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Stability Analysis for River Nile Floating Hotels

Review paper

A study of the Egyptian River Nile waterway and its characteristics is made to define the constraints on the dimensions of Nile floating hotels. Factors causing heeling moments or influencing the position of the ship's centre of gravity, thus affecting the righting moment curve, are discussed in this paper to attain a better stability analysis for Nile floating hotels. Stability of Nile floating hotels can be easily and quickly checked by use of the proposed formula for the critical metacentric height. A mathematical model, for a specially designed computer program, which calculates the maximum sunshade area, is presented. Another proposal, for the calculation of maximum lateral projected area of Nile floating hotels, is presented. The River Nile weather conditions are also investigated to establish a specified wind speed to be used in connection with stability calculation of Nile floating hotels.

Keywords: *floating hotels, stability, river vessels*

Analiza stabiliteta plovećih hotela za rijeku Nil

Pregledni rad

Načinjena je studija plovnog puta egipatskog dijela rijeke Nil s njegovim značajkama radi određivanja ograničenja dimenzija plovećih hotela na Nilu. U ovom članku su razmatrani čimbenici koji prouzročuju momente nagiba odnosno utiču na položaj težišta broda a time i na krivulju momenta stabiliteta, a u svrhu postizanja bolje analize stabiliteta plovećih hotela na Nilu. Stabilitet plovećih hotela na Nilu može se lako i brzo provjeriti uporabom predložene formule za kritičnu metacentarsku visinu. Prikazan je matematički model za posebno razvijen program na elektroničkom računalu, koji izračunava najveću natkrivenu površinu. Isto je tako prikazan i prijedlog proračuna najveće projicirane poprečne površine plovećih hotela na Nilu. Također su istraženi vremenski uvjeti na rijeci Nil radi utvrđivanja brzine vjetra koja će se koristiti prilikom proračuna stabiliteta plovećih hotela na Nilu.

Ključne riječi: *ploveći hoteli, stabilitet, riječni brodovi*

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Nomenclature

A_P = Above water lateral projected area
A_{sh} = Sunshade area
A_{sd} = Sundeck area
b = Tank maximum breadth
B = Ship breadth
BG = Vertical distance between the ship's centres of gravity and buoyancy
BM_T = Transverse metacentric radius
C_D = Coefficient of wind force
D = Ship depth
F_B = Ship freeboard
GM_o = Initial metacentric height
GM'_o = Metacentric height corrected for free surface effect
h = Tank maximum height
h_{add} = Additional heeling arm
h_H = Heeling arm
h_R = Righting arm
h_{Hcrit} = Critical heeling arm
i = Moment of inertia of free surface of liquid in the particular tank
I_T = Transverse moment of inertia
k = Dimensionless coefficient
KB = Vertical centre of buoyancy
KG = Vertical centre of gravity
KM = The height of the transverse metacentre above the keel
l = Passenger crowding heeling arm
l_1 = Tank maximum length
L.O.A. = Length over all
LWL = Ship length at the load water line
$M_{tot.}$ = Total heeling arm
M_H = Heeling moment
M_{Hcrit} = Critical heeling moment
M_P = Heeling moment due to crowding of passengers on one side
M_R = Righting moment
M_T = Turning heeling moment
M_W = Wind heeling moment
n = Number of passengers
R.T.A. = River transportation authority

T = Ship draught
v = Tank total capacity
V_S = Ship speed
V_W = Wind speed
W_P = Average weight of passengers
Z_{sh} = Sunshade heeling arm
Z_W = Wind heeling arm
∇ = Ship volume of displacement
Δ = Ship displacement
ρ = Mass density
δ = Tank block coefficient
γ_L = Weight density of liquid in the particular tank
γ = Weight density of sea water
θ_m = Maximum angle of heel

1 Introduction

From the history of casualties we know that in almost all cases the casualty is a result of a certain sequence of unfortunate events each of them taken separately may not pose a real danger. All of them or only some of them may be attributed to incorrect design, faulty construction, a wrong assessment of stability and human errors. Therefore a “safe” ship may be achieved only when all of the above factors are eliminated.

It is sometimes wrongly assumed that the development of better stability criteria would be sufficient to improve safety; that is to avoid the possibility of incorrect design. Other factors must be observed as well.

It is true that the operational factor is generally recognised and taken into account by the requirement to provide satisfactory information concerning stability for the master. Human factor might be also taken into account implicitly if an allowance for poor seamanship is introduced into safety criteria. Faulty construction might be eliminated when additional requirements are observed. However, it appears that discussion on stability criteria overshadowed the other factors which are equally important.

Stability analysis for the River Nile floating hotels, requires a complete study of the characteristics of the River Nile and the Nile floating hotels.

2 The River Nile characteristics

2.1 Main parts of the River Nile

The waterway of the River Nile is divided into three main parts as follows:

- From Aswan Dam to Cairo through the River Nile.
- From Cairo to Alexandria through Noubaria canal and El-Behairy canal.
- From Delta Bridges to Ismaillia through Ismaillia canal.

Usually Nile floating hotels run from Cairo to Aswan and vice versa. This navigation route has the following characteristics:

- First class waterway with a length of 980 km.
- Two-direction waterway.
- Connects all Upper Egypt governorates from Aswan to Cairo.
- Used for cargo, passenger and tourist transportation.
- Divided into four sections, contains three locks and twenty-one bridges.

Table 1 shows the list of locks and bridges along the waterway from Aswan Dam to Delta bridges [1].

2.2 River Nile standard cross-section

The General Authority of Nile Transportation has defined a certain standard cross-section for the River Nile waterway. The section is 100 m wide at bottom, minimum level of water is 2.5 m and the slope of the sides is 1:5. If the water depth or breadth of the waterway is changed due to sedimentation, the section must be dredged [1].

The following figures show the River Nile standard cross-sections drawn at two different locations, one of them needs to be dredged at the shaded part (Figure 1), and the other does not need dredging (Figure 2).

2.3 Navigation restrictions in the River Nile

The presence of locks and bridges along the waterway and shallow water nature of the Nile represent several constraints on the dimensions of the Nile ships. Where:

- The width and length of the Nile ships are often dictated by the existing locks.

Table 1 **Locks and bridges along the waterway from Aswan Dam to Delta bridges**
Tablica 1 **Ustave i mostovi duž vodenog puta od Asuanske brane do mostova u Delti**

Air Clearance (m)	Opening			Distance From Aswan (km)	Industrial Structure	No
	Length (m)	Breadth (m)	No.			
-	-	-	-	0	Aswan Dam	1
13	Width The River Nile			7	Aswan new bridge	2
13	-	50	3	116	Edfu high bridge	3
-	116	17	1	169	Isna lock	4
13	-	90	1	214	Louxor bridge	5
13	-	50	3	290	Kena high bridge	6
13	-	80	5	292	Kena bridge (rail way)	7
Movable	-	38	2	340	Nagaa Hamadi bridge	8
Movable	-	38	2	340.5	Nagaa Hamadi bridge	9
-	140	17	1	359	Nagaa Hamadi lock	10
13	-	40	3	425	Sohag bridge	11
13	-	45	3	545	Assiut bridge	12
-	80	16	1	546	Assiut lock	13
13		50	2	700	Al-Menia bridge	14
13	-	47	2	823	Bany- Swaif bridge	15
13	-	85	1	926	Al-Marazik bridge (rail way)	16
13	-	150	2	924.5	Al-Monib bridge	17
11	-	110	1	954	Giza high Dam	18
12	-	110	1	955	Al-Gamaa bridge	19
Movable	-	30	2	957	Al-Galaa bridge	20
10	-	55	1	958	6th October bridge	21
10	-	45	1	959	15th May bridge	22
Movable	-	21	2	960	Embaba bridge (rail way)	23
10	-	110	1	962	Rode El-Farag bridge	24
-	Under Construction			964	Al-Warak bridge	25
-	116	16	1	980	Delta bridges	26

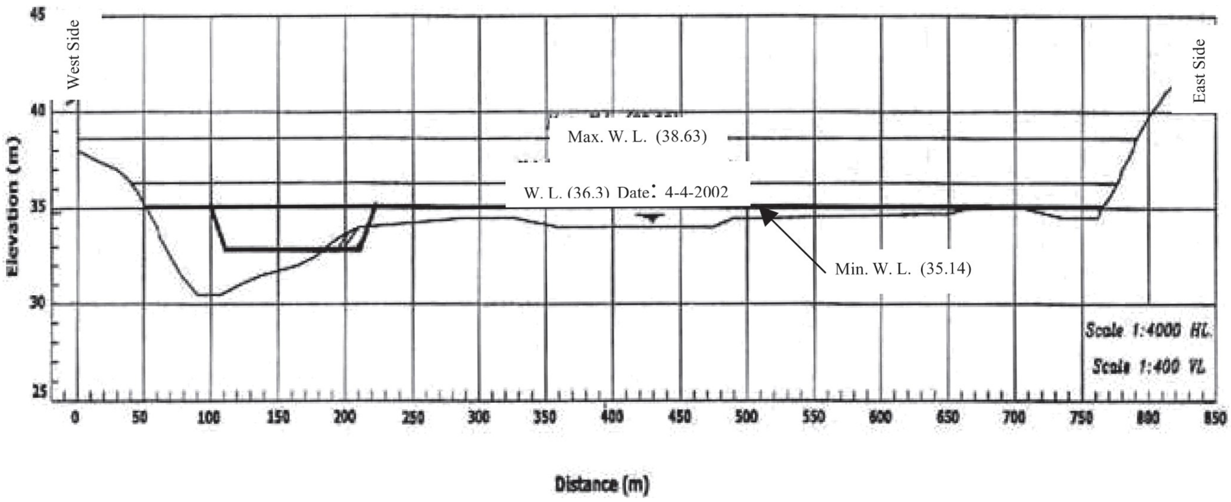


Figure 1 **Standard cross-section for the River Nile at a location needs to be dredged**
Slika 1 **Standardni poprečni presjek korita rijeke Nil na lokaciji gdje je nužno jaružanje**

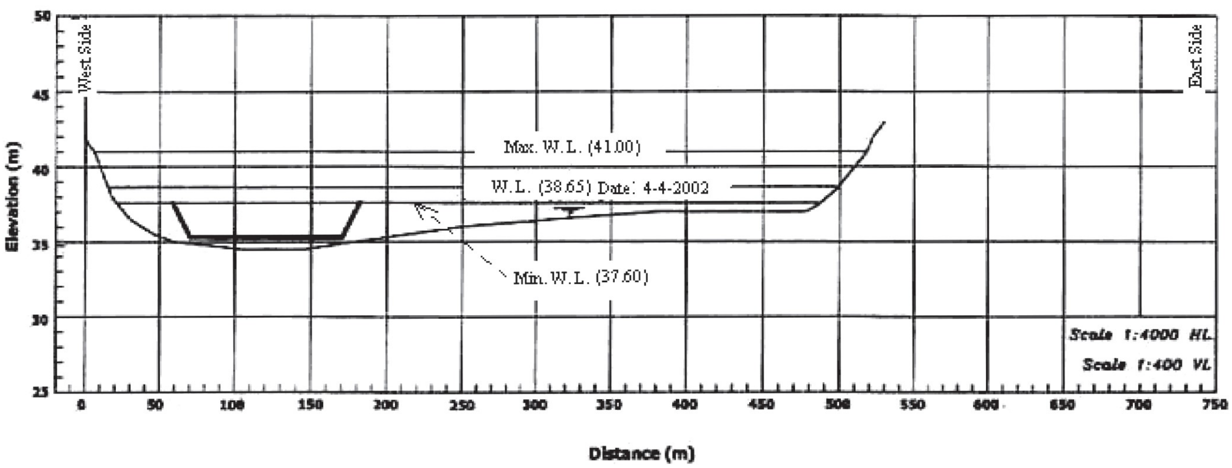


Figure 2 **Standard cross-section for the River Nile at a location does not need dredging**
Slika 2 **Standardni poprečni presjek korita rijeke Nil na lokaciji gdje jaružanje nije nužno**

- The air draught (height above water) is often dictated by the existing bridges.
- The draught and speed of the Nile ships are often dictated by the shallow water nature of the River Nile.

Because of the shallow water nature of the River Nile, the Nile ships are faced with many problems such as [2]:

1. The ship's draught should not exceed 1.5 m in the fully loaded condition, which restricts not only the loading capacity but also poses structural problems (strength and stiffness of a long flat vessel).
2. The shallow water nature of the River Nile increases the possibility of ship grounding, which is extremely dangerous, not only as regards to possible structural damages but mainly because of the large loss of transverse stability and consequently the possibility of capsizing with very small wind force.
3. The shallow water nature of the River Nile increases the resistance of a vessel at a given speed. The smaller under keel clearances, and the higher speed, the larger increase in resistance.
4. The shallow water nature of the River Nile increases the turning circle diameter. In shallow water, turning circle diameter could be increased 100 percent [3]. The effect of water depth on turning performance is shown in Figure 3 [4].

2.4 The maximum allowable dimensions of Nile floating hotels

Due to the existing navigation restrictions in the River Nile, the maximum allowable dimensions and speed of the Nile floating hotels are as follows:

- Length = 72.0 m,
- Breadth = 14.0 m,
- Draught = 1.5 m,
- Air draught =10.0 m
- Ship speed =18 km/h

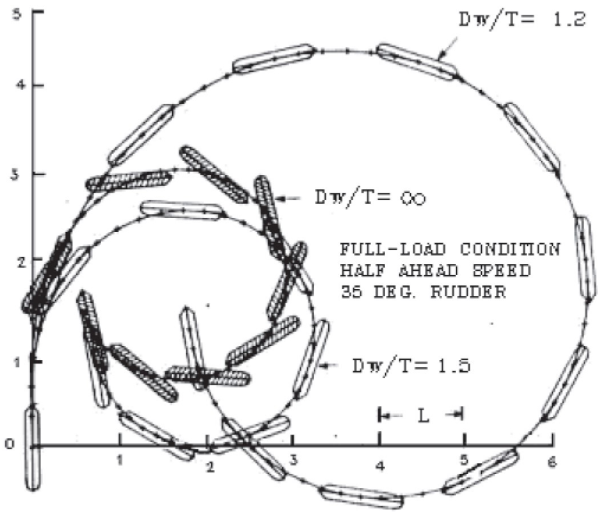


Figure 3 **Effect of water depth on turning performance**
Slika 3 **Utjecaj dubine vode na izvodljivost okretanja**

3 Factors causing heeling and influencing stability of Nile floating hotels

The principle of balancing of heeling and righting moments requires assessment of all possible factors causing heeling of ships or influencing the position of the centre of gravity, thus affecting the righting moment curve.

The vertical position of the centre of gravity of the ship in any loading condition is assumed to be the initial condition to which all factors affecting ship's stability are applied. Although some of the factors could be evaluated by simple methods described in many basic manuals, they will be discussed in the following part for the sake of completeness.

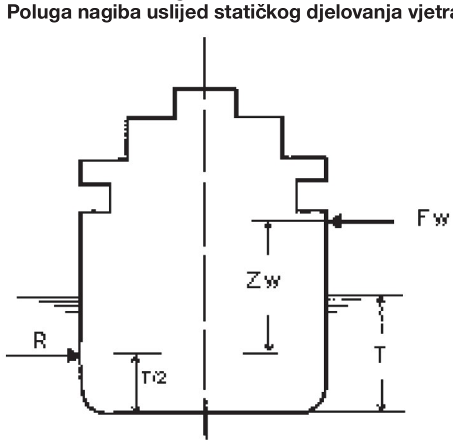
3.1 Heeling moment due to wind

It is often the additional effect of wind that determines whether or not the vessel will capsize. It is therefore vital that studies of extreme behaviour of vessels properly take account of wind loading. The wind heeling moment M_W could be calculated by the formula [5]:

$$M_W = 0.5 \cdot \rho \cdot C_D \cdot A_P \cdot Z_W \cdot v^2_w \quad (1)$$

Where ρ is the density of air, C_D is the coefficient of wind force, A_P is the above water lateral projected area, Z_W is the static wind heeling arm as shown in Figure 4 and V_W is the speed of wind.

Figure 4 **Static wind heeling arm**
Slika 4 **Poluga nagiba uslijed statičkog djelovanja vjetra**



3.2 Crowding of passengers on one side

In certain situation, passengers, normally to be found in various places onboard the ship, are crowding on a deck on one side. This is the case of transverse shift of loads, which results in heeling of the ship, which in certain cases might be dangerous, especially when combined with heeling caused by other factors. The resulting heeling moment M_P could be calculated by the following formula [6]:

$$M_P = n \cdot w_P \cdot l \quad (2)$$

Where n is the number of passengers, w_P is the average weight of passengers and l is the passenger crowding heeling arm as shown in Figure 5 below, it is always taken = $B/2$ (IMO).

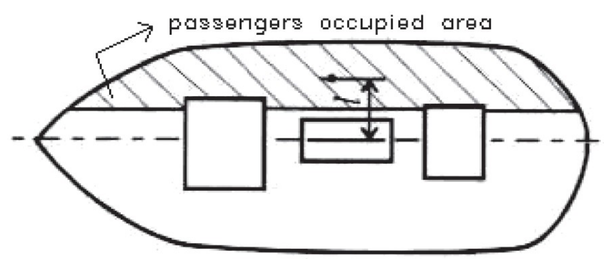


Figure 5 **Passenger crowding heeling arm**
Slika 5 **Poluga nagiba uslijed gomilanja putnika na boku broda**

When calculating metacentric height, passengers should be assumed as crowding on the highest deck, which is accessible. The height of the centre of gravity for passengers should be assumed equal to:

- 1.0 m above the deck for standing passengers.
- 0.3 m above the seat for seated passengers.

The maximum allowable heeling angle is estimated based on the "panic effect". This is the angle at which passengers feel that the ship is in danger and they may behave in an uncoordinated manner. Usually the angle of panic is assumed to be 10^o.

3.3 Heeling moment created in turning

When a body moves in a circular path there is acceleration towards the centre equal to V^2/R where V represents the velocity of the body and R represents the radius of the circular path. The force required to produce this acceleration, called "centripetal" force, is equal to $M\ V^2/R$, where M is the mass of the body.

In the case of a ship turning in a circle, the centripetal force is produced by the water acting on the side of the ship away from the centre of the turn. The force is considered to act at the centre of lateral resistance, which in this case, is the centroid of the underwater area of the ship's side away from the centre of turn. The centroid of this area is considered to be at the level of the centre of buoyancy. For equilibrium there must be an equal and opposite force, called the "centrifugal" force, and this force is considered to act at the ship centre of gravity.

It can be seen from Figure 6 that these two forces produce a couple which tends to heel the ship away from the centre of the turn.

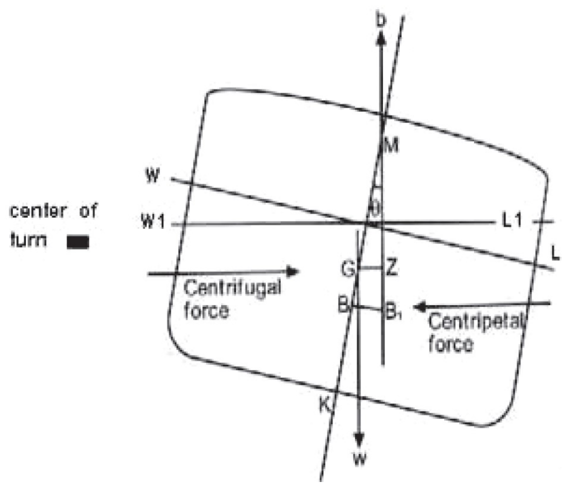


Figure 6 **Heeling moment created in turning**
Slika 6 **Moment nagiba prilikom okretanja**

Heeling moment due to turning of a ship can be calculated using the following formula [3]:

$$M_T = \frac{\Delta \cdot V_s^2}{g \cdot R} \cdot \left(KG - \frac{T}{2} \right) \quad (3)$$

Where V_S is the ship speed, Δ is the ship displacement, T is the ship mean draught, KG is height of the ship centre of gravity above baseline, g is the gravity acceleration and R is the turning radius.

3.4 Free surface of liquids in tanks

Liquids in partially filled tanks (i.e. where free surfaces of liquid exist) reduce ship's stability. So for all loading conditions, the initial metacentric height and the righting lever curve are to be corrected for the effect of free surfaces of liquids in tanks (see Figure 7).

Free surface effects are to be considered whenever the filling level in a tank is less than 98% of full condition. Free surface effects need not to be considered where a tank is nominally full, i.e. filling level is 98% or above. Free surface effects for small tanks may be ignored.

The values of the free surface moment M_{FS} at any inclination in ton.m for each tank may be derived from the following formula [6], [7], [8]:

$$M_{FS} = v \cdot b \cdot \rho \cdot k \cdot \sqrt{\delta} \quad (4)$$

Where v is the tank total capacity, b is the tank maximum breadth, ρ is the mass density of liquid in tank, k is a dimensionless coefficient to be determined from [6], [7], [8] and δ is the tank block coefficient, equal to:

$$\delta = \frac{v}{b \cdot l_1 \cdot h} \quad (5)$$

Where l_1 is the tank maximum length and h is the tank maximum height.

When there are several tanks filled partially with fluids, then the reduced metacentric height can be calculated by the following formula [6]:

$$GM' = \frac{I_T - \sum \frac{\gamma_L}{\gamma} i}{\nabla} - BG \quad (6)$$

Where I_T is the transverse moment of inertia of the water surface, γ_L is the weight density of liquid in the particular tank, γ is the weight density of sea water, i is the moment of inertia of free surface of fluid in the particular tank, ∇ is the ship volume of displacement and BG is the vertical distance between the ship centres of gravity and buoyancy.

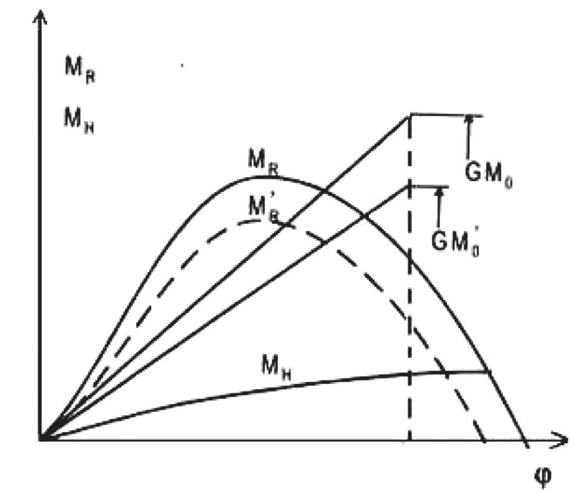


Figure 7 **Free surface effect on GZ curve**
Slika 7 **Učinak slobodne površine na GZ krivulju**

4 Stability requirements for River Nile floating hotels

The existing regulations of River Transport Authority **R.T.A.** as it stands now, for the calculation of intact stability can be summarised as follows [9]:

1. The angle of heel, under the most unfavourable crowding of all passengers on one side, should not exceed 10°.
2. The angle of heel should not exceed 12° under the combined effect of heeling moments resulting from the following:
   - The most unfavourable crowding of all passengers on one side at the top most usable deck.

- Beam wind of a speed of 100 km/h applied at the centre of the area subjected to wind.
- Centrifugal force when the ship is turning with half the maximum service speed (18 km/h).

3. This combined heeling moment is to be applied statically to the vessel and the resulting angle of heel is to be calculated for the worst stability condition of the vessel. The worst stability condition of the vessel is to be arrived at by considering various loading conditions.
4. Add 15% of the wind heeling moment to the combined heeling moment if there is a sunshade on the sun deck.
5. The distance between the individual waterline and the lowest opening from which water can be shipped into the vessel should at least be 5 cm.

5 Proposals for improvement of stability of Nile floating hotels

The principle of developing stability standards based on the consideration of heeling moments, which could be met in the process of operation of a ship, was widely used in national and also recently in international stability requirements developed by IMO.

Heeling moments, whether acting statically or dynamically, have to be balanced with the righting moment and the resulting heeling angle must be kept within safe limits. These considerations lead to the possibility of establishing safety criterion in the following form:

$$M_H < MR \quad \text{or} \quad h_H < h_R \tag{7}$$

and

$$M_H < MH\text{crit} \quad \text{or} \quad h_H < h_{H\text{crit}} \tag{8}$$

In all practical cases of stability criteria, heeling moments, acting statically or dynamically, were calculated in a simplified way.

5.1 Critical value of the metacentric height

The critical value of the metacentric height (GM_{crit}) could be calculated by the following equation:

$$GM_{crit} = \frac{\left(0.055 A_P Z_W + 0.0375 nB + 0.01 B^3\right)}{\left(1.6 F_B \cdot L + 0.127 B\right) T} \tag{9}$$

This equation can be easily applied to the Nile floating hotels to check the adequacy of stability.

It should be noted that, the derivation of the above equation is based upon the assumption that the ship must still have a margin of freeboard (20%F_B) when she is subjected to the heeling moments due to:

- Beam wind of a speed of 100 km/h applied at the centre of the area subjected to wind.
- The most unfavourable crowding of all passengers on one side at the top most usable deck.
- Centrifugal force when the ship is turning with half the maximum service speed (18 km/h).

In other words, in order that the ship does not heel statically in excess of "θ_m" due to the above mentioned forces, *GM* must be greater than or equal to $(M_W + M_T + M_P) / \Delta \tan \theta_m$. The derivation of equation (9) is given in Appendix 1. Equation (9) is a modification of that in [10].

5.2 Effect of sunshade area on ship stability

The problem of sunshade (see Figure 11) remains in that the created moment is not constant. It increases progressively by increasing the area subjected to wind (sunshade effect). This depends on the angle of inclination of the ship.

Table 2 **Main particulars of a Nile floating hotel**
Tablica 2 **Glavne značajke plovećeg hotela na Nilu**

L.O.A	60.5 m	Δ	639.425 tons
L.W.L	59.5 m	A_P	352.48 m^2
D	3.25 m	KG	3.032 m
B	9.6 m	Z_W	3.5 m
T	1.406 m	n	150 persons

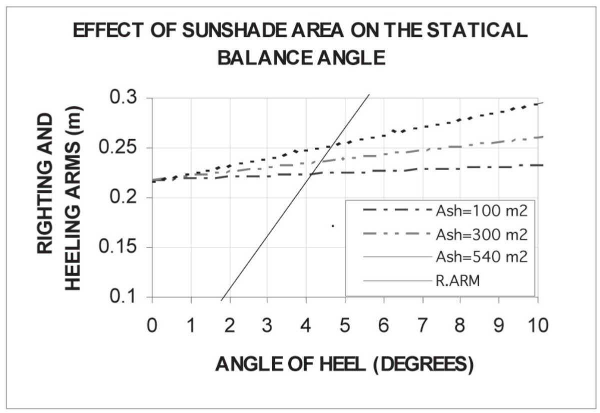
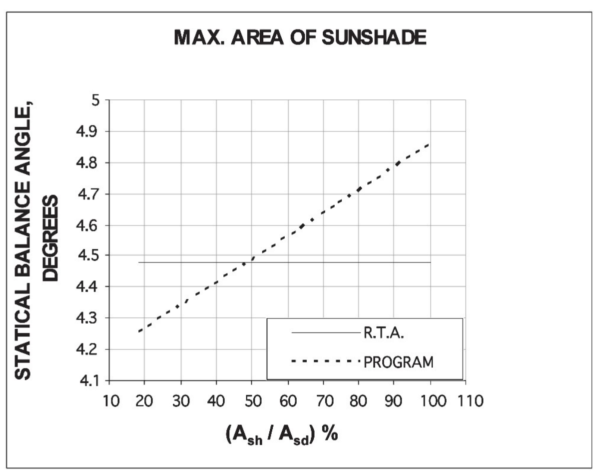


Figure 8 **Effect of sunshade area on the static balance angle**
Slika 8 **Učinak natkrivene površine na kut statičke ravnoteže**

Figure 9 **Max. area of sunshade**
Slika 9 **Najveća natkrivena površina**



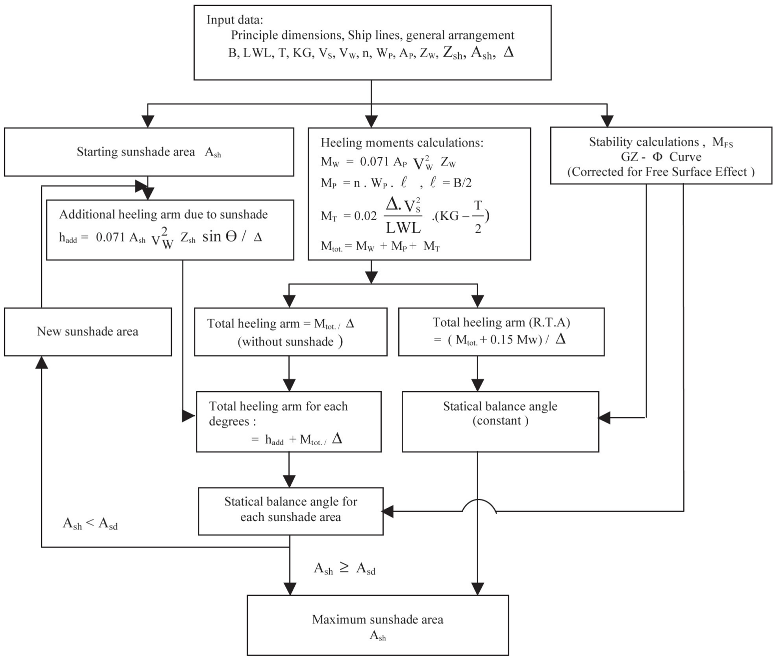


Figure 10 **Mathematical model for the developed program**
Slika 10 **Matematički model za razvijeni program**

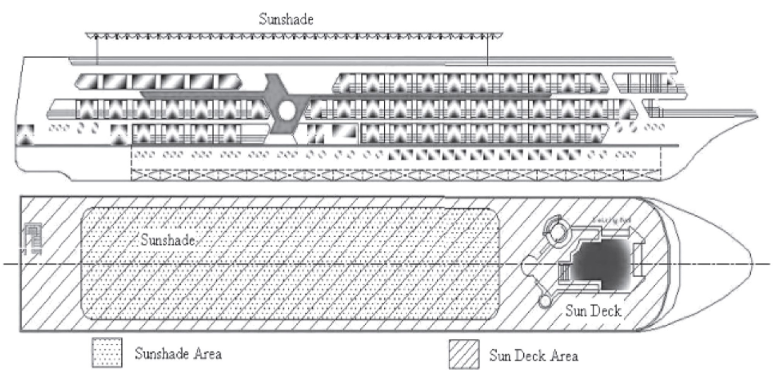
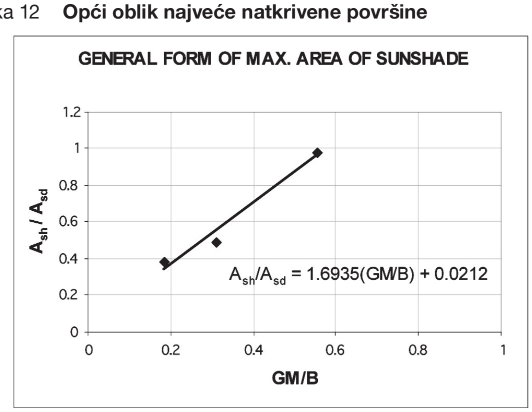


Figure 11 **Sunshade and sun deck arrangement**
Slika 11 **Opći plan natkrivene i suncu izložene palube**

Figure 12 **General form of maximum sunshade area**
Slika 12 **Opći oblik najveće natkrivene površine**



The existing regulations of R.T.A. recommend the addition of 15% of wind heeling moment to the combined heeling moment. This means that, for any sunshade area, the static balance angle is always the same. However, it may not reflect the actual condition, as to compensate for sunshade effect.

For this reason, a computer program was developed to calculate the consequent change in the total heeling arm, and the change of the static balance angle due to the change of sunshade area. A mathematical model of this program is shown in Figure 10. The program is used for a Nile floating hotel whose particulars are listed in Table 2 and the results are shown in Figure 8.

As shown in Figure 8, the increasing of the sunshade area increases the angle of static balance.

By plotting the angle of static balance obtained from Figure 8 and that recommended by **R.T.A.**, against the sunshade area as a percentage of the area of sun deck as shown in Figure 9, it is found that, to satisfying **R.T.A.** criteria, the area of sunshade must be less than 48.5% of the area of sun deck.

By repeating the above calculation, for a number of Nile floating hotels and plotting the maximum area of sunshade as a percentage of sun deck against *GM*/*B* as shown in Figure12, the following equation is obtained.

$$(A_{sh} / A_{sd}) = (1.6935(GM/B) + 0.0212) \qquad (10)$$

5.3 Effect of projected lateral area on ship stability

The projected lateral area is one of the most important factors which affect the stability of Nile floating hotels. Where, the wind force and wind heeling moment are proportional to the lateral projected area of the ship. This means that, for the same value of wind speed, any increase of the lateral projected area will result in the increase of the wind heeling moment and the angle of heel.

When dealing with the calculation of maximum projected lateral area for any Nile floating hotel, the distance between the individual waterline and the lowest opening from which water can be shipped into the vessel (5 cm as recommended by **R.T.A**) should be considered.

The maximum projected lateral area for the Nile floating hotel whose particulars are listed in Table 3 is shown in Figure 13.

Table 3 **Main particulars of a Nile floating hotel**
Tablica 3 **Glavne značajke plovećeg hotela na Nilu**

L.O.A	49.5 m	T	1.5 m
L.W.L	48.7 m	Δ	470.0 tons
D	3.1 m	KG	2.733 m
B	7.95 m	n	65 persons

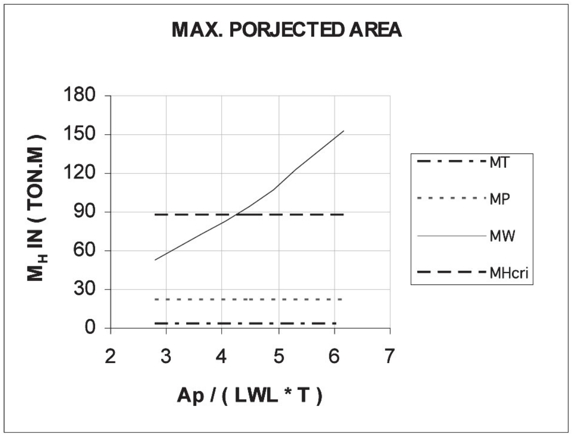


Figure13 **Maximum lateral projected area**
Slika 13 **Najveća projicirana poprečna površina**

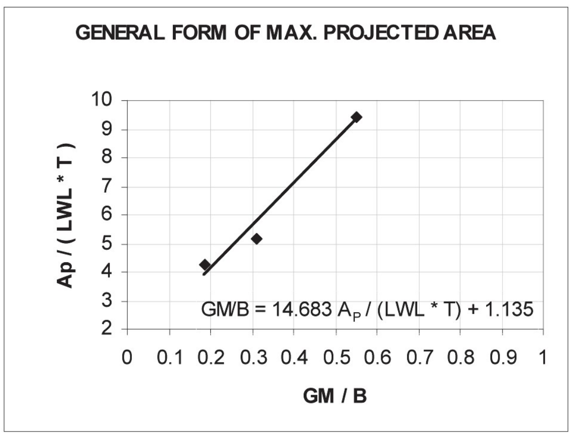


Figure 14 **General form of the maximum projected lateral area**
Slika 14 **Opći oblik najveće projicirane poprečne površine**

As shown in Figure 13, the maximum projected lateral area of that hotel must be less than 4.25 (*LWL* * *T*).

By repeating the above calculation for a number of Nile floating hotels and plotting the $A_p/(LWL*T)$ against *GM*/*B* as shown in Figure 14, it is found that:

$$A_P \,/\, (LWL*T) = 14.683\ (GM \,/\, B) + 1.135 \qquad (11)$$

5.4 Effect of wind velocity on ship stability

For most practical proposes, the wind force or pressure on a structure is proportional to the square of wind velocity. At high wind velocities, an accurate reading of the design wind speed is very important; for instance, a reading of 100 km/h instead of 80 km/h would cause a 56.25% error in wind force. Disparities of this order are uncommon, and stress the necessity for careful examination of all wind data.

The term "velocity" indicates direction and speed, although not all instruments measure both quantities. Wind is measured in a clockwise direction from north in 360 degrees. The determination of the wind velocity V_W is considerably more difficult, and it is necessary to consider V_W as varying continuously. Although peak and average velocities have been used for many years to determine static wind forces, their measurement has not been accurate or continuous in some parts of the world.

The extrapolation of maximum data for a long time period is the subject of the statistics of "extremes", performed on a continuous wind-speed record, and this technique is now used where possible to determine the occurrence probability of a maximum velocity. The technique enables the designer to select a rational design velocity for his structure's lifetime.

Table 4 **Wind data over the River Nile from Cairo to Aswan**
Tablica 4 **Podaci o vjetru na rijeci Nil od Kaira do Asuana**

No.	Station	Period		Most common Wind direction		Most common wind speed		Max. wind Speed
		from	to	(degrees)		(knots)		(knots)
1	ASWAN	1968	2003	345	14	7	10	27
2	DERAW	1970	2003	345	14	4	6	27
3	EDFU	1994	2003	315	344	7	10	27
4	LOUXOR	1968	2003	315	344	1	3	21
5	KENA	1968	2003	Calm		4	6	21
6	SOHAG	1968	2003	Calm		4	6	21
7	ASSIUT	1968	2003	315	344	7	10	33
8	MALWAY	1968	2003	345	14	1	3	21
9	AL-MENIA	1973	2003	345	14	7	10	27
10	BANY-SWAIF	1968	2003	345	14	7	10	33

Table 4 shows the wind data over the River Nile from Cairo to Aswan, as recorded by the Egyptian Meteorological Authority [11] during the period from 1968 to 2003.

As shown in Figure 15, the maximum measured wind speed is 33 knots, as recorded by Assiut and Bany-Swaif stations. The Egyptian Meteorological Authority recommends adding of five knots to the recorded wind speed because of the difference between the station location and the River Nile (land/water).

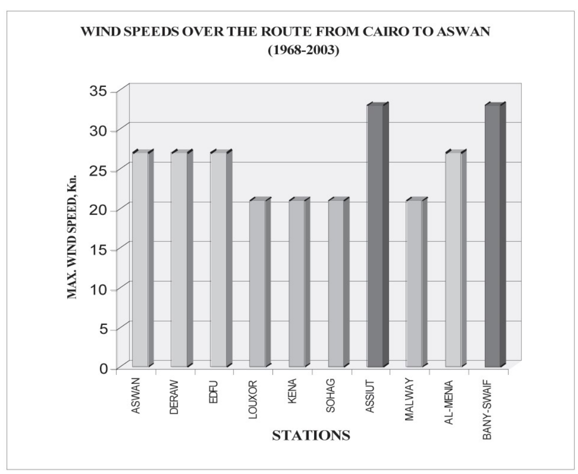


Figure 15 **The maximum wind speed over the River Nile from Cairo to Aswan**
Slika 15 **Najveća brzina vjetra na rijeci Nil između Kaira i Asuana**

It means that the maximum wind speed is 38 knots (70 km/h). Therefore, using a design wind speed of 100 km/h when dealing with heeling moment due to wind force (as recommended by R.T.A.) is safe with a reasonable factor of safety for the River Nile conditions.

6 Conclusions and recommendations

1. From the study of the Nile characteristics and its influence on Nile floating hotels, it is clear that bridges, locks and shallow water nature of the Nile are affecting the dimensions of such hotels.
2. The adequacy of stability of Nile floating hotels can be easily checked by using the following developed equation:

$$GM = \frac{\left(0.055 A_P Z_W + 0.0375 nB + 0.01 B^3\right)}{\left(1.6 F_B \cdot L + 0.127 B\right) T}$$

3. The effect of sunshade area on ship stability must be included into the existing regulations of the Egyptian River transport authority.
4. The addition of 15% wind heeling moment to the total heeling moment, to take the effect of sunshade area into consideration, is not enough. To satisfy that criterion:

$$\left(A_{sh} / A_{sd}\right) = \left(1.6935\left(GM / B\right) + 0.0212\right)$$

5. Superstructure lateral area is one of the most important factors which affect the stability of Nile floating hotels. Therefore, the superstructure lateral area of Nile floating hotels must satisfy the following developed equation:

$$A_P / \left(LWL \cdot T\right) = \left(14.683\left(GM / B\right) + 1.135\right)$$

6. It can be concluded that, the R.T.A. recommended wind speed is safe enough with a reasonable margin of safety for the River Nile applications.

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Appendix 1

Critical Metacentric Height (GM_{crit})

1. Heeling moment due to wind pressure M_W

By taking ρ = air density at 20°C = 1.2*10^{-4} tons.sec^2/m^4, C_D = 1.186 [12] and V_W = 27.778 m/sec (100 km/h), equation (1) for heeling moment due to wind pressure M_W will be in the following form:

$$M_W = 0.055 \cdot A_P \cdot Z_W \qquad (A1.1)$$

2. Heeling moment due to crowding of all passengers on one side M_P

By taking w_P = 75 kg and $l = B/2$, the equation (2) for heeling moment due to crowding of all passengers on one side M_P will be in the following form:

$$M_P = 0.0375.\ n\ .\ B \qquad (A1.2)$$

3. Heeling moment due to turning circle M_T

By taking ship speed V_S = 9 km/h (2.5 m/sec) and the radius of the turning circle $R = 5\ L$, equation (3) for heeling moment due to turning circle M_T will be in the following form:

$$M_T = \frac{0.127\Delta}{L} \cdot \left(KG - \frac{T}{2}\right) = \frac{0.127\Delta}{L} \cdot \left(KM - GM - \frac{T}{2}\right)$$

$$M_T = \frac{0.127\Delta}{L} \cdot \left(KB + BM - \frac{T}{2}\right) - \frac{0.127\Delta}{L} \cdot GM$$

By taking $KB = \frac{T}{2}$, therefore

$$M_T = \frac{0.127\Delta}{L} \cdot \left(BM - GM\right) = \frac{0.127\Delta}{L} \cdot \left(\frac{I_T}{\nabla} - GM\right)$$

By taking, for box vessels,

$$I_T = LB^3 / 12 \quad \text{and} \quad C_B = 1.0$$

Therefore,

$$M_T = 0.01 B^3 - \frac{0.127\Delta}{L} \cdot GM \qquad (A1.3)$$

4. Maximum permissible angle of heel θ_m

The maximum permissible angle of heel θ_m is limited in this criterion to 80% of the freeboard making a certain allowance for other effects, therefore

$$\text{Tan}\ \Theta_m = \frac{2\left(0.8 F_B\right)}{B} = \frac{1.6 F_B}{B} \qquad (A1.4)$$

5. Critical value of the metacentric height

By substituting from the above four factors into the following equation:

$$GM_{crit} \geq \left(M_W + M_T + M_P\right) / \Delta \tan\theta_m \qquad (A1.5)$$

Therefore, the critical value of the metacentric height (GM_{crit}) will be in the following form:

$$GM_{crit} \geq \frac{\left(0.055 A_P Z_W + 0.0375 nB + 0.01 B^3\right)}{\left(1.6 F_B \cdot L + 0.127 B\right) T}$$


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