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Grounding of a Membrane Tanker; Correlation Between Damage Predictions and Observations

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ABSTRACT

The paper gives a description of the damages suffered by a fully loaded 130 000 m^3 LNG carrier of the Gaz Transport membrane system type after grounding at high speed on a rock. It is the first time that enough precise data were available on a real grounding to allow a correlation between a theoretical method and the observed damages. Very few studies on grounding damage estimations exist. The Vaughan and basic Minorsky methods of predicting such damages retain the Authors' attention and are then presented. Both methods are applied and it is shown that the adaptation given by Vaughan appears adequate to such an accident analysis. The analysis also shows that, the shock was very strong and a large energy was dissipated to stop the ship. The membrane containment system suffered some large deflections but remained perfectly tight and the cargo was transferred some days later to a sister ship in perfect safe conditions.

1 INTRODUCTION

The rapid development of the transportation of hazardous cargo has increased interest in prediction methods of the estimation of damage due to possible collisions or groundings.
A large number of papers have been published on this subject during recent years and most of them are based on modifications or extensions of the Minorsky method [1, 2] . A extensive review of the methods has been performed and published in 1979 by S.S.C. [3, 4] .

One of the hazardous cargoes for which transportation methods have shown a large development is Liquefied Natural Gas. Thus some publications deal with damage estimations after collision or grounding of LNG tankers [5, 6, 7, 8,] , and seem to create some doubts about their safety and particularly for the membrane type.

An accident which occurred in 1979, the grounding of a 130 000 m^3 LNG tanker represents a very similar case to those of theoretical studies which have been considered to set up the previsional method which is described in paper [5] . Also it occurs that the available data on this case, i.e. navigation conditions and damage extension are very precisely known[9].

It therefore appeared interesting to try to perform a correlation analysis between the application of the original Minorsky method[1] , the Vaughan method [5, 6] and the actual observations.

The aim of this paper is then :

- to give a description of the observations,
- to present the damage estimation methods,
- and to analyse the results of their applications.

2 DESCRIPTION

The ship of interest, "El Paso Paul Kayser", is a Gaz Transport membrane LNG tanker of 130 000 m^3 class built in France Dunkerque Shipyard (Figure 1).

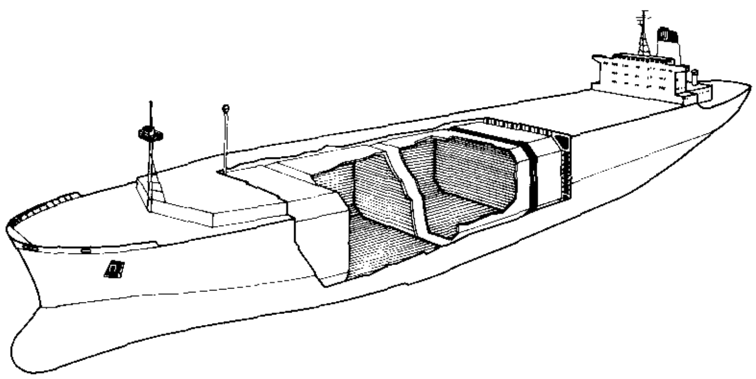

Fig. 1. General view of a membrane LNG carrier

She was operating between Algeria and U.S.A. The grounding occurred during a voyage from Algeria to U.S.A. the ship was fully loaded at the moment of the accident and the ship speed has been found to be about 18 knots [9] .

The grounding occurred in July 1979 on the Spannish Coast near Gibraltar on a rock called "La Perla". During the grounding, the hull was crushed by the upper part of the rock, and the ship remained stranded on the rock as shown in Figure 2.

After dismounting the primary membrane, there was noted :

- . a heavy deformation of the secondary membrane,
- . a partial crush of the insulation,
- . a large deformation of the stainless-steel corner piece (Figure 5).

After drydocking the ship, the surprises were greater.

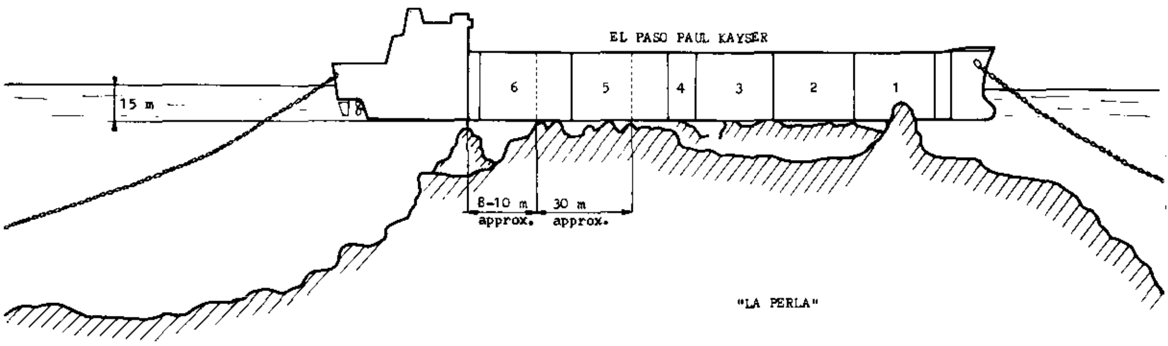

Fig. 2. View of the "Paul Kayser" ship and "La Perla" rock after the grounding

Although the shock was tremendous ; absolutely no leak was detected either in the membrane of the tank or in the double hull of the ship. So it was decided to float the ship by introducing compressed air into the damaged ballast tanks.

After this operation, the cargo was transferred at sea to a sister ship by means of flexible nose under the control of the Owner, Engineering Gaz Transport and the Classification Society.

The ship was then escorted to Lisbon for a preliminary survey and subsequently to Dunkirk for repairs.

After unloading the ship and reheating of the tanks, a survey was performed. This visit showed primary membrane deformation in two tanks, tank number 1 and tank number 2.

. In tank number 1, the corner between the bottom slope and tank bottom was pushed inside the tank. The amplitude was of 110 mm at the center of an area of 3 m length and 1 m breadth (Figure 3).

. In tank number 2, a bottom corner was pushed inside the tank. The primary membrane showed a deformation of some 60 mm on the corner over an area of 5 m length and 3 m breadth (Figure 4).

These deformations without rupture nor leaks in the membrane are an interesting confirmation of the Invar elongation capability (40 % at - 196°C at rupture) and of the results of performed tests on Laboratories at scale one with insulation - membrane panels.

The tests show a possibility of deflection of about 2 m on a tank length (about 25 m) without membrane cracks.

Fig. 3. Photograph of bottom primary membrane deformation in tank number 1

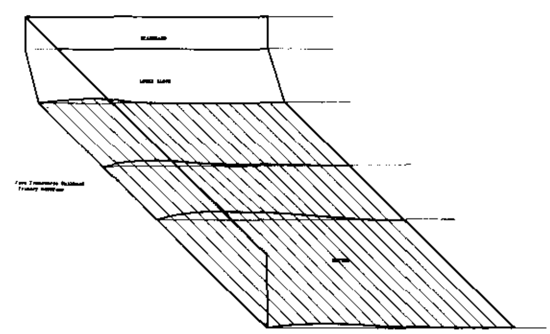

Fig. 4 Sketch of bottom primary membrane deformation in tank number 2

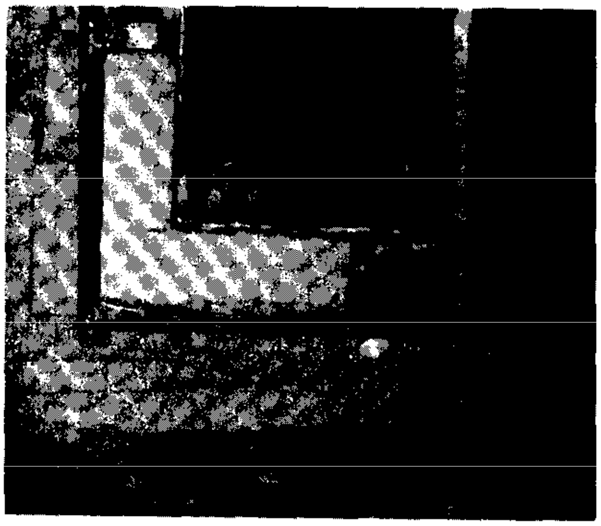

Fig. 5. View of the primary chair and secondary membrane in area of deformed double bottom

The extent of hull damage was particularly important, extending from the fore peak to the aftermost cargo tank (Figure 6).

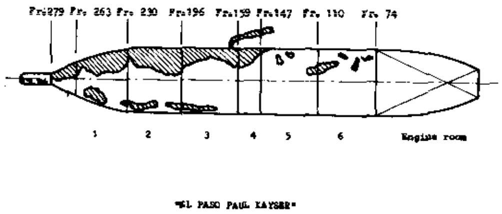

Fig. 6. Sketch of the damaged hull area in ship bottom

Also the importance of the damages was unexpected and showed a large capability for resistance of the ship. Views 7 and 8 give an idea better than words.

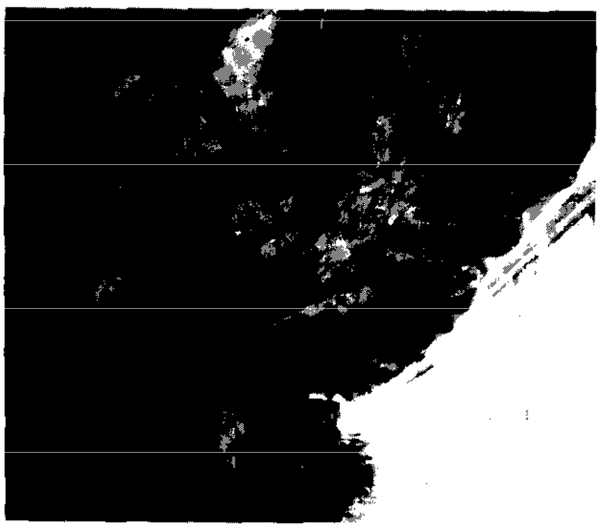

Fig.7. General view of hull damages

The repair of the hull, which was performed by France Dunkerque Shipyard, leads to a steel renewal of about 800 tons.

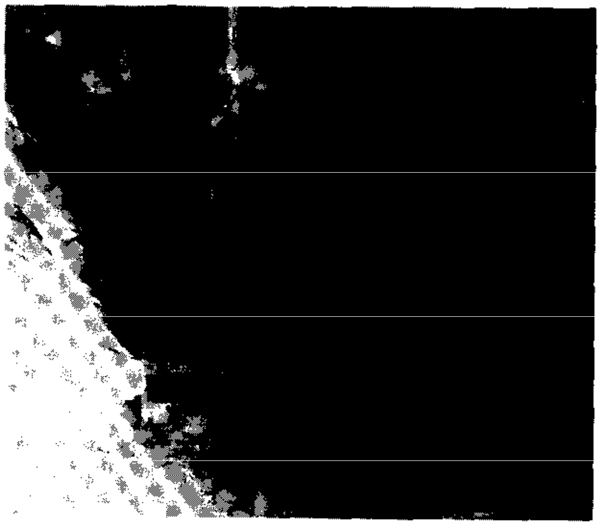

Fig. 8. Local view of crushed bottom plates

3 PREDICTING METHODS

Due to the precision of the available data on this grounding, it appeared interesting to try to apply predicting methods.

Concerning grounding, fewer publications than for collisions exist and an adaptation of the Minorsky method given by Vaughan [5, 6] was considered.

At the same time, we considered it interesting to apply the original Minorsky method [1].

Before giving results, the main lines of the two methods are summarised.

3.1. Minorsky's method

The basic method for global calculation of collision damages remains the well-known Minorsky formulation developed in 1959.

The method is based on the calculation of the volume of damaged metal of the structure and a relation between this volume and the corresponding absorbed energy.

The formulation is given by the following equation :

$$E = 176\ R + 121\ 900 \text{ tons-knots}^2$$

where :

R, the resistance factor, is calculated based on the following structural members :

- decks, flats and double bottom in both struck and striking vessels,
- transverse bulkheads, in the struck vessel - when hit squarely-,
- longitudinal bulkheads, in the striking vessel,
- the component in the direction of collision of the shell of the striking vessel (assumed at 0.7 of shell area).

The coefficients have been calculated from experimental data and analysis of damages observed on real collisions between ships.

$$R = \Sigma P_N L_N t_N + \Sigma P_n L_n t_n \quad m^2 x \ mm \qquad (1)$$

where :

- P_N, P_n (m) are the depth of damage in Nth and nth structural members of striking and struck ships respectively,
- L_N, L_n (m) are the length of damage in Nth and nth members of striking and struck ships,
- t_N, t_n (mm) are the thickness of Nth and nth members of striking and struck ships,
- R is therefore the volume of damaged metal, consisting of the sum of the individual resistance factors of the colliding ships.

On the other hand, the Kinetic energy loss can be calculated from the velocities and masses of both striking and struck ships from the conservation of the momentum :

$$\vec{V} (M_1 + M_2 + m) = M_1 \vec{V}_1 + M_2 \vec{V}_2 \qquad (2)$$

where :

- M_1, $\vec{V}_1$ mass and velocity of striking ship,
- M_2, $\vec{V}_2$ mass and velocity of struck ship,
- $\vec{V}$ final common velocity,
- m added mass,

the kinetic energy at the end of the impact is :

$$1/2 \ (M_1 + M_2 + m) \ V^2 \qquad (3)$$

Assuming a penetration normal to the struck ship, the component of $\vec{V}_2$ in that direction is 0.

Hence :

$$V = M_1 \ V_1 \ / \ (M_1 + M_2 + m) \qquad (4)$$

and the energy absorbed by the two ships is :

$$E = 1/2 \ M_1 V_1^2 - 1/2 \ (M_1+M_2+m) \ \left(\frac{M_1}{M_1+M_2+m}\right)^2 V_1^2 \qquad (5)$$

considering :

$$\mu = \frac{M_2 + m}{M_1} \qquad (6)$$

$$E = 1/2 \ M_1 \ V_1^2 \ \frac{\mu}{\mu + 1} \qquad (7)$$

according to Minorsky, the added mass can be taken approximatively as 0.4 M_2.

So :

$$\mu = 1.4 \ \frac{M_2}{M_1} \qquad (8)$$

which leads to the following expression :

$$E = \frac{M_1 \ M_2}{1.43 \ M_1 + 2 \ M_2} \ V_1^2 \qquad (9)$$

As shown in Figure 9, Minorsky's formula gives a fairly consistent correlation for high energy collisions.

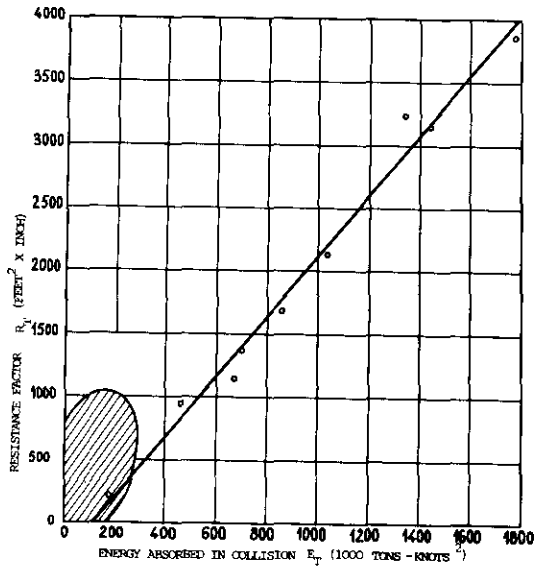

Fig.9. Minorsky curve which defines the absorbed energy, resistance factor relationship

For grounding the formula can be used with $M_2 = \infty$, so the formula becomes :

$$E = \frac{M_1}{2} \ V_1^2 \qquad (10)$$

3.2. Vaughan's method

Vaughan's method is derived from that of Minorsky and is presented in references [5, 6].

This method is given to be used in cases for which Minorsky's method does not appear adequate, in particular for a grounding on a sharp rock.

The damages are then, mainly localized in the hull plate presenting large tearing associated with crushed structural elements.

The absorbed energy in tearing of the structure is estimated by considering a plate cut as shown in Figure 10.

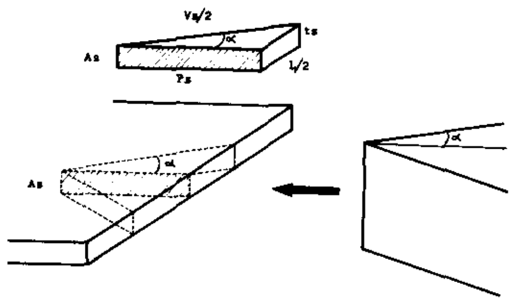

Fig. 10. Basic definition of the parameters used by the Vaughan method.

It is assumed that the necessary energy to allow the angle penetration is given by two independent parameters :

- to tear or fracture the plate,
- to push aside the material.

The dimensional analysis leads to the formula :

$$w_s = \bar{a} \; A_s + \bar{b} \; V_s \qquad (11)$$

where :

A_s total area of the crack,

V_s volume of crushed metal.

The coefficients $\bar{a}$ and $\bar{b}$ are obtained by an analysis of the Minorsky formula and results published by Akita Y. and Kitamura Ke [10] .

To determine the coefficient, Vaughan analysed the results of [10] taking into account two parts for the absorbed energy,

. the energy given by the crushed bow of the striking ship,

. and the length of penetration in the side shell of the struck ship.

$$P = P_s + P_b \qquad (12)$$

where :

P total penetration,

P_s penetration in struck ship,

P_b crushed length of the striking ship.

Then the energy and the Minorsky coefficient R are calculated only for the struck ship.

For the angle penetration, the value of R can be obtained by the following formula :

$$R = P_s \; L_s \; t_s = 2V_s \qquad (13)$$

where :

L_s damage length

P_s damage depth

t_s plate thickness

Then the energy obtained by both formulas, angle penetration and Minorsky leads to :

$$b \; V_s = 176 \quad 2 \; V_s \qquad (14)$$

Now by expressing the total energy, the value of a can be calculated and leads to the following formula :

$$w_s = 352 \; V_s + 126 \; A_s \qquad (15)$$

where :

V_s crush volume in m^2.mm

A_s tearing area in m.mm

w_s energy in ton.knots^2

A_s is calculated as the section of the torn plates in the direction of the damage length,

V_s is the volume of the longitudinal elements which are compressed during the damage.

For example, transverse rings are not taken into account.

4 RESULTS AND ANALYSIS

From the drawing of the damaged area, given by the Shipyard and Engineering, the various parameters which enter in the formulae have been calculated [11] .

The Figure 6 gives a sketch of the damage area. On port side the torn plates extend from section 281 to section 84 on a length of about 185 m. From section 281 to section 215 on a length of 60 m, the plate thicknesses are 21 and 26 mm. From section 215 to section 89 the plate thickness is 20 mm.

On starboard side few plates are torn. It was observed between section 281 and section 230 a length of about 25 m of plates of 16 mm and aft of the section 230 a length of about 42 m of plates of 20 mm.

A delicate calculation, the detail of which is out of the scope of this paper, leads to the following values :

. total crushed elements volume : 49.84 m^3

. total torn plate section...... : 5.144 m^2.

From the given formulae, the corresponding energy has been calculated for the two methods :

. Vaughan

$$E = 352 \times 49840 + 126 \times 5144 = 18191824 \text{ t.kn}^2$$

. Minorsky

$$E = 176 \times 49840 + 121900 = 8893740 \text{ t.kn}^2$$

The displacement of the ship, which was fully loaded in the departure condition was :

M = 98 000 t.

It is then possible to estimate the corresponding ship speed :

$$V = \left(\frac{2\,E}{M}\right)^{1/2}$$

or :

. Vaughan :

V = 19.3 kn

. Minorsky :

V = 13.4 kn.

One can note that the value given by Vaughan method gives the best correlation with the actual known data.

The calculation shows that with the Vaughan method the part of energy absorbed by tearing is low, when compared to the part absorbed by the crushing of plates. The energy absorbed by tearing is only 3.6 % of the total energy. The Minorsky method considers only crushed plates, so the difference between the two results comes from the different coefficients used to calculate the energy absorbed from the crushed volume of plates.

The simple application of the Minorsky method leads to an underestimation of the energy absorbed by the damaging of the structure.

Thus the modification introduced by Vaughan appears adequate in such a case of grounding.

The study has been limited to a correlation between theory and observed data.

It allows the checking of the accuracy of the method and the coefficient used in the equation. It was not intended to predict in this analysis, the damage from the ship speed. In such a case the main difficulty comes from the necessary assumptions about the shape and extent of the expected damage area. It can be seen that this type of damage prediction, based on global energy calculation, presents difficulties when used.

5 CONCLUSION

The use of the Vaughan method of damage estimation after grounding on sharp rock applied to the actual case suffered by the "Paul Kayser" LNG carrier, shows a good correlation.

This method seems adequate to study damage in which a large amount of energy is absorbed by structural deformation and plate tearing.

So in the case of much plate tearing, the Minorsky method seems to underestimate the energy absorbed by the crushed structure.

If used for prediction, for example possible damage for a given ship speed, one will face some difficulties in defining the necessary assumptions, relative position of the ship and the rock, and expected extent and shape of the damaged area.
But the method presents the advantage of being easily handled to require only un-sophisticated means. It can thus be used at design stage to compare various structures or structural disposition facing the same typical accident.

The analysis of the accident also showed that the grounding was of high energy type, with very extensive damage, and in spite of the hardness of the shock, the membrane containment system remained perfectly tight without any release of cargo and allowed salvage without any troubles.

This example can be added to the other known casualties which show that a double hull presents a good level of safety with respect to grounding.

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