Shipping Accidents, damage assessment & accident consequences

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• Ship Accidents – Causes and types of accidents

• Ship Accidents – Damage assessment
  • Collision models
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Introduction

• Shipping is the fundamental as well as dominant means of transport for the world trade as the Earth is almost covered by sea. Nearly 90,000 vessels of various size and more than 250 different types, specialized on cargo or passenger trade or both, serve for humanity.

• Yet shipping is the bulk delivery mechanism of international trade, and it plays a massive part in humanity’s collective well-being as billions of tons of raw materials and finished goods are carried onboard ships between ports and port terminals economically, cleanly and without mishap everyday.

• However, ships operate in a high-risk environment. In the age of precision navigation and the satellite era, very many casualties still occur at sea. Even the available advanced and sophisticated navigation instruments and the enhanced communication technologies have been unable to halt shipping accidents.

• A shipping accident could be defined as “a usually sudden event or change, occurring without intent or volition through carelessness, unawareness, ignorance, or combination of causes and producing an unfortunate result.”

• Any shipping accident, whatever in nature, is an unfortunate event. Should it occur in a confined area, like a channel or a strait where the traffic is heavy, several as well as serious risks are likely to be faced. On the other hand, a major shipping accident becomes even more critical by way of, say, water ingress thus possibly worsening the ship’s damage stability if exacerbated by heavy weather or strong current. In some other accidents however the issue becomes more “environmental” due to oil spillage.
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Marine accidents around the world

• Marine accidents have been occurring ever since men started to set sail. The custom of the trade has been systematized over time, and later, by the middle of the 19th century, the navigational standards emerged primarily as regulations for preventing collisions at sea. Since the beginning of the last century, marine accidents have resulted in maritime industry efforts to improve ship construction, ship systems reliability and onboard operations organization aiming at reduction of marine accidents.

• However...
Marine Casualties & Incidents

- A Marine Casualty can be defined as any event directly connected with the operations of a ship that has resulted in any of the following scenarios:
  - the death of, loss of or serious injury to, a person
  - the loss, or abandonment of a ship
  - material damage to a ship or to marine infrastructure
  - the stranding or disabling of a ship, or the involvement of a ship in a collision
  - severe or potential for severe damage to the environment, brought about by the damage of a ship.

- A Marine Incident can be defined as any event, or sequence of events, other than a marine casualty, which has occurred directly in connection with the operations of a ship that endangered, or, if not corrected, would endanger the safety of the ship, its occupants or any other person or the environment.

- It should be noted that neither a marine casualty nor incident include a deliberate act or omission, with the intention to cause harm to the safety of a ship, an individual or the environment.
Classification of casualties according to severity

- Casualties according to their severity can be classified among:
  - Very Serious Casualties which are marine casualties involving the total loss of the ship or a death or severe damage to the environment.
  - Serious Casualties which are marine casualties to ships which do not qualify as very serious casualties and which involve for example a fire, collision, grounding, heavy weather damage, suspected hull defect, etc., which result in the ship being unfit to proceed or pollution.
  - Less Serious Casualties which are marine casualties that don’t qualify as very serious or serious casualties.
- Note: In Europe only 3.6% of all accidents reported were classified as very serious, while 18.1% were serious and 78.3% were less serious and marine incidents.
Accidents by ship type in Europe

- The cargo ships category includes general and refrigerated cargo ships, bulk carriers and vehicle carriers. The great majority of commercial ships fall into this category. Consequently, it is no surprise that this was also by far the biggest category for shipping accidents in and around EU.

- The tankers category includes tankers of all kinds, including oil, chemical and gas tankers. Tankers are a high interest category, given that the Erika (1999) and Prestige (2002) oil tanker disasters took place off the EU coast, and that they extensively polluted a large proportion of the western coastline.

- Container ship accidents can be particularly expensive in insurance terms. The reason for this is that, tone for tone, ‘box ships’ often carry very high value cargoes, and they are also increasing in size. Should an entire cargo be lost or significantly damaged, the costs can be huge as even if a small number of high value containers are lost overboard, the insurance cost can be more than the loss of a general cargo ship. Added to this, larger and larger ships are carrying more and more bunker fuel on board, so the pollution risk that they pose is increasing.

- The passenger ship category includes ferries and cruise ships. There was no significant loss of life in passenger ship accidents during the last years, but there were several accidents where the consequences could have been a lot worse. This continues to be a cause for concern, because there were large numbers of passengers on the vessels, and any one of the accidents could have become a disaster.
Why do shipping accidents occur?

Causes and cause relations of accidents are often complex as many different factors have an impact on the cause of an accident. Due to this complex interplay, there are many different ways of categorizing shipping accident causes.

The majority of shipping accidents can be attributed to the following causes:

• **Human factor/ Manning Issues/ crew negligence** :

  Crew negligence is often a driver behind three of the top five causes of loss.

  Human errors may include, inter alia, a lack of adequate knowledge and experience, technical inability, bad look-out, not paying proper attention to procedures and rules, carelessness in commanding a ship, misinterpretations of radar information, fatigue and lack of alertness, overworking, tiredness, insufficient rest periods, etc.

  Crew fatigue and complacency can often be a major factor in incidents. The prudent ship-owner or manager will ensure that these are addressed by way of additional manning or rotating the ship staff more regularly if the ship is employed on a demanding trade route. There are, however, owners and managers who are unable to do this, which could in part be due to a shortage of available trained seafarers, but is more often attributed to commercial or operational considerations. Good equipment can cost more, but safety should be accorded a higher priority, because a ship cannot be operated safely without the seafarer.

• **Abnormal weather conditions**:

  Abnormal weather conditions could be natural phenomena such as current, tide and tidal stream, severe wind, reduced visibility (fog, heavy snow and rain), storm seas, darkness etc. affecting the ship or those controlling it.

• **Technical failures**

  Technical failures are shortcomings within the ship, such as corrosion, steering failure, engine failure, or hull failure arising from defective materials or construction, or by the shore-based installations, such as aids to navigation.
Why do shipping accidents occur? (cont.)

• **Route conditions:**
  Route conditions may include navigational error like over reliance on inaccurate nautical charts, charts of suspect reliability or based upon old surveys, narrow channels with abrupt and angular windings, allowing for very limited maneuverability and exposed to dense marine traffic, such as the Turkish Straits, anchorage contiguous to traffic separation lanes, confined marine areas with insufficient sea-room as well as navigational hazards such as shoals, reefs, wrecks etc.

• **Ship-related factors:**
  Ship related factors could be the weakness of a ship, associated with her larger size, hence less maneuvering capability and stability or draught constraints.

• **Cargo-related factors:**
  Cargo related factors mostly include dangerous goods and heavy cargoes; i.e. their hazardous characteristics (oils, chemicals, nuclear substances), the place / compartment they are stowed onboard ships (on deck or under deck), and degree of diligence that such cargoes need (grain, timber), all of which are related to ships’ seaworthiness.

• Any accident may have more than one cause. Nevertheless, statistical analyses on the basis of the main causal trends explicitly reveal that human errors, though declining marginally, continue to be the major cause for all shipping accidents - being almost 80 percent. In other words, “the acts or omissions of human beings play some part in virtually every accident, including failures, like structural or equipment ones, which may be the immediate cause.”

• Most of the accidents are attributed to human error; quite a lot to bad weather conditions and some also to force majeure reasons.
  The density of vessel traffic, particularly in those narrow areas such as straits, channels, port approaches where there is likely insufficient sea-room, close-quarter situations frequently exist, and more ships are concentrated, remains second to human errors as contributing factor of marine casualties.

  Finally, it should be stated that accidents may take place anywhere, anytime and under any conditions – day or night, in clear weather or restricted visibility, in narrow straits, canals, inland waterways, coastal waters or on the high seas; and even due to defective or off-station navigational marks
Types of casualty events

Casualty events are unwanted events in which there was some kind of energy release with impact on people and/or ship including its equipment and its cargo or environment.

- According to literature and experience the major types of casualty events can be classified among the following categories:

- Capsizing/Listing:
  - is a casualty where the ship no longer floats in the right side-up mode due to: negative initial stability (negative metacentric height), or transversal shift of the centre of gravity, or the impact of external forces.
  - Capsizing: when the ship is tipped over until disabled;
  - Listing: when the ship has a permanent heel or angle of roll.
Types of casualty events

• Collision:

• Collision is a casualty caused by ships striking or being struck by another ship, regardless of whether the ships are underway, anchored or moored. This type of casualty event does not include ships striking underwater wrecks. The collision can be with other ship or with multiple ships or ship not underway.
Types of casualty events

• Contact:
  Contact is a casualty caused by ships striking or being struck by an external object. The objects can be: Floating object (cargo, ice, other or unknown); Fixed object, but not the sea bottom; or Flying object.

• Grounding/stranding:
  occurs when a moving navigating ship, either under command, under Power, or not under command, Drift(ing), striking the sea bottom, shore or underwater wrecks
Types of casualty event – main hazards

- The following are the five major collision/grounding hazards identified by the experts:
  1. Officer on-duty not watch-keeping
  2. Failure of critical navigational aids (in fog)
  3. Severe loss of functionality (e.g. loss of rudder/steering at full speed; failure of shaft bearings)
  4. Lack of knowledge of navigating procedures
  5. Misinterpretation of bridge information
- While also the list of the next five hazards (with lower risk) includes:
  • Collision between two ships (cruise-other) where cruise ship is not at fault
  • Wrong pilot intervention
  • Lack of interpersonal communication on bridge
  • Severe loss of functionality (e.g. loss of power, blackout, etc.)
  • Contamination of fuel tanks
Types of casualty events (cont.)

- Fire/explosion:
  an uncontrolled ignition of flammable chemicals and other materials on board of a ship:
  - Fire is the uncontrolled process of combustion characterized by heat or smoke or flame or any combination of these.
  - Explosion is an uncontrolled release of energy which causes a pressure discontinuity or blast wave.
Types of casualty events – main hazards

• The following are the five major fire/explosion hazards identified by the experts:
  1. Arson – deliberate act resulting in a fire (could be anywhere, anytime)
  2. Galley – deep fat fryers, greasy cooking appliances catching fire (due to overheating)
  3. Engine room – flammable fluids on hot surfaces
  4. Laundry – lint from tumble driers catching fire
  5. Cabins – fire starts in cabin (cigarettes, candles, electrical equipment failure, etc.)
• While the list with the next five hazards (with lower risk) includes:
  • Hot work procedures (including engine room)
  • Mooring deck (mooring ropes catch fire)
  • Bunkering – leakage whilst bunkering, ignition through sparks, etc
  • Theatre (front stage and backstage) – hot lights and flammable materials
  • Storage areas – self ignition (chemical reactions)
Types of casualty events (cont.)

• Foundering:
  Foundering is considered when the vessel has sunk. Foundering should only be regarded as the first casualty event if we do not know the details of the flooding which caused the vessel to founder. In the chain of events foundering can be the last casualty event in this case there is the need to add accidental events.

• Flooding:
  Flooding refers to a casualty when a vessel takes water on board and can be:
  - Progressive if the water flow is gradual
  - Massive if the water flow is extensive.
Types of casualty events (cont.)

• Hull failure:
  Consists of a failure affecting the general structural strength of the ship.

• Loss of control:
  a total or temporary loss of the ability to operate or manoeuvre the ship, failure of electric power, or to contain on board cargo or other substances:
  • Loss of electrical power is the loss of the electrical supply to the ship or facility;
  • Loss of propulsion power is the loss of propulsion because of machinery failure;
  • Loss of directional control is the loss of the ability to steer the ship;
  • Loss of containment is an accidental spill or damage or loss of cargo or other substances carried on board a ship.

• Missing:
  a casualty to a ship whose fate is undetermined with no information having being received on the loss and whereabouts after a reasonable period of time.

• Non-accidental events:
  Non accidental events are intentional events as a result of illegal or hostile acts therefore they are not marine casualties or incidents.
  They are:
  • Acts of war: any act, against a ship or the people on board, by a State that would effectively terminate the normal international law of peacetime and activate the international law of war
  • Criminal acts: any crime, including an act, omission, or possession under the laws of a State or local government, which poses a substantial threat to people on board of a ship or to property (e.g. terrorism, sabotage, piracy)
  • Illegal discharge: an intentional discharge of polluting substances, oil or other noxious substances, from ships
  • Other casualties:
    other intentional act that incur loss of or damage to a ship or environmental damage or harm to people on board.
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Ship Accident Damage assessment

• A great variety of incidents exist, such as collisions, grounding, explosions and fires, severe storms, etc as described above. Therefore, a great variety of hull structure damages exist as well.

• Besides holes, there are many damages of the hull that can be identified, such as rupture of elements (infringement of integrity of a hull structure element due to exhaustion of its plastic deformation limit), cracks (infringement of integrity of a hull structure element due to fatigue) or one-time overload in area of indents or bulges resulting from buckling, as well as different kinds of deformations that are observed after accident.

• The following types of residual deformations can be defined: indentions (local plate permanent deflection in some areas between stiffeners); corrugation (permanent deflections of several adjacent areas of plate between stiffeners); dents (local permanent deflection of a panel, which includes the plate and supporting stiffeners); bulge (permanent deflection of the stiffener’s web plate or the stiffener’s attached plate).

• The assessment of the effect of incidents on the hull structure strength and ship survivability is based on the damage dimensions, i.e. length, height, depth. The assessment of the effect of changed external loads on the hull structure is based on data for the wind and wave conditions during the incident and the distance to a place of refuge, which determines the greatest possible wave load. Therefore, statistical data for damages resulting from incidents is necessary both in the design stage and in the process of developing operative methods to save the ship.
Damage assessment models - Collision Models

• Models for analyzing ship collision were initially developed in 1950s for ships transporting radioactive materials, and later on, were applied to other types of ships, mainly tankers and LPG/LNG carriers.

• Collision analysis models consist of three elements:
  • an external ship dynamics sub-model;
  • an internal sub-model of structural mechanics for the struck and striking ships; and
  • the simulation approach that couples the internal and external sub-models.

Existing models use different sub-models and simulation or coupling approaches to assess ship accident damages.
Collision models - External ship dynamics models

The external sub-model calculates the ship dynamics in collision. Different models have been developed from different assumptions and for different purposes. The simplest is the one-dimensional approach (striking ship surge, struck ship sway) proposed by Minorsky

• **Minorsky Method:** Collision analysis models were first developed for analyzing the design of ships transporting nuclear materials. The crash-worthiness of these ships under the worse case conditions was the primary concern. The totally inelastic right angle collision with the struck ship at rest was considered the “worse case”. Hence, the majority of currently 8 available models consider only right angle collisions, and assumes that the kinetic energy parallel to the struck ship’s center-line is negligible. The most popular of these approaches is the one proposed by Minorsky.

• Minorsky’s approach is based on the following assumptions:
  • The collision is totally inelastic.
  • The system kinetic energy along the struck ship’s longitudinal direction is negligible.
  • The rotations of the struck and striking ships are small and can be neglected.

  The first two assumptions define the so-called “worse case”.

The third is based on the observation of only small rotations in actual collisions during the damage event. Small rotations have also been observed in theoretical analysis

• **In DAMAGE analysis,** a second degree of freedom, is allowed for the struck ship, but the struck ship is still assumed to have zero initial forward speed and the collision angle is assumed to be a right angle.

  It is also assumed that the striking ship remains on its course during the collision, which means the striking ship only has one-degree of freedom, surge.
Collision models - External ship dynamics models

- In Hutchison’s study for barges carrying radioactive cargo, a global coordinate system with three degrees of freedom is used. The virtual masses of both struck and striking ships are developed in matrix form, including the added mass terms.

  The kinetic energy and momentum of the ship is determined from the velocity vector and virtual mass matrix. It is necessary to calculate the final velocities of both struck and striking ships in order to determine the lost kinetic energy.

  In Hutchison’s study, this is accomplished using conservation of momentum with the following assumptions:
  
  - Changes in the global orientation angles, or rotation angles of the ships during the collision are small and can be neglected in certain parts of the analysis.
  
  - There is no change in the distribution of mass after the initial contact.
  
  - After the “inelastic” collision, the striking ship is attached to the struck ship and both ships move together as a single body.

- Zhang’s Model instead of considering the collision in a global system as in Hutchison’s study, Zhang applies three local coordinate systems to the striking ship, the struck ship and the impact point separately.

  By analyzing the motions and impulses around the impact point, the kinetic energy lost in collision is derived. Implicit assumptions in this analysis include:

  Small rotation during the collision

  and a constant ratio of absorbed plastic deformation energy is assumed in the transverse and longitudinal directions.

  The absorbed energy is calculated uncoupled from the internal mechanics problem.
Collision models – Internal mechanics models

- Currently available methods for analyzing internal collision mechanics may be categorized as:
- Correlation of actual collision data;
- Direct calculations;
- Finite element analysis; and
- Model experiments.

The Minorsky method is representative of empirical formula derived from data of actual accidents. Based on an investigation of 26 ship-ship collisions, Minorsky relates the volume of damaged structural steel to the energy absorbed during the collision.

The major problem with the Minorsky method is with low energy collisions that do not cause the rupture of side shell.

Direct Calculations Collision research continues to develop new methods to predict the structural response of ships in collision from the first principles of engineering.

There are several analysis schemes available today. The basic principle behind these methods is similar. They decompose the struck ship into simple substructures or components, such as plates, stiffeners, web frames and panels, etc.

The energy absorbed in each substructure during the collision process is calculated separately. The total absorbed energy up to rupture of the cargo boundary is obtained by summing up the absorbed energy for all components.
Collision models – Internal mechanics models

- A number of these methods are based on plastic membrane tension analysis.
- These schemes were developed primarily for minor ship collisions before rupture of cargo boundaries. Others are derived based on the energy absorbed during plastic deformation of basic structural elements such as angles, T-sections and cruci-forms.
- The methods used in the Rosenblatt study were developed and summarized by McDermott:
  - Their purpose is to calculate the maximum kinetic energy that can be absorbed in the tanker side structure without rupture so that the structure can be optimized for crashworthiness in the design stage. They assume that the bow of the striking ship is infinitely stiff and that only the striking ship absorbs plastic energy.
  - Thus, the collision procedure can be decomposed into a series of deformation mechanisms, including bending of the stiffened hull plating, membrane stretching, web frame failures, and deck folding, until rupture of the cargo boundary.
Collision models – Internal mechanics models

- **Reckling’s** model is actually an extension of the Rosenblatt methods.
- In this model, the striking bow is no longer treated as a rigid wedge, and can deform. Therefore, the collision force exerted by the deformed striking bow is not treated as a concentrated force, but a distributed one over a certain length.
- To determine the resistant force and deformation of the striking bow, Reckling introduced detailed calculations of crushing loads of different shapes of plates under different loads. Deformations of both striking and struck ships are determined by comparing their collision resistant forces.
- Reckling also suggested a 5% rupture strain instead of the 10% strain used in the Rosenblatt method.
- Both **DAMAGE** and the **DTU** model calculate the absorbed energy for direct contact deformation of struck ship super-elements by the striking ship bow.
- However, this is not a finite element method as deformation away from the actual striking ship penetration is not considered.
Collision models – Internal mechanics models

• With the assistance of computers, many structural problems can be solved by the finite element method. The finite element method is also used widely as a tool to simulate and recreate model tests and actual accidents.

• Because of the size and complexity of the ship structure, a finite element analysis usually takes hundreds of hours to create and solve. This is a significant disadvantage and much effort has been applied to simplifying these models.

• Since most deformation in collisions is local, instead of modeling the whole struck ship or a whole segment of it, only a piece of the side panel with coarse triangular elements was modeled. The principle of stationary potential energy was applied to analyze the deformation and energy at the point of rupture.

• Another simplified method, the Idealized Structural Unit Method (ISUM), was developed by Paik.

• ISUM is an idealized non-linear stress-strain method. A coarse mesh method is used to model a segment of the struck ship with elements the size of whole panels supported by web frames and stringers.

• These are also super-elements, but solved in a finite element matrix vice by direct contact. ISUM considers the coupling between local and global deformation and failure modes inside model. Based on ISUM, Paik developed the collision simulation software, ALPS/SCOL.

• With these simplifications, the computing time is reduced dramatically, and in the case of Paik’s model, the time is reduced to a fraction of hour to run a single collision case.
Collision models – Internal mechanics models

• Because of the complexity of the ship structure and collision mechanisms, and the lack of accurate and detailed data of actual collisions, it is necessary to conduct model experiments to understand the internal mechanics behind collisions.

• An important example is the German GKSS experiments. Based on these experiments, Woisin developed an extension to Minorsky’s correlation and proposed methods to improve the crashworthiness of several types of ships. To adequately simulate the structural response of ships in collisions, it is necessary to use full scale or at least large-scale models so that the structural behavior of the model represents that of a real ship. These experiments are extremely expensive. Therefore, experiments are more often used as a tool to verify the theoretical results derived from other methods rather than as a direct simulation approach.

• Experiments conducted at US Steel Research Laboratory were used extensively in the Rosenblatt study. On the basis of the results of a series model tests, Ito generated and verified their simplified method to analyze the response of double hull structures in minor collisions. Recently, Paik has also completed an experimental study of internal collision mechanics to demonstrate the accuracy of his ISUM model. These experiments have also uncovered unexpected collision mechanisms.
Collision models – Coupling internal & external models

• Most of the previous and current work in collision analysis, including the Minorsky method, DAMAGE, the DTU model and Paik’s ALPS/SCOL, determine the lost kinetic energy in an uncoupled solution of the external problem, then calculate the deformation energy of the colliding structures with increasing penetration, and finally find the maximum penetration by matching the deformation energy to the lost kinetic energy.

• This approach relies on the solution of final velocities of struck and striking ships by an external model. This uncoupled solution requires significant simplifying assumptions, and/or restricting degrees of freedom of the system.

• The analysis can also be done in the time domain with a fully coupled time-stepping solution similar to Hutchison and Crake.

• Starting with the initial external condition, impact forces are calculated based on internal structural mechanics at each time step and applied to the struck and striking ships in the external model until the forces go to zero.
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Damage assessment - Grounding Models

- As in collision models the probability of a grounding occurrence and in general an accident occurrence may be computed from statistics based on historical data, expert opinions and predictive calculations.

- Historical data provide realistic figures, which nevertheless should be used for future predictions with caution, because
  
a) they are relevant to structures, which may differ from those in use today, and

b) operation methods are usually improved with time, in order to offer higher safety standards.

Grounding accounts for total losses amounting to 17% in number of ships and 24% in GT. The grounding incident rate for Ro–Ro and merchant navy ship types with lengths greater than 100 m is approximately 0.02 per ship year, which is about half the incident rate for ship collision.

This facts imply that if it is assumed that the life of a ship is 25 years, every second ship is expected to experience grounding in her life.

In order to quantify the probability of grounding occurrence and to investigate the effect of various factors on the likelihood and consequences of grounding, Samuelides developed a database of accidents and populated it with data of accidents on Greek ships over 100 GT. The data were retrieved from the records of the Directorate of the Safety of Navigation of the Hellenic Ministry of Mercantile Marine (HMMM), which should cover all accidents of ships sailing under the Greek flag with size over 100 GT, from 1992 to 2005.

The investigations of accidents of ships over 100 GT, with Greek flag, from 1992 to 2005 revealed that groundings were the most frequent accidents: 47% of the total number of the reported accidents were groundings or caused grounding of a ship. However, only a few of those had catastrophic consequences.

Further investigation of the accidents also revealed that:

The decrease with time of the total number of accidents is proven to be statistically significant whereas the trend for groundings cannot be given as statistically significant;

There is a statistical difference between the mean values of the size (in GT) of the tankers that after grounding produced pollution and of those that did not lead to oil spillage; whereby larger ships tend to pollute more rather than smaller.
Damage Assessment - Grounding models

• The process of ship grounding involves large contact forces, crushing of the hull structure and rupture of shell plating, while interacting with global motions and overall hull strength.

• It may cause serious consequences. The property of the sea bed, the bottom topology and the grounding scenarios are the governing factors for the damage process. Adequate information on sea floor topology is, however, very limited. Most of the analysis models for ship grounding in the past published works assumed that a rock opened a large part of the ships bottom structures.

• The damages of hull structures after grounding were classified into five fundamental damage modes, which are:

  • (a) the stretching mode of shell plating and local large deformation,
  • (b) plate perforating model for ruptured plating,
  • (c) plate denting mode for main supporting members and
  • (d) axial crushing mode for intersection of main supporting members and
  • (e) plate tearing mode for plate in plane compressed by sharp body.
Damage Assessment - Grounding models

• The simplified formula for the approximation of energy dissipation and impact resistance of four fundamental damage modes were derived. The overall energy dissipation and impact resistance of struck structures can be estimated by assembly of these fundamental failure mechanisms.

• The ship bottom is loaded with a conical indenter with a rounded tip, which is forced laterally into the structures in different positions. The resistance forces, energy absorption and penetration with fracture for four different structures were compared, which were:
  • type I, a conventional double bottom,
  • type II a structure with hat-profiles stiffened bottom plating,
  • type III, a structure with steel sandwich panel in outer bottom and
  • type IV, a structure with hat-profiles in both inner and bottom.

• The results showed that the penetration where the tank top fractures is almost the same

• Moreover, the energy absorption at this point of puncture of the inner bottom was quite high for structures II and IV, whereas the weights of those structures are not much higher than for the conventional structure.
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Damage Assessment- Fire & Explosion

• When the composite plates are exposed to fire, ignition will occur after about 30 seconds, the polyester matrix will be charred, and the plate will be delaminated and cracked. Following ignition, combustion of epoxy resin causes a large reduction in the mechanical properties. The residual shear strength and stiffness correlates with the thickness of burnt region, and the residual tensile strength correlates with the mass loss of the laminate.

• The residual flexural and compressive properties were measured at room temperature, and were found to decrease rapidly with increasing exposure time. The risk of fire and of fire-related structural degradation and failure are the challenge to the safe design and accurate structural assessment of composite ship structures.

• Lua developed a temperature and mass dependent heat diffusion model to characterize the temperature and mass dependent heat conduction, energy consumption resulting from the decomposition, and the energy transfer associated with vaporous migration. The temperature dependent thermal conductivity and specific heat capacity are determined for the composite at a given resin decomposition stage using a recently developed small-scale test apparatus.

• The effects of temperature dependent thermal conductivity, specific heat capacity, and kinetic parameters determined at different heating rates are explored through the application of the temperature and mass dependent fire model to a composite plate subjected to a hydrocarbon fire. The thermal gradient due to fire induces a gradient of structural properties, reduces the overall stiffness, e.g. degradation, and thus reduces the load carrying capacity.
Damage Assessment- Fire & Explosion

• **Gu and Asaro** proposed an analytical expression for the buckling load obtained from the theory of functionally graded materials. The solutions are given in a relatively simple form, which can be used to guide design practice, to verify large finite element calculations, as well as to provide insights in fire testing.

• **Teixeira and Guedes Soares** have presented a reliability formulation that accounted for the compressive loads induced by local thermal loading of plates, as induced by a fire.

• The collapse strength of the plates were determined by a finite element code that too into account the changes in material properties as the temperature was spreading in the plate. The sudden energy release associated with the explosion of a high explosive leads to the formation of a superheated, highly compressed gas bubble and the generation of a shock wave in the surrounding medium. If the explosion occurs in water, it will be followed by a gas bubble pulsation.

• The intensity of explosion determines whether a plate undergoes elastic deformation, yielding, plastic deformation or fracture. When the deformation is in the elastic range, the stress developed in the plate is given as a function of the material and shock wave parameters. As the intensity of explosion progressively increases, the elastic to plastic transition occurs over a specific shock factor. Plastic deformation is predicted as a function of geometric and material properties of the plate and shock pulse impulse. Deflection-time history reveals the reloading effects of the shock wave. As the deforming plate absorbs maximum energy, depending on its strength and ductility, it undergoes fracture.

• **Rajendran & Narasimhan** reviewed the sequence of events of underwater explosion and its effect on plate specimens. The damage of plate panels subjected to air blasting loading can be classified into three modes namely

  • (a) large deformation or permanent stretch of plate (Mode I),
  • (b) tensile tearing of plate (Mode II) and
  • (c) shearing failure of plate (Mode III).
Damage Assessment - Fire & Explosion

- **Vendhan** conducted a series of near field UNDEX experiments, which covered all three failure modes, similar to that of panels under air blast loading.

- **Brett** studied the explosive effects in close proximity to a submerged cylinder. The results showed that the primary shock wave impact generated a significant response in all cases; the bubble pulsation was less significant, generating a peak velocity approximately half that caused by the shock wave. The immediate collapse of the bubble onto the cylinder was the most severe impact, inducing a peak velocity approximately twice that caused by the primary shock wave, and brought about significant local plastic deformation.

- **Hung** conducted experimental and numerical studies of linear and nonlinear dynamic response of three cylindrical shell structures subjected to UNDEX. They concluded that when the deformation of the cylinder stayed in linear range after impact of primary shock, the bubble pulsation has only small effects on dynamic responses. If the plastic deformations occurred after the impact of the primary shock wave, the deformations increased remarkable after the attack of bubble pulsation.

- **Zhang and Yao** analyzed the response of a ship under the bubble loading. From the stress-time history curves of typical elements of the structure, it can be seen that the pressure reaches its maximum when the bubble collapses and this validates that the pressure generated by the bubble collapse and the jet can cause serious damage on the ship structure. From the dynamic process of the interaction between the three-dimensional bubble and the ship, the low order vertical mode of the ship is provoked, and the ship presents whipping motion; and the ship does elevation and subsidence movement with the expansion and shrinkage of the bubble.

- **Shin** conducted a ship shock analysis using finite element based coupled ship and fluid model. Three-dimensional ship shock modeling and simulation has been performed and the predicted results were compared with ship shock test data.

- **Librescu** examined the problem of the dynamic response of sandwich flat panels subjected to explosive blast loadings produced by both underwater and in-air explosions, which were carried out in the context of a geometrically nonlinear model of sandwich structures featuring anisotropic laminated face sheets and a transversely compressible orthotropic core. The unsteady pressure generated by the explosion and acting on the face of the sandwich panel includes the effect of the pressure wave transmission through the core.
Agenda

• Introduction
• Ship Accidents – Causes and types of accidents
• Ship Accidents – Damage assessment
  • Collision models
  • Grounding models
  • Fire & explosion
• Shipping Accident consequences
• Conclusions
Shipping accidents consequences

• Often, a shipping incident or a series of incidents provides a spark for a new regulatory framework of international character.
• For example:
  • the Titanic disaster prompted the first SOLAS Convention;
  • the disastrous grounding of Torrey Canyon made its mark and was instrumental in providing the impetus for the MARPOL Convention;
  • the Estonia case accelerated the thorough review of the safety of ro/ro ferries;
  • the Prestige incident led to increases in the amount of compensation available to the victims of oil spills;
  • while both the Prestige and Erika incidents however caused the regulations surrounding single and double-hull tankers to be reviewed.
• Hence, the ever growing technical, operational and administrative profiles of shipping are shaped to a great extent by the outcome of such or similar incidents.
Shipping accidents consequences

Marine accidents adversely affect the human, the marine environment, properties and activities aboard ships and ashore in various forms and degree of extent. The effects of accidents vary from:

• minor injuries to fatalities and from
• insignificant damage to very severe damage to the environment
• and damage to property.

The cost of accidents, including fatalities and injuries, damage to property and the environment, prevention and mitigating measures, and insurance accounts for a considerable share of transport costs.

Any shipping accident, whatever in nature, is every seafarer’s nightmare. Should it occur in a confined area, like a channel or a strait where the traffic is heavy, several as well as serious risks are likely to be faced.

On the other hand, a major shipping accident becomes even more critical by way of, say, water ingress thus possibly worsening the ship’s damage stability if exacerbated by heavy weather or strong current. In some other accidents however the issue becomes more “environmental” due to oil spillage.

Shipping accidents affect marine environment in different ways. Not only accidents and collisions are the reasons of marine pollution, but also human errors as oil spillage, solid waste, oil transferring or bunkering accidentally may cause marine pollution.
Environmental Damage

• Over one million metric tons of petroleum enters the marine environment annually from municipal and industrial sources, marine transport, natural oil seeps and accidental oil spills. Although the number of the latter has decreased significantly during the past decades, catastrophic accidents such as the sinking of the Prestige tanker near the coast of Galicia (Spain) and the Deepwater Horizon (DWH) platform blowout in the Gulf of Mexico, still pose an important threat to marine and coastal ecosystems, causing extensive environmental and economic damages.

• While the past history has been promising, new environmental concerns arise as the oil industry is venturing to recover oil into more hostile, challenging and dangerous regions such as ultra-deep-water, Arctic and along national boundaries that lack the infrastructure to respond effectively to any mishaps.

• When we consider ship related marine environment cases, there are many ways of ship generated pollution types according to IMO’s 2012 Report named International Shipping Facts and Figures Information Resources on Trade, Safety, Security, Environment. Measures introduced by IMO have helped ensure that the majority of oil tankers are safely built and operated and are constructed to reduce the amount of oil spilled in the event of an accident.

• Operational pollution, e.g. from routine tank cleaning operations, has also been cut. Despite the rare major accident, which can cause a spike in the annual statistics, the overall trend demonstrates a continuing improvement, both in the number of oil spills and quantity of oil spilled each year.

• The biggest single decade-to-decade reduction in oil spills was from the 1970s to the 1980s, coinciding with the adoption and entry into force of the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto MARPOL European Scientific Journal , which is rightly credited with having had a substantial positive impact in decreasing the amount of oil that enters the sea from maritime transportation activities.
Exxon Valdez oil spill
• The International Convention for the Safety of Life at Sea (SOLAS), 1974 also includes special requirements for tankers. The amount of oil spilt at sea today bears no comparison with the levels of twenty or even ten years ago, accidents involving tankers causing serious pollution still happen from time to time.

• There is also concern about continuing instances of deliberate non-compliance, whereby a small minority of ship officers flout company procedures and MARPOL pollution prevention rules, despite the million-dollar fines being imposed on parties found guilty of such malpractices (IMO, 2012).

• When we investigate the number of spills and quantity of oil spill, statistics show that 50% of large spills occurred while the vessel was underway in open water, collision groundings accounting for just over half of these. These same causes accounted for some 95 incidents when the vessel was underway in inland or restricted waters.

• The impact of these accidents on marine environment is significant especially in terms of oil spill. Oil spills can cause a wide range of impacts in the marine environment and are often portrayed by the media as “environmental disasters” with dire consequences predicted for the survival of marine flora and fauna.

• In a major incident the short-term environmental impact can be severe, causing serious distress to ecosystems and to the people living near the contaminated coastline, affecting their livelihoods and impairing their quality of life. Given the highly charged and emotional reaction usually associated with oil spills, it can be difficult to obtain a balanced view of the realities of spill effects and subsequent recovery.

• A scientific appraisal of typical oil spill effects reveals that, while damage occurs and can be profound at the level of individual organisms, populations are more resilient. In time, natural recovery processes are capable of repairing damage and returning the system to its normal functions. Long term damage has been recorded in a few instances.

• However, in most cases, even after the largest oil spills, the affected habitats and associated marine life can be expected to have broadly recovered within a few seasons.
Environmental Damage

Oil may impact an environment by one or more of the following mechanisms:

• Physical smothering with an impact on physiological functions;
• Chemical toxicity giving rise to lethal or sub-lethal effects or causing impairment of cellular functions;
• Ecological changes, primarily the loss of key organisms from a community and the takeover of habitats by opportunistic species;
• Indirect effects, such as the loss of habitat or shelter and the consequent elimination of ecologically important species.

The nature and duration of the effects of an oil spill depend on a wide range of factors. These include:

• the quantity and type of oil spilt;
• its behavior in the marine environment;
• the location of the spill in terms of ambient conditions and physical characteristics;
• and the timing, especially in relation to the season and prevalent weather conditions.
• Other key factors are the biological composition of the affected environment, the ecological importance of the component species and their sensitivity to oil pollution.
Environmental Damage

The selection of appropriate clean-up techniques and the effectiveness with which operations are conducted can also have a significant bearing on the effects of a spill.

On the other hand, the ability of the marine environment to recover from severe perturbations is a function of its complexity and resilience. While considerable debate exists over the definition of recovery and the point at which an ecosystem can be said to have recovered, there is broad acceptance that natural variability in ecosystems makes a return to the exact pre-spill conditions unlikely. Most definitions of recovery instead focus on the re-establishment of a community of flora and fauna that is characteristic of the habitat and functioning normally in terms of biodiversity and productivity.

This principle can be illustrated by the experience of inappropriate clean-up operations following the loss of the tanker “Torrey Canyon” off the coast of England in 1967, in which the use of toxic cleaning agents on rocky shorelines led to considerable damage. Although the detailed distribution of particular species present was altered and the effects of the perturbation could be traced over more than two decades, the overall functioning, biodiversity and productivity of the ecosystem was reestablished within one to two years.

Under the definition proposed above, the rocky shore community could be said to have recovered within the two year period. Nevertheless, the limitations of this definition can be recognized by considering the age distribution of the component organisms. Instead of the full range of ages prior to the incident, from juveniles to mature organisms, the newly recruited plants and animals fell within a narrow age range and consequently the community was, initially, less robust. In most cases recovery typically takes place within a few seasonal cycles and for most habitats within one to three years, mangroves being a notable exception.
Marine casualty reporting to prevent ship accidents

- The purpose of marine casualty reporting is to assist the Authorities in responding to marine casualties and conducting timely investigations. Prompt reporting of marine casualties and hazardous conditions enables the Authorities to properly respond to incidents and assist parties in need. It also helps the Coast Guard to determine the contributing factors for each incident and use the lessons learned to promote the safety of life and property throughout the maritime domain.

- The statutes and regulations provide the Coast Guard the authority and jurisdiction to investigate a wide range of occurrences irrespective of reporting requirements. These occurrences include both commercial and recreational vessel activities. Authorities shall use the following procedures when responding to all reports of potential or actual “marine casualties or accidents.”:

a. **Notifications phase**: the receiving unit shall immediately pass the information to a qualified Investigating Officer (IO) for the Evaluation Phase at the appropriate Sector or Marine Safety Unit office. The receiving unit shall immediately document the notification in the Coast Guard’s Marine Information for Safety and Law Enforcement data system.

b. **Evaluation Phase**: Upon receiving a report of a potential “marine casualty or accident,” authorities shall immediately commence an evaluation of the facts to determine whether the occurrence is a reportable marine casualty and whether further action is necessary. As appropriate, qualified marine inspectors should also be contacted and consulted to determine if vessel operational controls are necessary. In most cases, vessel operational control actions should not be based solely upon an initial marine casualty report. Vessel control actions should be determined after careful consideration by a qualified Prevention Officer who has conducted a risk assessment based upon the consideration of redundant equipment and/or equivalent levels of safety.

c. **Action Phase**: (1) Upon determining that an occurrence is a reportable marine casualty or, by policy, requires further action, an Investigating Officer shall conduct the investigation, (2) Upon completing the preliminary investigation and determining an occurrence is either not a reportable marine casualty or meets policy exclusion for further action, no further investigative effort is required. The Investigating Officer shall ensure that the preliminary investigation activity contains copies of all documents received relevant to the occurrence, in order to proceed to an investigation report.
Marine casualty reporting to prevent ship accidents

• A MARINE SAFETY INVESTIGATION REPORT is a report that contains:
  • a summary outlining the basic facts of the marine casualty or marine incident and stating whether any deaths, injuries or pollution occurred as a result
  • the identity of the flag State, owners, operators, the company as identified in the safety management certificate, and the classification society (subject to any national laws concerning privacy)
  • where relevant the details of the dimensions and engines of any ship involved, together with a description of the crew, work routine and other matters, such as time served on the ship
  • a narrative detailing the circumstances of the marine casualty or marine incident
  • analysis and comment on the causal factors including any mechanical, human and organizational factors
  • a discussion of the marine safety investigation’s findings, including the identification of safety issues, and the marine safety investigation’s conclusions, and
  • where appropriate, recommendations with a view to preventing future marine casualties and marine incidents

https://www.youtube.com/watch?v=9tN4ROtMjI
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Conclusions

• Shipping accidents of today have become more “environmental” and the issue has been though than ever for all parties concerned, as those may end up with huge financial losses. Shipping accidents are also a threat to smooth flow of shipping trade and damage to the environment.

• Ships are exposed to various external hazards such as darkness, different visibility conditions, bad weather, and currents, which one way or another, may contribute to shipping accidents like collisions, strandings or groundings. Bad look-outs, not taking the proper action until a very late stage, close presence of a third ship which prevents taking early action and a late proper maneuver as against the crossing, overtaking and meeting end-on rules, etc. also constitute the internal threats of such incidents.

• A large oil spill resulting from a shipping activity, or a series of activities, does not hurt only the people directly involved. Neighbouring economies may also be badly affected as a result of a pollution incident occurred in other state’s territorial water.

• Almost every new ship built today and very many others as existing ships are fitted with sophisticated shipboard equipment to reduce navigational risks, sustain and enhance safety of life and property, and preserve the environment.

• Increasing the dimensions of ships to an incredibly larger size for the good sake of economies of scale however, has brought in higher risks and ultimately more costly actions in case of emergency
End of Session

Thank you for your attention!

Q&A