Journal of
Fundamentals of Renewable Energy
and Applications

Gorlov, J Fundam Renewable Energy Appl 2014, 5:1
DOI: 10.4172/2090-4541.1000147

Review Article **Open Access**

Some Speculations about the Capsizing of the Sewol Korean Ferry

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Abstract

The sinking of the South Korean ferry Sewol occurred on April 16, 2014, en route to Jeju Island from Incheon. The ferry, carrying 476 people, mostly school students, capsized and sank not far from Jindo Island. It appears that most of the passengers perished in this tragic accident. In the following article we are trying to reveal what actually caused the capsizing and could have been a possibility to save the ship.

Keywords: Korean ferry sewol; Kinetic energy

Introduction

Many experts are studying and discussing various aspects that might have caused the catastrophe. The author is familiar with the site where it happened near the Jindo Island, which is characterized by very strong ocean currents, suitable for the harnessing of kinetic energy by floating turbines. The author helped to introduce this technology into Korea in 1999 and later (see the Attachment). Helical turbines of the author's invention were installed, generating energy from the tidal currents in Uldolmok Strait.

Discussion

To our knowledge, the problem with the instability of the ferry only appeared when it approached the region of high lateral currents mentioned above. Before that, it had sailed for several hours from the port of Incheon without any warning signs of the possibility of tilting. This leads us to conclude that the ship was quite well balanced during the first part of the journey from Incheon to the site of capsizing. What could have happened to destabilize it? To answer this question, let us consider the simplified Free Body diagrams, illustrated in Figures 1 and 2. We employ these to designate the principal external forces which affect the ship's tilting in the worst case scenario–– when wind and ocean currents are in opposite directions. Figure 1 demonstrates the loading conditions just before the ship begins to tilt. Figure 2 shows all the forces at work when the ship is tilting. The designated positions of center of gravity (CG) and center of tilt (CT) are reasonable assumptions of what would occur at the instant of catastrophe.

1. We first consider the lateral pressure on the underwater part of the ship from the ocean currents. The resultant force of that pressure can be calculated as a drag force equation:

$$P_s = 0.5\ C_d \rho\ A\ V^2 \tag{1}$$

where C_d (= 2.0) is the drag coefficient for a long rectangular vertical barrier, ρ is the saltwater density, A (= 918 m^2) is the frontal underwater surface area of the hull, and

V (= 2.2 m/s) is the water velocity.

After substitution, we get the lateral resultant P_s = 453 metric tons, which should be one of the major force factors causing an initial inclination of the ship. Note, that the 453 tons of pull is much greater than a dozen modern railroad locomotives can derive in chain.

2. The superstructure is loaded by pressure P_w from strong wind gusts, which might act opposite to the water stream direction in our assumed reconstruction of the worst case scenario. P_w is calculated by the same drag formula (1). It appears that the resultant force of a 40 km/h wind gust on the frontal wall of the superstructure might be about 80 tons.
3. The combined forces of current (P_s) and wind (P_w) develop an initial moment about the center of tilt at the ocean surface (point CT) of M ≈ 1,800 to 1,900 ton-meters. This total moment is the principal factor strong enough to force the ship to start leftward tilting as the first stage, preliminary to completely capsizing. The tilting accelerates under the influence of new forces that come from the weight of the cargo, consisting of a centrifugal force F_c and the vertical downward weight of the cargo W = 3608 tons (cars, trucks, containers, etc) generated at the Center of Gravity, displaced by initial tilting (Figure 2).
4. Soon after entering the area of high lateral water velocities, the ship performed a sharp right turn, followed by a single loud 'bang'. The 'bang' is assumed to be caused by a part of the cargo, perhaps a truck, that broke loose from the holding straps when the centrifugal force appeared. Some people have attributed the entire capsizing to that sharp turn of the ship which caused the centrifugal force F_c that possibly displaced part of the cargo.
5. However, we are not sure that the centrifugal (inertial) force $F_c = m\ \omega^2\ R$ (mass x angular velocity squared x radius of curvature) is a substantial component of the twisting moment M, which actually forces the vessel to incline, since F_c acts perpendicularly to the hull, and is located at the same level as the center of cargo gravity which is near to the ocean surface. In other words, F_c itself cannot develop substantial leverage as an addition to the twisting moment M. Also, the mass m of the displaced part of cargo (that "bang" that was heard) remains unknown, thus excluding the possibility of calculating a precise value for the centrifugal force. Nevertheless, we understand that the force F_c contributed to the displacement of a part of the cargo W, although it cannot have been large enough to critically change the rocking moment M.

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Received August 07, 2014; **Accepted** December 04, 2014; **Published** December 12, 2014

Citation: Gorlov A (2014) Some Speculations about the Capsizing of the Sewol Korean Ferry. J Fundam Renewable Energy Appl 5: 147. doi: 10.4172/20904541.1000147

An additional unfortunate factor to be considered is that the water ballast stored in the bottom of the hull was partially discharged before the start of the voyage to allow for the loading of more cargo above. This unavoidably raised the ship's center of gravity CG, contributing to a reduction in its stability when it encountered the high underwater lateral current pressure [1-3].

Effect of Dynamics

Dynamics might play a critical role in the calculation of the resultant lateral pressure on the underwater part of the vessel in this analysis. Indeed, Equation (1) describes the static lateral pressure as the drag force resistant to the water flow.

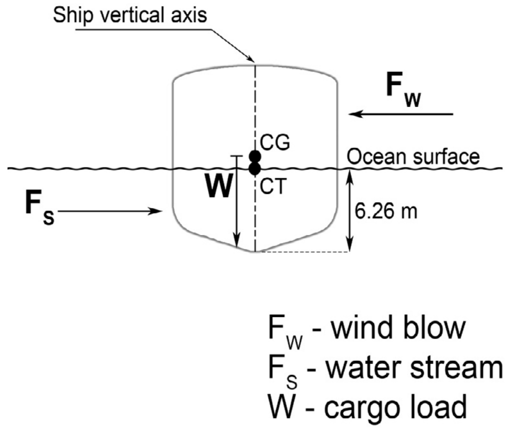

Figure 1: Load before tilting.

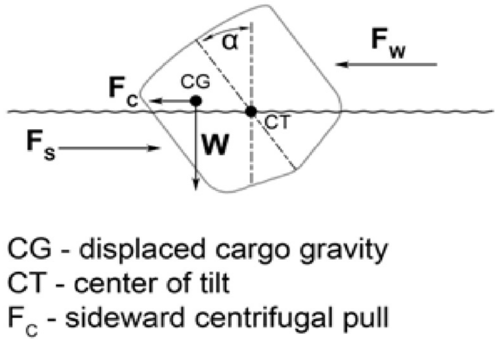

Figure 2: Beginning of ship tilting.

Figure 3: Discussing current strength at Garorim Bay in Tae-an Peninsula, May 29, 1999. (Author is second at left).

Meanwhile, a fast moving ship with a speed of more than 21 knots (about 11 meters/sec) needs just a few minutes to appear in the region of 2.2 m/s lateral water stream, creating a sort of barrier for the free water flow. This would require including the added mass of water displaced by the ship into the calculation of the lateral resultant force on the underwater part of the vessel, a huge mass of water contained in the approximate volume of $(22 \times 6.26 \times 146.61)$ m^3.

The added mass means, in our case, introducing the shock impulse G = m(dv/dt), or roughly m(V/t) , where V is the resultant vector velocity of the 2.2 m/s (current) and the 11 m/s (vessel speed) appearance an instantaneous sideward hydraulic impact on the underwater part of the ship. It is analogous to the lift on an airplane wing. Also, the smaller is dt in the expression dv/dt the grater is impulse G.

But there is no reason at this stage to proceed with further calculation of the shock impulse, as it obviously would increase substantially our previous static figure of 453 metric tons from Equation (1). This figure is convincing enough for initial ship inclination. A more precise dynamic calculation is also not possible, because of uncertainty as to the new location and mass of the displaced part of the cargo weight W.

The effect of ocean waves is left untouched in our study because of its uncertainty at the moment. However, this factor should also be investigated in future as an important contributing factor in the catastrophe.

Conclusions

1. From the foregoing analysis, and specifically the effect of the shock impulse, we learn that the vessel, at least, must be immediately brought to a stop when the first signs of tilting appear to eliminate that shock impulse. Unfortunately, it looks like nobody on board the ship understood the physical phenomenon of what was going on. Under the circumstances, neither the captain nor crew could prevent the inevitable capsizing, except, possibly, by turning the vessel to the left, towards the direction of the current flow (see the note below).
2. We are sure that the initial inclination of the ship that finally led to its capsizing was caused primarily by the lateral pressure of the current on the submerged parts of the ship. This inclination most likely triggered a displacement of the cargo, moving weight W far to the left (Figure 2).
3. The change in position of the center of gravity (CG) of the displaced cargo accelerated the tilting of the ship, as a result of the huge moment M which is increased by weight (W) produced about the point CT.
4. A new dynamic factor, namely the Shock Impulse G = mV (mass of displaced water times the resultant vector of 2.2 m/s current velocity and ~ 11 m/s ship velocity actually completed the process of turning over the ship.

A special note: Looking again at the above structural and hydro-mechanical analysis, we come up with the surprising conclusion that the captain still had a chance to restore the ship's balance at the first appearance of tilt, by very sharply turning it left wise, following the bicycle rule of turning in the direction of falling, but not in the opposite direction. Indeed, if such a maneuver were successfully carried out, all the outside forces shown in Figures 1 and 2 would change their direction to the opposite one, reducing the rocking moment M and possibly helping to restore the stability of the ship.

Acknowledgement

The author would like to thank Professor Victor Lyatkher for his valuable comments on the Shock Impuls effect on the Sewol catastrophe.

We are also thankful to Ilya Feoktistov for his interest and help in technical assistance for preparation this article.

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