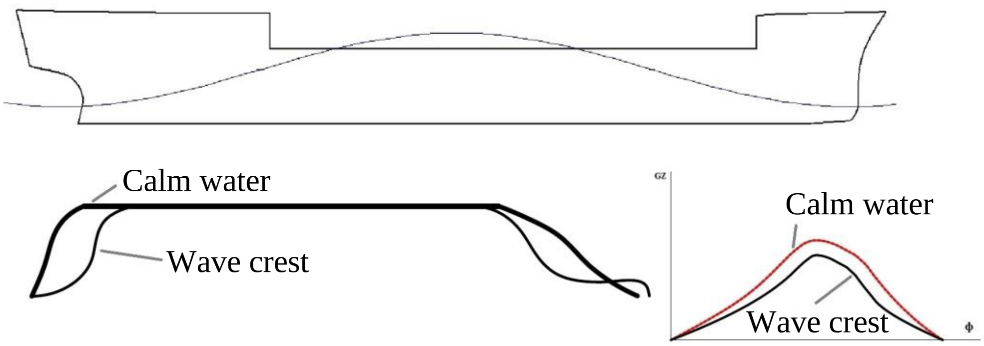

Figure 2. Changes in waterplane and GZ curve when a wave crest is amidships.

The vulnerability assessment method for pure loss of stability applies to ships over 24 meters in length with a Froude number greater than 0.24.
The Froude number is calculated as follows:

$$F_N = \frac{V_S}{\sqrt{gL}} \tag{1}$$

where:

F_N -Froude number [–],
L -ship's length [m],
g -acceleration due to gravity [m/s^2],
V_s -service speed [m/s].

In addition, the following requirement must be met in order to apply the method:

$$\frac{V_D - V}{A_W(D-d)} \geq 1{,}0 \qquad \textbf{(2)}$$

where:
V_D -volume of displacement at draft equal to depth, D [m^3],
V -volume of displacement for the loading condition under consideration [m^3],
d -mean draft corresponding to the loading condition under consideration [m],
A_W -waterplane area [m^2],
D -molded depth at side to the weather deck [m].

2.1.1. Level 1 Assessment (Option A)

The Level 1 assessment using Option A requires calculating the GM_{min} value associate with the lowest draft as a longitudinal wave passes the ship. The ship is considered not to be vulnerable to pure loss of stability if GM_{min}>0.05 m.
The wave length (λ) is equal to the ship length (L) where the wave height (H_W) is calculated as:

$$H_W = 0.0334 \cdot \lambda \qquad \textbf{(3)}$$

If both 1 and 2 conditions are satisfied, the following Equation can be used to calculate GM_{min}:

$$GM_{\min} = KB + \frac{I_L}{V} - KG \qquad \textbf{(4)}$$

where:

V -displacement volume [m^3],
KB -vertical height of center of buoyancy [m],
KG - vertical height of center of gravity [m],
I_L - moment of inertia for the waterplane corresponding to d_L [m^4].

The method for Option A assumes the moment of inertia of the waterplane area in the waves to be equal to that of the parallel waterplane area in calm water at the lowest draught shown in Figure 3 (denoted by d_L).

The lowest draught d_L for the moment of inertia of the waterplane (I_L) corresponding to the loading case is computed as:

$$d_L = d - \delta d_L \quad \textbf{(5)}$$

$$\delta d_L = \min\left(d - 0.25 d_{full}, 0.5 H_W\right) \quad \textbf{(6)}$$

where:
d_{full} -draft corresponding to the full loading condition [m],
d_L -draft for calculating the transverse moment of inertia of the waterplane [m],
δd_L -draft difference to be deducted due to ship's loading condition; the smallest value from Equation 6 [m],
H_W -wave height in Equation 3.

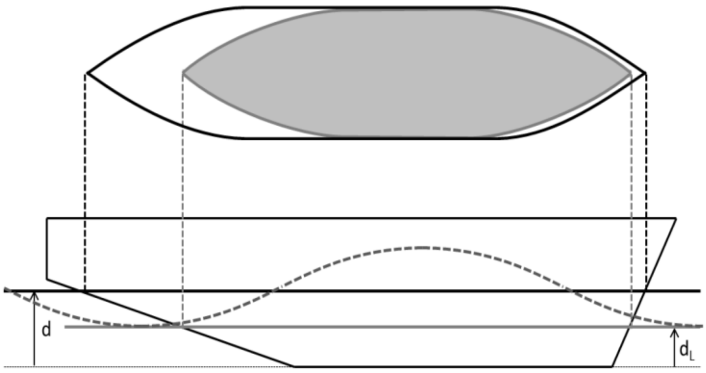

Figure 3. Parallel waterplane at the lowest draft (d_L) (Grinnaert, 2017).

2.1.2. Level 1 Assessment (Option B)

The method for option B consists of computing the minimum metacentric height for different wave crest locations. GM_{min} calculations are carried out for 11 points along the wave crest: with the wave crest located amidships and intervals of 0.1L, 0.2L, 0.3L, 0.4L, 0.5L forward and aft of amidships, and the lowest value among these is chosen.

Wave length (λ) is equal to ship length (L), and wave height (H_W) is calculated as shown in Equation 3. The ship is considered to not be vulnerable to pure loss of stability in Option B when GM_{min} > 0.05 m. If Level 1 is satisfied, the Level 2 assessment is unnecessary.

2.1.3. Level 2 Assessment (Option A)

Level 2 consists of a probabilistic approach associated with a wave scattering table that includes 16 different waves. Table 1 is used for the Level 2 Option A assessment of pure loss of stability.

The Level 2 assessment is done using the actual GZ curves (Figure 4). A ship is considered not to be vulnerable to the failure mode of pure loss of stability when the greatest value of parameters CR_1, CR_2, CR_3 does not exceed 0.06 m. This is presented as follows.

$$CR_{\max} < 0.06 \tag{7}$$

$$CR_{\max} = \max \begin{cases} CR_1 \\ CR_2 \\ CR_3 \end{cases} \tag{8}$$

CR_1, CR_2, CR_3 are a weighted average of specific stability parameters for a ship considered to be statically positioned in defined waves as in Table 1.

$$CR_1 = \sum_{i=1}^{N} W_i C1_i \tag{9}$$

$$CR_2 = \sum_{i=1}^{N} W_i C2_i \tag{10}$$

$$CR_3 = \sum_{i=1}^{N} W_i C3_i \qquad \textbf{(11)}$$

where:

W_i -weight factor obtained from Table 1 for Option A,

i -number of each wave described in Table 1,

N -total wave number in Table 1.

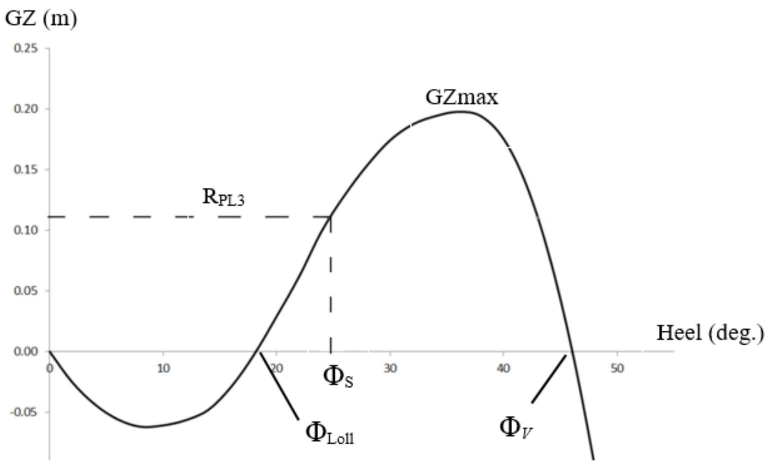

Figure 4. GZ curve with an angle of stability (Φ_S), equilibrium under heeling lever R_{PL3}, angle of vanishing stability (Φ_V) and angle of Loll (Φ_{Loll}).

The first short-term criterion of $C1_i$ concerns the minimum angle of vanishing stability ($\Phi_{V,min}$) and is determined as the minimum of the computed values for each wave height (H_W) in Table 1 with the wave crest located amidships and intervals of 0.1L, 0.2L, 0.3L, 0.4L, 0.5L forward and aft of amidships.

$$C1_i = \begin{cases} 1 & \Phi_{V\min i} < 30 \\ 0 & otherwise \end{cases} \qquad \textbf{(12)}$$

The second short-term criterion of $C2_i$ concerns the angle of loll (Φ_{Loll}) caused by a negative value for the initial metacentric height and is determined as the minimum of the computed values for each wave height

(H_W) in Table 1 with the wave crest located amidships and intervals of 0.1L, 0.2L, 0.3L, 0.4L, 0.5L forward and aft of amidships.

$$C2_i = \begin{cases} 1 & \Phi_{loll,\min i} > K_{PL2} \\ 0 & otherwise \end{cases} \quad \textbf{(13)}$$

where:

K_{PL2} -15 degrees for passenger ships,
-25 degrees for all other ships

The third short-term criterion for $C3_i$ refers to the ship's maximum righting lever (GZmax) and determined as the minimum of the computed values for each wave height (H_W) in Table 1 with the wave crest located amidships and intervals of 0.1L, 0.2L, 0.3L, 0.4L, 0.5L forward and aft of amidships.

$$C3_i = \begin{cases} 1 & GZ\max_{\min i}(m) < R_{PL3} \\ 0 & otherwise \end{cases} \quad \textbf{(14)}$$

$$R_{PL3} = 8\left(\frac{H_i}{\lambda_i}\right) dFn^2 \ \text{[m]} \quad \textbf{(15)}$$

where:

H -significant wave height,
λ -wave length,
d -draft corresponding to the loading condition,
F_n -Froude number corresponding to ship's service speed.

The ship is considered to not be vulnerable when the largest value among CR_1, CR_2 and CR_3 does not exceed 0.06.

Table 1. Wave parameters used in Level 2 Option A Assessment.

Regular wave number	Weighting factor	Wave length	Wave height	Wave steepness	Reversed wave steepness parameter
	Wi	*λi* [m]	*Hi* [m]	*Swi* [–]	1/*Swi* [–]
1	1,30E-05	22,574	0,700	0,0310	32,2
2	1,65E-03	37,316	0,990	0,0265	37,7
3	2,09E-02	55,743	1,715	0,0308	32,5
4	9,28E-02	77,857	2,589	0,0333	30,1
5	1,99E-01	103,655	3,464	0,0334	29,9
6	2,49E-01	133,139	4,410	0,0331	30,2
7	2,09E-01	166,309	5,393	0,0324	30,8
8	1,29E-01	203,164	6,351	0,0313	32,0
9	6,25E-02	243,705	7,250	0,0297	33,6
10	2,48E-02	287,931	8,080	0,0281	35,6
11	8,37E-03	355,843	8,841	0,0263	38,0
12	2,47E-03	387,440	9,539	0,0246	40,6
13	6,58E-04	422,723	10,194	0,0230	43,4
14	1,58E-04	501,691	10,739	0,0214	46,7
15	3,40E-05	564,345	11,241	0,0199	50,2
16	7,00E-06	630,684	11,900	0,0189	53,0

2.1.4. Level 2 Assessment (Option B)

Level 2 Option B also consists of a probabilistic approach associated with a wave scattering table. According to the SDC, the North Atlantic wave scatter diagram (Table 2) from IACS Recommendation No. 34 can be used for Level 2 Option B (IMO-SDC, 2019). This table lists 16 wave periods and 17 wave heights, with 197 waves having a non-zero number of occurrence. Because many waves need to be calculated, Grim proposed a new method based on the concept of effective wave height (Grim, 1961). The method consists of computing the effective height of the 3% highest waves corresponding to an equivalent wave whose length is equal to the ship's length. The effective wave heights are generated using Equations 16-23 from Table 2. For the subject ship, the calculated effective wave heights are presented in Table 3.

$$Hr_i = \begin{cases} 5.97 \cdot \sigma_{Heff} & if \quad 4.0 \cdot \sigma_{Heff} \leq 0.1 \cdot L \\ 0.1 \cdot L & 4.0 \cdot \sigma_{Heff} > 0.1 \cdot L \end{cases} \quad \textbf{(16)}$$

$$\sigma_{Heff}^2 = \sum_{i=1}^{N_{eff}} \left(RAO_{Heff}(\omega_i) \right)^2 S_W(\omega_i) \Delta\omega \quad \textbf{(17)}$$

$$RAO_{Heff}(\omega) = \begin{cases} \left\{ \dfrac{k_w(\omega) \cdot L \sin\left(0.5 k_w(\omega) \cdot L\right)}{\pi^2 - \left(0.5 k_w(\omega) \cdot L\right)^2} \right\} & if \quad \omega \neq \omega_L \\ 1.0 & if \quad \omega = \omega_L \end{cases} \quad \textbf{(18)}$$

$$k_W(\omega) = \frac{\omega^2}{g} \quad \textbf{(19)}$$

$$\omega_i = (i+1)\Delta\omega; \quad i = 1,2,..N_{eff} \quad \textbf{(20)}$$

$$\Delta\omega = \frac{3\omega_L}{N_{eff}} \text{ ; and} \quad \textbf{(21)}$$

$$\omega_L = \sqrt{\frac{2g\pi}{L}} \quad \textbf{(22)}$$

$$S_W(\omega) = \frac{H_S^2}{4\pi} \cdot \left(\frac{2\pi}{T_Z} \right)^4 \omega^{-5} \exp\left(-\frac{1}{\pi} \left(\frac{2\pi}{T_Z} \right)^4 \omega^{-4} \right) \quad \textbf{(23)}$$

where:

Hr_i	-effective wave height;
RAO_{eff}	-response amplitude operators;
H_S	-significant wave height in Table 2;
T_Z	-zero-crossing period in Table 2;
S_W	-wave steepness
N_{eff}	-total wave number (197 in Table 2);
i	-from 1 to 197 (total wave in Table 2).
w_i	-wave frequency

Table 2. Wave scatter diagram for the North Atlantic (from IACS, 2001).

HS	3,50	4,50	5,50	6,50	7,50	8,50	9,50	10,50	11,50	12,50	13,50	14,50	15,50	16,50	17,50	18,50
0,50	1,30	133,70	865,60	1186,00	634,20	186,30	36,90	5,60	0,70	0,10	0,00	0,00	0,00	0,00	0,00	0,00
1,50	0,00	29,30	986,00	4976,00	7738,00	5569,70	2375,70	703,50	160,70	30,50	5,10	0,80	0,10	0,00	0,00	0,00
2,50	0,00	2,20	197,50	2158,80	6230,00	7449,50	4860,40	2066,00	644,50	160,20	33,70	6,30	1,10	0,20	0,00	0,00
3,50	0,00	0,20	34,90	695,50	3226,50	5675,00	5099,10	2838,00	1114,10	337,70	84,30	18,20	3,50	0,60	0,10	0,00
4,50	0,00	0,00	6,00	196,10	1354,30	3288,50	3857,50	2685,50	1275,20	455,10	130,90	31,90	6,90	1,30	0,20	0,00
5,50	0,00	0,00	1,00	51,00	498,40	1602,90	2372,70	2008,30	1126,00	463,60	150,90	41,00	9,70	2,10	0,40	0,10
6,50	0,00	0,00	0,20	12,60	167,00	690,30	1257,90	1268,60	825,90	386,80	140,80	42,20	10,90	2,50	0,50	0,10
7,50	0,00	0,00	0,00	3,00	52,10	270,10	594,40	703,20	524,90	276,70	111,70	36,70	10,20	2,50	0,60	0,10
8,50	0,00	0,00	0,00	0,70	15,40	97,90	255,90	350,60	296,90	174,60	77,60	27,70	8,40	2,20	0,50	0,10
9,50	0,00	0,00	0,00	0,20	4,30	33,20	101,90	159,90	152,20	99,20	48,30	18,70	6,10	1,70	0,40	0,10
10,50	0,00	0,00	0,00	0,00	1,20	10,70	37,90	67,50	71,70	51,50	27,30	11,40	4,00	1,20	0,30	0,10
11,50	0,00	0,00	0,00	0,00	0,30	3,30	13,30	26,60	31,40	24,70	14,20	6,40	2,40	0,70	0,20	0,10
12,50	0,00	0,00	0,00	0,00	0,10	1,00	4,40	9,90	12,80	11,00	6,80	3,30	1,30	0,40	0,10	0,00
13,50	0,00	0,00	0,00	0,00	0,00	0,30	1,40	3,50	5,00	4,60	3,10	1,60	0,70	0,20	0,10	0,00
14,50	0,00	0,00	0,00	0,00	0,00	0,10	0,40	1,20	1,80	1,80	1,30	0,70	0,30	0,10	0,00	0,00
15,50	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,40	0,60	0,70	0,50	0,30	0,10	0,10	0,00	0,00
16,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,20	0,20	0,20	0,10	0,10	0,00	0,00	0,00

Table 3. Effective wave heights generated from wave scatter diagram (in Table 2).

HS	3,50	4,50	5,50	6,50	7,50	8,50	9,50	10,50	11,50	12,50	13,50	14,50	15,50	16,50	17,50	18,50
0,50	0,414	0,539	0,514	0,444	0,371	0,309	0,258	0,217	0,185	0,159	0,000	0,000	0,000	0,000	0,000	0,000
1,50	0,000	1,616	1,542	1,331	1,113	0,926	0,773	0,652	0,554	0,476	0,412	0,360	0,317	0,000	0,000	0,000
2,50	0,000	2,693	2,570	2,218	1,855	1,543	1,289	1,086	0,923	0,793	0,687	0,600	0,528	0,468	0,000	0,000
3,50	0,000	3,770	3,598	3,105	2,597	2,160	1,805	1,520	1,293	1,110	0,961	0,840	0,739	0,655	0,585	0,000
4,50	0,000	0,000	4,626	3,992	3,339	2,777	2,320	1,955	1,662	1,427	1,236	1,080	0,951	0,843	0,752	0,000
5,50	0,000	0,000	5,654	4,879	4,081	3,394	2,836	2,389	2,032	1,744	1,511	1,320	1,162	1,030	0,919	0,824
6,50	0,000	0,000	6,682	5,766	4,823	4,012	3,352	2,823	2,401	2,061	1,786	1,560	1,373	1,217	1,086	0,974
7,50	0,000	0,000	0,000	6,653	5,565	4,629	3,867	3,258	2,770	2,378	2,060	1,800	1,584	1,404	1,253	1,124
8,50	0,000	0,000	0,000	7,541	6,307	5,246	4,383	3,692	3,140	2,696	2,335	2,040	1,795	1,592	1,420	1,274
9,50	0,000	0,000	0,000	8,428	7,049	5,863	4,898	4,127	3,509	3,013	2,610	2,280	2,007	1,779	1,587	1,424
10,50	0,000	0,000	0,000	0,000	7,791	6,480	5,414	4,561	3,879	3,330	2,884	2,520	2,218	1,966	1,754	1,574
11,50	0,000	0,000	0,000	0,000	**8,533**	7,097	5,930	4,995	4,248	3,647	3,159	2,760	2,429	2,153	1,921	1,724
12,50	0,000	0,000	0,000	0,000	5,770	7,715	6,445	5,430	4,617	3,964	3,434	3,000	2,640	2,340	2,088	0,000
13,50	0,000	0,000	0,000	0,000	0,000	8,332	6,961	5,864	4,987	4,281	3,709	3,239	2,852	2,528	2,255	0,000
14,50	0,000	0,000	0,000	0,000	0,000	5,770	7,477	6,298	5,356	4,598	3,983	3,479	3,063	2,715	0,000	0,000
15,50	0,000	0,000	0,000	0,000	0,000	0,000	7,992	6,733	5,726	4,915	4,258	3,719	3,274	2,902	0,000	0,000
16,50	0,000	0,000	0,000	0,000	0,000	0,000	0,000	7,167	6,095	5,232	4,533	3,959	3,485	0,000	0,000	0,000

The maximum effective height is obtained from Table 3, with 11 effective wave heights being generated from zero to the maximum effective wave height whose wave length is equal to the ship's length. The minimum angle of vanishing stability ($\Phi_{V,min}$) and maximum angle of stable equilibrium ($\Phi_{S,max}$) are calculated for these 11 waves for the wave crest centered at the longitudinal center of gravity and each λ/10 increment forward and aft thereof. Next, the values for $\Phi_{V,min}$ and $\Phi_{S,max}$, which are required to calculate coefficients $C1_i$ and $C2_i$ associated to all waves in the scatter diagram, are calculated by interpolating the values of the previously calculated 11 effective wave heights. After obtaining all these values, the Level 2 assessment of the vulnerability to pure loss of stability is done as follows:

$$CR_{\max} < 0{,}06 \quad \textbf{(24)}$$

$$CR_{\max} = \max\begin{cases} CR_1 \\ CR_2 \end{cases} \quad \textbf{(25)}$$

According to this method, the CR parameters are calculated as follows:

$$CR_1 = \sum_{i=1}^{N} W_i C1_i \quad \textbf{(26)}$$

$$CR_2 = \sum_{i=1}^{N} W_i C2_i \quad \textbf{(27)}$$

where:

W_i -weight factor or wave occurrence value

$C1_i$ concerns the minimum angle of vanishing stability ($\Phi_{V\min}$) and is calculated as:

$$C1_i = \begin{cases} 1 & \Phi_{V\min i} < 30 \\ 0 & otherwise \end{cases} \quad \textbf{(28)}$$

$C2_i$ concerns the maximum angle of stable equilibrium ($\Phi_{S,\max}$) and is calculated as:

$$C2_i = \begin{cases} 1 & \Phi_{S,\max i} > 25 \\ 0 & otherwise \end{cases} \quad \textbf{(29)}$$

For each wave, the heeling lever R_{PL3} is defined as follows:

$$R_{PL3} = 8\left(\frac{H_i}{\lambda_i}\right) dFn^2 \text{ [m]} \quad \textbf{(30)}$$

where:

H -significant wave height,
λ -wave length,
d -draft corresponding to the loading condition,
F_n -Froude number corresponding to ship's service speed.

The ship is considered to not be vulnerable when the largest value among CR_1 and CR_2 does not exceed 0.06.

2.1.5. Level 3 Direct Assessment Method

When a ship qualifies for a Level 3 assessment, (after obtaining a negative vulnerability evaluation at both Levels 1 and 2), it is subject to a direct stability assessment (DSA).

DSA is an additional model test that may involve numerical calculations using a mathematical model that broadly describes pure loss of stability. Performing model experiments in DSA is a very expensive task. Therefore, the demand for direct stability assessment using computer simulations is expected to increase.

3. SAMPLE CALCULATIONS FOR THE PURE LOSS OF STABILITY

Vulnerability assessments for pure loss of stability have been performed in two stages (i.e., Levels 1 and 2). Calculations have been made using two different solution methods (i.e., Options A and B).

This study uses a Turkish navy tanker as the sample ship. The main dimensions are presented in Table 4, and the plan views are presented in Figure 5. Half load condition with free surface effect has been assumed as the loading condition. The hydrostatic parameters and GZ curves have been calculated using the program Maxsurf Stability (Bentley, 2020).

Table 4. Main dimensions of Turkish Navy Tanker.

L (L_{BP})	57.7	m
B	9.40	m
D	4.25	m
d (%50 load)	2.817	m
L_{CG}	29.407	m
V_{CG}	3.778	m
KB	1.496	m
V_S	12	knot

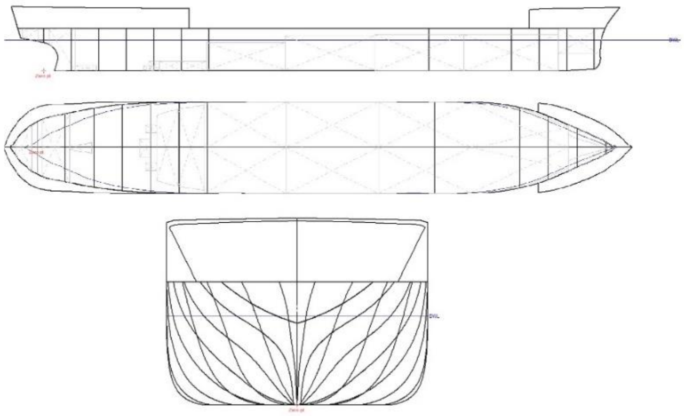

Figure 5. Hull plan views of the Turkish Navy Tanker.

3.1. Example Calculations

3.1.1. Level 1 Criterion Assessment (Option A)

Conditions 1 and 2 are satisfied for the subject ship as follows:

$$F_N = \frac{V_S}{\sqrt{gL}} = \frac{12x0.5144}{\sqrt{9.81x57.7}} = 0.259 \quad \textbf{(31)}$$

$$0.259 > 0.24$$

The Froude number is greater than 0.24, so the requirement is satisfied. The second check is as follows:

$$\frac{V_D - V}{A_W (D-d)} \geq 1.0$$
$$\frac{1849.094 - 1086.588}{442.762x(4.450 - 2.817)} = 1.054 \qquad \textbf{(32)}$$

The expression described in Equation 2 is satisfied.

According to the method, the wave length is equal to ship length as in Eq. 33. The wave height is calculated using Equation 3 as shown in Eq. 34.

$$\lambda = L = 57.7 \text{ m} \qquad \textbf{(33)}$$
$$H_W = 0.0334 \cdot \lambda = 1.927 \text{ m} \qquad \textbf{(34)}$$

In the next step, the lowest draught d_L and I_L are calculated using Equations 5 and 6 as follows.

$$\delta d_L = \min\left(d - 0.25 d_{full}, 0.5 H_W\right)$$
$$\delta d_L = \min\left(1.867, 0.963\right) \qquad \textbf{(35)}$$
$$\delta d_L = 0.963$$

$$d_L = d - \delta d_L$$
$$d_L = 2.817 - 0.963 \qquad \textbf{(36)}$$
$$d_L = 1.854 \text{ m}$$

Next, using d_L, the value for I_L is calculated as:

$$I_L = 2530.999 \text{ m}^4 \qquad \textbf{(37)}$$

Using Equation 4, the minimum initial metacentric height GM_{min} is calculated as follows:

$$GM_{\min} = KB + \frac{I_L}{V} - KG \qquad \textbf{(38)}$$

$$GM_{\min} = 1.49 + \frac{2530.99}{1086.85} - 3.778 \ = \ 0.0467 \text{ m}$$

As a result, the ship is vulnerable to pure loss of stability for Level 1 Option A, because $GM_{min} < 0.05$ m. The Level 2 assessment must be applied to the ship for the next vulnerability check.

3.1.2. Level 1 Criterion Assessment (Option B)

Firstly, both Conditions 1 and 2 must be satisfied as was done in Option A. The wave length (λ) is equal to the ship length (L), and the wave height (H_W) is calculated as follows.

$$\lambda = L = 57.7 \text{ m} \quad \textbf{(39)}$$

$$H_W = 0.0334 \cdot \lambda = 1.927 \text{ m} \quad \textbf{(40)}$$

Using Equation 4, the GM_{min} is calculated as the smallest value among the 11 calculations with the wave crest located amidships and at 0.1L, 0.2L, 0.3L, 0.4L and 0.5L intervals forward, and at 0.1L, 0.2L, 0.3L, 0.4L and 0.5L intervals aft. The calculated GM_{min} values are shown in Table 5.

Table 5. GM_{min} values corresponding to different wave crest locations.

Wave crest location from AP	**GM_{min}**
0L	0.558
0.1L	0.548
0.2L	0.441
0.3L	0.307
0.4L	0.228
0.5L	0.206
0.6L	0.205
0.7L	0.242
0.8L	0.340
0.9L	0.468
1L	0.558
GM_{min}	**0.205**

The ship is considered to not be vulnerable in the Level 1 Option B assessment because $GM_{min} > 0.05$ m. Therefore, no Level 2 assessment is necessary for further investigation. As can be seen in Table 5, the critical wave crest location is near amidship.

3.1.3. Level 2 Criterion Assessment (Option A)

Level 2 assessment of the vulnerability to pure loss of stability is done by using the 16 different waves shown in Table 1.

The results from the angle of vanishing (Φ_V) stability are listed in Table 6, and the CR_1 assessment is performed with respect to Equations 12 and 9. All the minimum Φ_V values have been calculated to be greater than 30 degrees, which means no critical situation is found for the sample ship. Therefore, CR_1 has been calculated to be equal to zero, as shown in Table 6.

Table 6. Level 2 assessment results for the CR_1 criterion.

Wave number	Angle of vanishing stability (deg)	C1 criterion control	Weighting factor	CR_1 criterion control
1	54,54	0	1,30E-05	0
2	55,45	0	1,65E-03	0
3	31,81	0	2,09E-02	0
4	38,18	0	9,28E-02	0
5	32,72	0	1,99E-01	0
6	37,27	0	2,49E-01	0
7	49,09	0	2,09E-01	0
8	48,18	0	1,29E-01	0
9	49,09	0	6,25E-02	0
10	50	0	2,48E-02	0
11	50,9	0	8,37E-03	0
12	52,72	0	2,47E-03	0
13	52,72	0	6,58E-04	0
14	53,63	0	1,58E-04	0
15	52,72	0	3,40E-05	0
16	52,72	0	7,00E-06	0
Value of criterion CR_1				**$\Sigma CR_1=0$**

The results for the minimum angle of loll (Φ_{Loll}) are listed in Table 7, and the CR_2 assessment has been performed with respect to Equations 13 and 10. No situation is found where an angle of loll had occurred.

Table 7. Level 2 assessment results for the CR_2 criterion.

Wave #	Φ_{Loll} (deg)	C2 control	Weighting factor	CR_2 control
1	0	0	1,30E-05	0
2	0	0	1,65E-03	0
3	0	0	2,09E-02	0
4	0	0	9,28E-02	0
5	0	0	1,99E-01	0
6	0	0	2,49E-01	0
7	0	0	2,09E-01	0
8	0	0	1,29E-01	0
9	0	0	6,25E-02	0
10	0	0	2,48E-02	0
11	0	0	8,37E-03	0
12	0	0	2,47E-03	0
13	0	0	6,58E-04	0
14	0	0	1,58E-04	0
15	0	0	3,40E-05	0
16	0	0	7,00E-06	0
Value of Criterion CR_2				**$\Sigma CR_2=0$**

Results for the minimum GZmax and R_{PL3} are listed in Table 8; the CR_3 assessment has been performed with respect to Equations 11, 14 and 15. All minimum GZ_{max} values have been calculated to be greater than R_{PL3} as shown in Table 8.

Table 8. Level 2 assessment results for the CR_3 criterion.

Wave #	GZmax (m)	R_{PL3} (m)	Weighting factor	CR_3 control
1	0,435	0,047	1,30E-05	0
2	0,213	0,040	1,65E-03	0
3	0,066	0,047	2,09E-02	0
4	0,076	0,050	9,28E-02	0
5	0,078	0,051	1,99E-01	0
6	0,093	0,050	2,49E-01	0
7	0,126	0,049	2,09E-01	0
8	0,128	0,047	1,29E-01	0
9	0,134	0,045	6,25E-02	0
10	0,142	0,043	2,48E-02	0
11	0,145	0,038	8,37E-03	0
12	0,162	0,037	2,47E-03	0
13	0,162	0,037	6,58E-04	0
14	0,181	0,032	1,58E-04	0
15	0,171	0,030	3,40E-05	0
16	0,170	0,029	7,00E-06	0
Value of criterion CR_3				**$\Sigma CR_3=0$**

The ship has been concluded to not be vulnerable in the Level 2 Option A assessment as CR_{max} has been calculated to be smaller than 0.06 as follows:

$$CR_{\max} = \max\begin{cases} CR_1 = 0 \\ CR_2 = 0 \\ CR_3 = 0 \end{cases} \quad \textbf{(41)}$$

$$CR_{\max} < 0.06 \quad \textbf{(42)}$$

3.1.4. Level 2 Criterion Assessment (Option B)

The Level 2 Option B assessment was applied to the subject ship. The lengths of all waves (λ) used in the calculations are considered equal to the length of the ship (L=57.7 m).

The maximum effective wave height values in Table 3 have been used to generate 11 effective wave heights. The maximum effective wave height was obtained for T_Z=9.5 s and H_s=15.5 m at λ_{max}=8.533 m.

This value was used to generate 11 effective waves whose heights range from 0 to 8.533 m at intervals of 0.853 m. A heeling lever (R_{PL3}) was calculated for each wave, based on the Froude number, draft, and wave steepness; the results are presented in Table 9.

Table 9. Wave charecteristics and R_{PL3} values.

Wave length (m)	**Wave height (m)**	**R_{PL3}**
57.7	0.000	0.000
57.7	0.853	0.022
57.7	1.707	0.045
57.7	2.560	0.067
57.7	3.413	0.089
57.7	4.267	0.112
57.7	5.120	0.134
57.7	5.973	0.156
57.7	6.826	0.179
57.7	7.680	0.201
57.7	8.533	0.224

The GZ values for each wave (Table 9) have been calculated from 0 to 35 degrees at 5 degree intervals. For each wave height and wave length, the angle of vanishing (Φ_V) stability and stable equilibrium (Φ_S) corresponding to the R_{PL3} values have been calculated from the GZ curves. The results are shown in Table 10.

Table 10. Results from the Angle of Vanishing (Φ_V) Stability and Stable Equilibrium (Φ_S) corresponding to $R_{PL3.}$

Wave #	**H_{eff} (m)**	**R_{PL3} (m)**	**$\Phi_{V.min}$ (deg)**	**$\Phi_{S.max}$ (deg)**
Calm	0.000	0.000	35	0
1	0.853	0.022	35	1.8
2	1.707	0.045	35	4.09
3	2.560	0.067	35	6.36
4	3.413	0.089	35	8.18
5	4.267	0.112	35	35
6	5.120	0.134	28.18	35
7	5.973	0.156	16.81	35
8	6.826	0.179	0	35
9	7.680	0.201	0	35
10	8.533	0.224	0	35

The angle of vanishing (Φ_V) and stable equilibrium (Φ_S) values corresponding to the wave heights in Table 11 were derived from Table 10 using linear interpolations. The calculated results are presented in the Appendix in Table 11.

As a result of the calculations, CR_{max} has been calculated as 0.02873 which is smaller than the criterion value 0.06. This means the ship is not vulnerable to pure loss of stability according to the Level 2 Option B assessment.

4. CONCLUSION

This study has examined the case of a Turkish Navy tanker for pure loss of stability, one of the second-generation intact stability (SGISC) failure modes. Level 1 and Level 2 assessments were carried out in detail. The subject ship was found to be vulnerable to pure loss of stability for Level 1 Option A, but not for Level 1 Option B. The subject ship was found to not be vulnerable to pure loss of stability for both Options A and B of the Level 2 assessment.

In conclusion, we offer the following remarks and comments:

a) The Level 1 vulnerability check result showed inconsistency between Options A and B. This reduces the reliability of the method.

b) Applying the Level 1 Option A assessment was found to be easier than Option B, which does not require any software like Maxsurf. However, the reliability of this method is weak as no vulnerability was shown.

c) Applying the Level 2 Option B assessment was found to be easier than the Level 2 Option A assessment because Grim's theorem was used to generate 11 effective wave heights while the values for the other waves were obtained by interpolating data.

d) The stability of the ship differs in the case of different loading weights. Therefore, the vulnerability analysis will also differ for different loading cases. Instead of calculating all load cases, the worst loading condition can be used with the minimum GM.

e) IMO's Second Generation Intact Stability Criteria require the use of computer programs to obtain hydrostatic data on waves.

f) North Atlantic Wave Scatter Data were used for the IMO Second Generation Intact Stability Criteria's Level 2 assessments. A different wave scatter diagram should be used when the ship sails in a restricted area.

g) A new type of ship has been added to the literature with IMO's endorsement of applying the new criteria for assessing consistency and validity.

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APPENDIX

Table 11. CR_1 and CR_2 results for the Level 2 Option B Assessment.

Tz (s)	**Hs (m)**	**Heff (m)**	**Φ_v (deg)**	**Contribution to CR_1**	**Φ_S (deg)**	**Contribution to CR_2**
3,50	0,50	0,41	35,00	0	0,87	0
4,50	0,50	0,54	35,00	0	1,14	0
4,50	1,50	1,62	35,00	0	3,85	0
4,50	2,50	2,69	35,00	0	6,64	0
4,50	3,50	3,77	35,00	0	19,40	0
5,50	0,50	0,51	35,00	0	1,08	0
5,50	1,50	1,54	35,00	0	3,65	0
5,50	2,50	2,57	35,00	0	6,38	0
5,50	3,50	3,60	35,00	0	13,98	0
5,50	4,50	4,63	32,13	0	35,00	6,00E-05
5,50	5,50	5,65	21,06	2,11E-04	35,00	1,00E-05
5,50	6,50	6,68	2,85	2,85E-05	35,00	2,00E-06
6,50	0,50	0,44	35,00	0	0,94	0
6,50	1,50	1,33	35,00	0	3,08	0
6,50	2,50	2,22	35,00	0	5,45	0
6,50	3,50	3,10	35,00	0	7,52	0
6,50	4,50	3,99	35,00	0	26,37	1,96E-03
6,50	5,50	4,88	30,10	0	35,00	5,10E-04
6,50	6,50	5,77	19,57	1,96E-04	35,00	1,26E-04
6,50	7,50	6,65	3,41	3,41E-05	35,00	3,00E-05
6,50	8,50	7,54	0,00	0,00E+00	35,00	7,00E-06
6,50	9,50	8,43	0,00	0,00E+00	35,00	2,00E-06
7,50	0,50	0,37	35,00	0	0,78	0
7,50	1,50	1,11	35,00	0	2,50	0
7,50	2,50	1,86	35,00	0	4,48	0
7,50	3,50	2,60	35,00	0	6,44	0
7,50	4,50	3,34	35,00	0	8,02	0
7,50	5,50	4,08	35,00	0	29,17	4,98E-03
7,50	6,50	4,82	30,55	0	35,00	1,67E-03
7,50	7,50	5,57	22,25	2,22E-04	35,00	5,21E-04
7,50	8,50	6,31	10,23	1,02E-04	35,00	1,54E-04
7,50	9,50	7,05	0,00	0,00E+00	35,00	4,30E-05
7,50	10,50	7,79	0,00	0,00E+00	35,00	1,20E-05

-Continuation of the Table 11.

7,50	11,50	8,53	0,00	0,00E+00	35,00	3,00E-06
7,50	12,50	5,77	35,00	0	35,00	1,00E-06
8,50	0,50	0,31	35,00	0	0,65	0
8,50	1,50	0,93	35,00	0	1,99	0
8,50	2,50	1,54	35,00	0	3,65	0
8,50	3,50	2,16	35,00	0	5,30	0
8,50	4,50	2,78	35,00	0	6,82	0
8,50	5,50	3,39	35,00	0	8,14	0
8,50	6,50	4,01	35,00	0	26,99	6,90E-03
8,50	7,50	4,63	32,10	0	35,00	2,70E-03
8,50	8,50	5,25	26,50	2,65E-04	35,00	9,79E-04
8,50	9,50	5,86	18,28	1,83E-04	35,00	3,32E-04
8,50	10,50	6,48	6,82	6,82E-05	35,00	1,07E-04
8,50	11,50	7,10	0,00	0,00E+00	35,00	3,30E-05
8,50	12,50	7,71	0,00	0,00E+00	35,00	1,00E-05
8,50	13,50	8,33	0,00	0,00E+00	35,00	3,00E-06
8,50	14,50	5,77	35,00	0	35,00	1,00E-06
9,50	0,50	0,26	35,00	0	0,54	0
9,50	1,50	0,77	35,00	0	1,63	0
9,50	2,50	1,29	35,00	0	2,97	0
9,50	3,50	1,80	35,00	0	4,35	0
9,50	4,50	2,32	35,00	0	5,72	0
9,50	5,50	2,84	35,00	0	6,95	0
9,50	6,50	3,35	35,00	0	8,05	0
9,50	7,50	3,87	35,00	0	22,45	0
9,50	8,50	4,38	34,07	0	35,00	2,56E-03
9,50	9,50	4,90	29,95	2,99E-04	35,00	1,02E-03
9,50	10,50	5,41	24,26	2,43E-04	35,00	3,79E-04
9,50	11,50	5,93	17,39	1,74E-04	35,00	1,33E-04
9,50	12,50	6,45	7,51	7,51E-05	35,00	4,40E-05
9,50	13,50	6,96	0,00	0,00E+00	35,00	1,40E-05
9,50	14,50	7,48	0,00	0,00E+00	35,00	4,00E-06
9,50	15,50	7,99	0,00	0,00E+00	35,00	1,00E-06
10,50	0,50	0,22	35,00	0	0,46	0
10,50	1,50	0,65	35,00	0	1,37	0
10,50	2,50	1,09	35,00	0	2,42	0
10,50	3,50	1,52	35,00	0	3,59	0
10,50	4,50	1,95	35,00	0	4,75	0
10,50	5,50	2,39	35,00	0	5,91	0

-Continuation of the Table 11.

10,50	6,50	2,82	35,00	0	6,92	0
10,50	7,50	3,26	35,00	0	7,85	0
10,50	8,50	3,69	35,00	0	16,95	0
10,50	9,50	4,13	35,00	0	30,60	1,60E-03
10,50	10,50	4,56	32,65	0	35,00	6,75E-04
10,50	11,50	5,00	29,18	2,92E-04	35,00	2,66E-04
10,50	12,50	5,43	24,05	2,41E-04	35,00	9,90E-05
10,50	13,50	5,86	18,26	1,83E-04	35,00	3,50E-05
10,50	14,50	6,30	10,40	1,04E-04	35,00	1,20E-05
10,50	15,50	6,73	1,85	1,85E-05	35,00	4,00E-06
10,50	16,50	7,17	0,00	0,00E+00	35,00	1,00E-06
11,50	0,50	0,18	35,00	0	0,39	0
11,50	1,50	0,55	35,00	0	1,17	0
11,50	2,50	0,92	35,00	0	1,99	0
11,50	3,50	1,29	35,00	0	2,98	0
11,50	4,50	1,66	35,00	0	3,97	0
11,50	5,50	2,03	35,00	0	4,95	0
11,50	6,50	2,40	35,00	0	5,94	0
11,50	7,50	2,77	35,00	0	6,81	0
11,50	8,50	3,14	35,00	0	7,60	0
11,50	9,50	3,51	35,00	0	11,20	0
11,50	10,50	3,88	35,00	0	22,81	0
11,50	11,50	4,25	35,00	0	34,42	3,14E-04
11,50	12,50	4,62	32,20	0	35,00	1,28E-04
11,50	13,50	4,99	29,24	2,92E-04	35,00	5,00E-05
11,50	14,50	5,36	25,03	2,50E-04	35,00	1,80E-05
11,50	15,50	5,73	20,11	2,01E-04	35,00	6,00E-06
11,50	16,50	6,09	14,41	1,44E-04	35,00	2,00E-06
12,50	0,50	0,16	35,00	0	0,33	0
12,50	1,50	0,48	35,00	0	1,00	0
12,50	2,50	0,79	35,00	0	1,67	0
12,50	3,50	1,11	35,00	0	2,49	0
12,50	4,50	1,43	35,00	0	3,34	0
12,50	5,50	1,74	35,00	0	4,19	0
12,50	6,50	2,06	35,00	0	5,03	0
12,50	7,50	2,38	35,00	0	5,88	0
12,50	8,50	2,70	35,00	0	6,65	0
12,50	9,50	3,01	35,00	0	7,33	0
12,50	10,50	3,33	35,00	0	8,00	0

-Continuation of the Table 11.

12,50	11,50	3,65	35,00	0	15,52	0
12,50	12,50	3,96	35,00	0	25,49	1,10E-04
12,50	13,50	4,281	34,88	0	35,00	4,60E-05
12,50	14,50	4,60	32,35	0	35,00	1,80E-05
12,50	15,50	4,92	29,81	2,98E-04	35,00	7,00E-06
12,50	16,50	5,23	26,68	2,67E-04	35,00	2,00E-06
13,50	1,50	0,41	35,00	0	0,87	0
13,50	2,50	0,69	35,00	0	1,45	0
13,50	3,50	0,96	35,00	0	2,09	0
13,50	4,50	1,24	35,00	0	2,83	0
13,50	5,50	1,51	35,00	0	3,56	0
13,50	6,50	1,79	35,00	0	4,30	0
13,50	7,50	2,06	35,00	0	5,03	0
13,50	8,50	2,34	35,00	0	5,76	0
13,50	9,50	2,61	35,00	0	6,47	0
13,50	10,50	2,88	35,00	0	7,05	0
13,50	11,50	3,16	35,00	0	7,64	0
13,50	12,50	3,43	35,00	0	8,83	0
13,50	13,50	3,71	35,00	0	17,46	0
13,50	14,50	3,98	35,00	0	26,10	1,30E-05
13,50	15,50	4,26	35,00	0	34,73	5,00E-06
13,50	16,50	4,53	32,87	0	35,00	2,00E-06
14,50	1,50	0,36	35,00	0	0,76	0
14,50	2,50	0,60	35,00	0	1,27	0
14,50	3,50	0,84	35,00	0	1,77	0
14,50	4,50	1,08	35,00	0	2,41	0
14,50	5,50	1,32	35,00	0	3,05	0
14,50	6,50	1,56	35,00	0	3,70	0
14,50	7,50	1,80	35,00	0	4,34	0
14,50	8,50	2,04	35,00	0	4,98	0
14,50	9,50	2,28	35,00	0	5,61	0
14,50	10,50	2,52	35,00	0	6,25	0
14,50	11,50	2,76	35,00	0	6,79	0
14,50	12,50	3,00	35,00	0	7,30	0
14,50	13,50	3,24	35,00	0	7,81	0
14,50	14,50	3,48	35,00	0	10,26	0
14,50	15,50	3,72	35,00	0	17,80	0
14,50	16,50	3,96	35,00	0	25,35	1,00E-06
15,50	1,50	0,32	35,00	0	0,67	0

-Continuation of the Table 11.

15,50	2,50	0,53	35,00	0	1,11	0
15,50	3,50	0,74	35,00	0	1,56	0
15,50	4,50	0,95	35,00	0	2,06	0
15,50	5,50	1,16	35,00	0	2,63	0
15,50	6,50	1,37	35,00	0	3,19	0
15,50	7,50	1,58	35,00	0	3,76	0
15,50	8,50	1,80	35,00	0	4,33	0
15,50	9,50	2,01	35,00	0	4,89	0
15,50	10,50	2,22	35,00	0	5,45	0
15,50	11,50	2,43	35,00	0	6,01	0
15,50	12,50	2,64	35,00	0	6,53	0
15,50	13,50	2,85	35,00	0	6,98	0
15,50	14,50	3,06	35,00	0	7,43	0
15,50	15,50	3,27	35,00	0	7,88	0
15,50	16,50	3,49	35,00	0	10,44	0
16,50	2,50	0,47	35,00	0	0,99	0
16,50	3,50	0,66	35,00	0	1,38	0
16,50	4,50	0,84	35,00	0	1,78	0
16,50	5,50	1,03	35,00	0	2,27	0
16,50	6,50	1,22	35,00	0	2,78	0
16,50	7,50	1,40	35,00	0	3,28	0
16,50	8,50	1,59	35,00	0	3,78	0
16,50	9,50	1,78	35,00	0	4,28	0
16,50	10,50	1,97	35,00	0	4,78	0
16,50	11,50	2,15	35,00	0	5,28	0
16,50	12,50	2,34	35,00	0	5,78	0
16,50	13,50	2,53	35,00	0	6,27	0
16,50	14,50	2,71	35,00	0	6,69	0
16,50	15,50	2,90	35,00	0	7,09	0
17,50	3,50	0,58	35,00	0	1,23	0
17,50	4,50	0,75	35,00	0	1,59	0
17,50	5,50	0,92	35,00	0	1,98	0
17,50	6,50	1,09	35,00	0	2,42	0
17,50	7,50	1,25	35,00	0	2,87	0
17,50	8,50	1,42	35,00	0	3,32	0
17,50	9,50	1,59	35,00	0	3,77	0
17,50	10,50	1,75	35,00	0	4,22	0
17,50	11,50	1,92	35,00	0	4,66	0
17,50	12,50	2,09	35,00	0	5,10	0

-Continuation of the Table 11.

17,50	13,50	2,25	35,00	0	5,55	0
18,50	5,50	0,82	35,00	0	1,74	0
18,50	6,50	0,97	35,00	0	2,12	0
18,50	7,50	1,12	35,00	0	2,53	0
18,50	8,50	1,27	35,00	0	2,93	0
18,50	9,50	1,42	35,00	0	3,33	0
18,50	10,50	1,57	35,00	0	3,73	0
18,50	11,50	1,72	35,00	0	4,14	0
			ΣCR_1 =	**0,00439**	**ΣCR_2 =**	**0,02873**