Anatomy of a Capsize: Then and Now

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Abstract

Capsizing of a ship is always a tragedy no matter what the magnitude might be. This paper deals with capsizing of a small size LPG tanker. Stability of the tanker has been analyzed by considering various aspects of stability qualities of it. Different loading conditions were taken into account to determine the effect of displacement and center of gravity variations on stability. Dynamic stability of the ship has also been looked at and compared with the international rules and regulations. The analyses and accidents reports carried out by the panel of experts following the accident were repeated. Possibly causes of the incident were investigated and some comments and suggestions were made. This work also gives us the opportunity to compare the technology of late 60's and today in terms of accuracy and capabilities.

1. Introduction

A small size LPG tanker was found in a capsized position by a Danish ship near Calamata bay off the coast of Mora Peninsula in the Mediterrenean sea on March 25, 1969. Seventeen people perished in the tragic accident. A committee which was composed of experts was established to investigate the accident and asked to prepare a report on the possible causes. There was an eye witness from the crew who survived the incident. His testimony helped the panel to understand the situation and chain of events leading to and during the accident. Although the ship complied with the current stability criteria of IMCO, it still capsized like many other incidents in the history of seafaring.

The tanker had no cargo at the time of accident. The accident occurred on March 24, 1969 at 4:05 AM in a 6-7 Beaufort sea state from NE. The ship was said to be sailing westward in following waves at about 10.5 knots. The capsize took about two minutes without wild rolling. The roll period was claimed to be long and roll motion was slow.

Engineering and construction technology 36 years ago was quite different then today's technology. Engineers used integrators and planimeters to carry out cumbersome engineering calculations. Some of the work carried out by engineers and the effort put into this work seems amazing. Thus, examples of grueling and painstaking effort spent back then during the design and accident investigation process are given throughout this paper just to show the technological development and Same calculations were repeated by using suitable computer programs in this work.

2. The Tanker

The LPG tanker was launched in 1966. The main dimensions of the ship are given below:

Length overall	L_{OA}	= 61.05 m.
Length between perpendiculars	L_{BP}	= 55.5 m.

Breadth	B	= 9.0 m.
Depth	D	= 4.25 m.
Draft	T	= 3.10 m.
Displacement tonnage	Δ	= 1122 tons
Cargo capacity		= 800 m^3
Service speed	V	= 10.5 kn.
Class	ABS	
Main engine	800 HP 375 rpm MWM 6 cylinder diesel	

The tanker had 6 liquid gas tanks located in the fore and aft cargo holds as shown in Fig.1. Body plan of the tanker is shown in Fig.2.

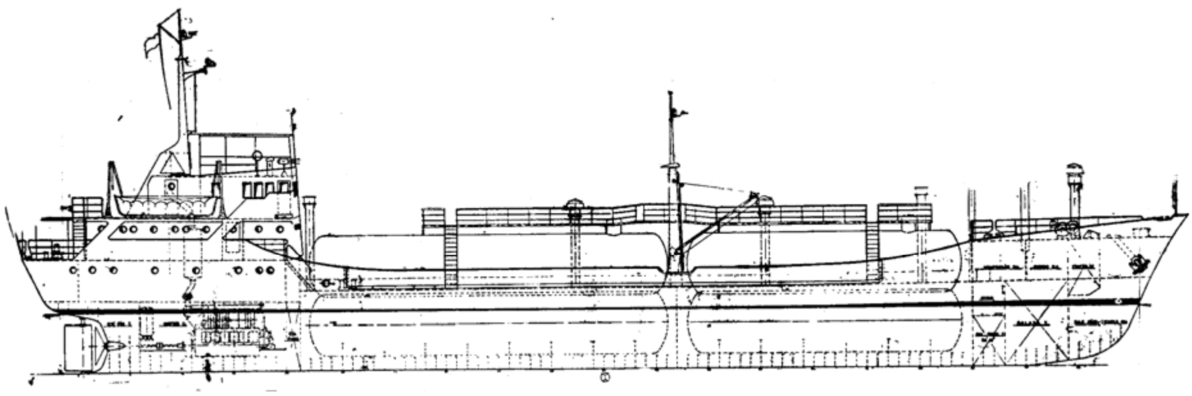

Fig.1. General arrangement of the tanker [2].

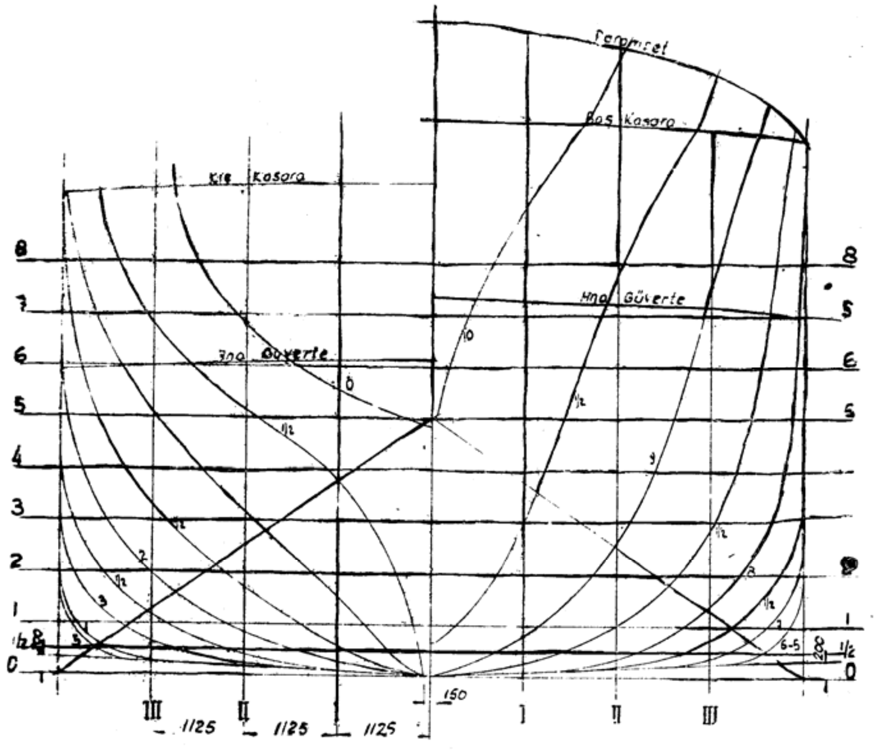

Fig.2. Body plan of the tanker [2].

3. The Accident According to the Witness Statement

Unfortunately, the tragic accident claimed 17 lives. There was only one survivor from the capsized boat. His statements about the condition of the ship, environmental conditions and events leading to capsize at the time of accident were precious and only evidence for the investigators, engineers and scientists. Based on the available data and his information, engineers were able to simulate the conditions and try to answer the questions raised by the incident.

Weather report from the Maltese meteorological authorities indicated that the wind was 3-4 Beaufort from SE on the night of March 23 around 18:00 hours, but increased its speed to 5-6 Beaufort until 6:00 hours from East and to 6-7 Beaufort at the time of accident. The corresponding wave conditions can be estimated as follows, Table 1;

Table 1. Wave conditions at the time of accident.

Beaufort Scale	Wave speed (kn)	Wave period (sec)	Wave length (m)	Max. wave height (m)	H/L
6	21.7	7.2	80	5.34	1/15
7	26.9	8.9	123	6.62	1/18

Loading condition of the ship when it capsized was determined by the witness testimony as:

Δ = 752.32 tons.
KG = 4.037 m.
LCG = 0.76 m. (fwd, from amidships)
V = 10.5 knots

The tanker had no cargo, the ballast and fore peak tanks were full. The details of the loading condition are given in Table 2;

Table 2. Loading details at the time of the accident.

Tanks	**Weight (tons)**	**VCG (m)**	**LCG (m)**
Lightship	642.18	4.13	25.45
Fore peak tank	18.00	1.93	53.30
Ballast tank	62.00	2.90	50.00
Fwd Fuel tank	19.50	2.00	47.50
Aft fuel tank	6.00	2.25	11.10
Fuel service tank	0.50	4.50	8.00
Lube oil tank	0.70	1.20	9.80
Stores	2.00	4.60	1.80
Crew and effects	1.44	4.55	27.00
TOTAL	752.32	3.93	28.51

Note: LCG is taken from AP.
Free surface correction : 0.107 m.

As was mentioned earlier, it was claimed that the ship heeled very fast (about 2 minutes) and didn't experienced rapid roll motion with long periods. The witness further claimed that there was no water entered the deck.

4. Stability of the Tanker in Calm Water

The tanker complied with all the IMCO stability standards based on SOLAS 1966;

a. the area under the GZ curve should be 0.055 m.rad up to 30^0 and 0.090 m.rad. up to 40^0
b. GZ > 0.20 m. for $\varphi = 30^0$ or more
c. Maximum GZ value should preferably occur at 30^0 of heel but should not occur less than 25^0
d. Initial metacentric height GM > 0.15 m.

In the design stage, five different loading conditions were considered, Table 3. GZ Curves for the loading conditions in Table 3 are given in Fig. 3.

Table 3. Various loading conditions of the tanker.

Cond. No.	Loading condition	Displacement (tons)	VCG (m)	LCG (m)	GM (m)
1	Lightship	604.07	3.74	25.15	1.23
2	Half load (lower tanks)	778.98	3.30	26.62	1.00
3	Half load (upper tanks)	707.08	3.83	26.16	0.72
4	Full load (upper tanks)	809.64	3.96	27.39	0.35
5	Full load (all tanks)	1126.97	3.53	28.28	0.46

Note: LCG is taken from AP.
GM values are corrected for free surface effects

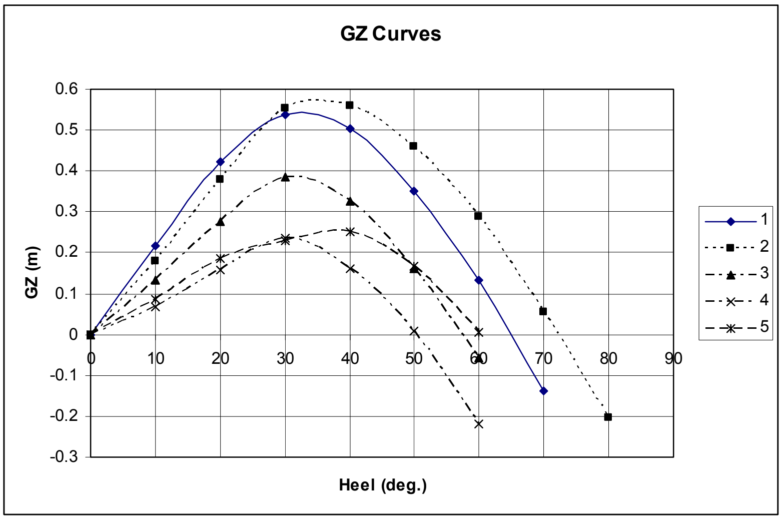

Fig. 3. GZ curves for 5 different loading conditions.

From Table 3 and Fig. 3 it is seen that the tanker satisfies IMCO stability standards.

5. Stability of the Tanker in Waves

Although stability of the tanker complies with the IMCO standards, it is stability in waves needs to be checked since it was in rough seas at the time of capsize. For this reason IMO weather criterion was applied to the above-mentioned loading conditions. Windage areas and wind heeling moments were calculated in advance in order to perform the computations, Table 4. Wind speed and pressure are chosen for 6-7 Beaufort wind (25 knots wind speed). Roll period is calculated to be 10 seconds and roll angle 23 degrees from the formulation in the regulation.

Table 4. Wind projection areas and heeling moments.

Cond. No.	**Loading condition**	**Mean draft (m)**	**Area (m^2)**	**Lever (m)**	**Moment (t.m)**
1	Lightship	1.86	432	4.83	213
2	Half load (lower tanks)	2.28	409	4.83	201
3	Half load (upper tanks)	2.11	418	4.83	206
4	Full load (upper tanks)	2.36	404	4.83	199
5	Full load (all tanks)	3.10	363	4.83	178

By using a suitable computer software which is able to calculate stability in waves, the following results may be obtained, Table 5;

Table 5. Stability in qualities in waves.

Cond. No.	**Loading condition**	**List angle (deg)**	**IMO reguirement**	**Pass/ Fail**
1	Lightship	15.16	16.0	P
2	Half load (lower tanks)	13.28	16.0	P
3	Half load (upper tanks)	18.75	16.0	F
4	Full load (upper tanks)	24.53	16.0	F
5	Full load (all tanks)	15.63	12.60	F

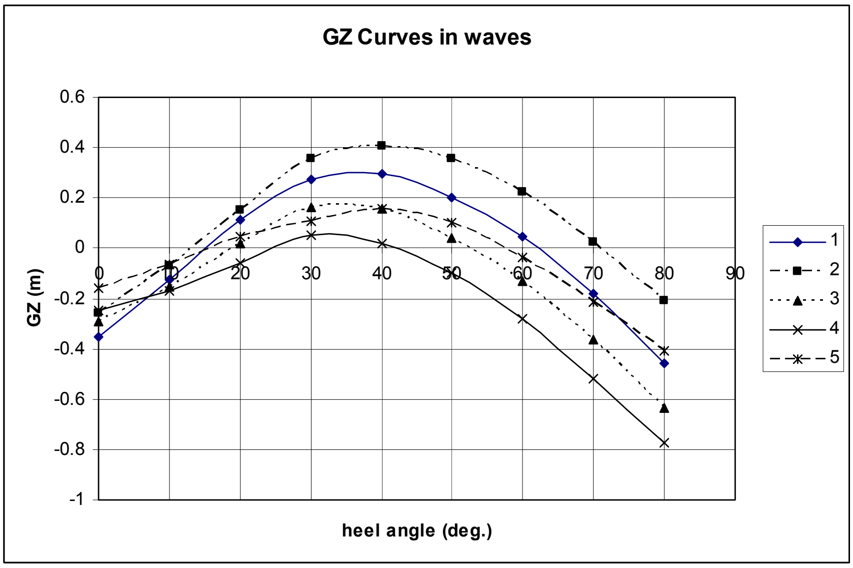

Fig. 4. residual GZ curves in waves.

When the requirements of weather criterion are compared with the results in Table 5, it is seen that although all of the cases met the roll area requirement, three of the cases, loading conditions 3, 4 and 5, failed to meet list angle requirement. That means, the tanker was not fully in compliance with the IMO weather criterion.

6. Capsize Condition

As was mentioned earlier, all the simulation about the state of the environmental and ship loading conditions are set up based on the witness statements. Thus, the loading condition details, which may be described as ballasted lightship condition, were given in Section 3. Same stability analysis in calm water and waves was repeated for the capsize condition. During the accidents investigation, there appeared a suspicion about the lightship values of the vessel and another inclining experiment was conducted. This time lightship values were found different than the initial values, Table 2. Therefore, stability calculations were repeated for the original and new lightship characteristics.

Stability of the tanker in calm water complies with IMCO stability criteria for both original and new KG values. However, when it comes to stability in waves, list angle for the new KG fails to satisfy the criteria, while the original KG barely passes it, Table 6. Corresponding righting arms curves for two different KG values as plotted in Fig. 5.

Table 6. Stability qualities in waves for the capsize condition.

VCG (m)	List angle (deg)	IMO regiurement	Pass/ Fail
Original	15.391	16.0	P
New	21.953	16.0	F

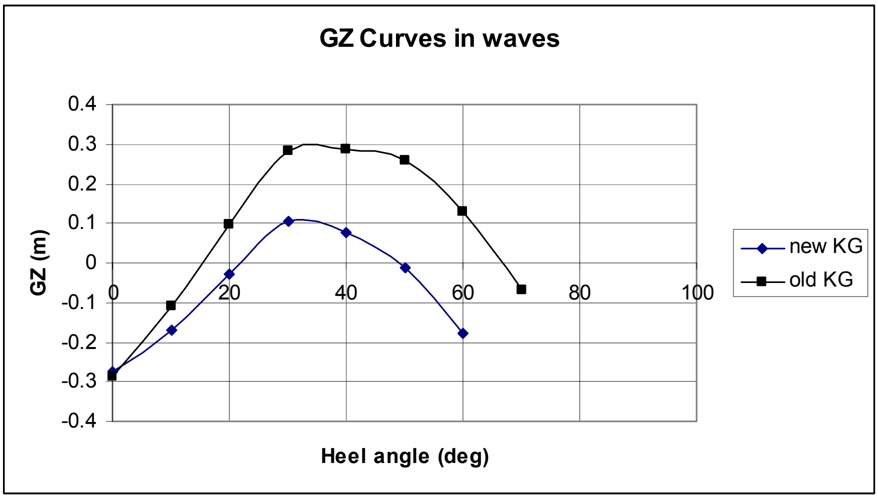

Fig. 5. Residual GZ curves in waves for old and new KGs.

Based on the information supplied by the eye witness of the accident, simulations are carried out for two different disputed KG values of the tanker. Although the tanker met the weather criterion for its original KG value, it is obvious that the tanker doesn't have reserve stability margins to overcome excessive heeling forces.

Another aspect of the capsize is the lost of stability especially on wave crest. It was found that the stability is reduced greatly on wave crest with compared to calm water stability. Furthermore, since the ship was sailing in stern quartering seas, broaching phenomenon may likely to be observed. Due to space and time limitations, thorough stability analysis of the tanker in waves considering broaching possibility and nonlinear effects is left to future research.

7. Technology: Then and Now

This capsize incident may be viewed from different perspectives. From the engineering point of view, the causes of the accident were investigated by the panel of experts of the time. They included the outcome of their work and investigation in the official report.

Most of the time, it looks like an ordinary accident to many people. But when we step back and think about the engineering and shipbuilding technology of those day, we cannot refrain ourselves to admire what they had achieved with limited resources and equipment. An excerpt is quoted from [1] just to reveal the difficulty they have faced for the tasks which is a keyboard button away from us today: "*We have performed three and a half month of integrator work to calculate GZ curve of the tanker on a 7 Beaufort state wave crest from KR values for the loading condition and KG value at Ship Institute in 1969. In early 1971, we calculated GZ curve of the vessel on a 6 Beaufort state wave crest whose length is equal to the ship length*". Despite all the hurdles and difficulties, it is amazing to see the accuracy of the results when compared to computer simulations. Similar difficulties were faced in construction process as well.

Similar remarks may be made for the evolution of stability and safety standards dating back to mid eighteen century. It is a continuing process and there is no end to it.

8. Conclusions

In this work, anatomy of a particular capsize phenomenon of a LPG tanker has been analyzed in terms of technical details of the incident and other influencing factors such as technology and existing conditions. Comparable capsizing events in those days can be found in literature in similar conditions. Main focus of this work was not so much to answer all the questions behind the capsize incident, but also to draw attention to technological evolution in ship science and engineering and the response of International organizations such as IMO and classification societies to this evolution.

Accidents and mistakes cannot be ruled out hundred percent since there is human factor in it. The important thing is to learn from these mistakes and to minimize them. In fact, these type of an accidents offer scientists plenty of subject and food for thought to work on and find solutions to possible problems. It is the authors belief that, technological and scientific improvement can only be sustained by learning lessons from the past and pursuing the unthinkable.

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