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Hazard Identification for Tugboat Girting During Towing Operations

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ABSTRACT

This study aims to investigate the dangers associated with the use of conventional tugboats during towing operations, with a focus on the loss of stability caused by girting. There are many risks involved with towing, including grounding, fire, flood, collision, tug capsize, etc., depending on whether the tug masters are pulling at sea or at a harbour. The possibility of a tug capsize is increased by external factors such as girting. Girting can quickly result in tug capsizing, the loss of life, and / or possible environmental harm. An effective risk assessment strategy would aid in creating a successful towing plan in a towing operation where the consequences of poorly thought-out actions are high. The Formal Safety Assessment (FSA) method had been used to determine important events that lead to a tug capsize due to girting. For harbour tug operators, some guidelines and guidance on efficient risk management measures are also provided.

Keywords: Tug Girting, Towing Operation, Hazard Identification.

1 INTRODUCTION

One of the most critical parts of the maritime sector are tug boats. Tugboats, which are small but strong boats, are made to handle a variety of tasks, such as pushing and towing ships with restricted manoeuvrability during berthing, as well as escorting, salvaging, and rescuing, performing underwater duties, fighting fires, and responding to oil pollution [1].

There are three main categories of harbour tugs, each with its advantages and disadvantages. Tugs come in three different types: conventional tugs, azimuth stern drive tugs, and tractor tugs.

During the towing of the vessel, there were multiple accidents that caused numerous injuries, property losses, and environmental harm. The fact that tugboats operate in restricted areas and come into direct contact with ships that have limited manoeuvrability increases their risk of being engaged in accidents. Any towing activity involves some level of risks. One of the tug's biggest worries is when the towline angles away from its normal position over the stern and toward the beam. The tug may capsize if the towline's lead traverses in the direction of its beam rather than producing the required pulling action; this movement is referred to as "girting" the tug. Certain tugs are more likely to suffer girting than others, and conventional single screw tugs are particularly susceptible.

As an example, on 1 October 2019, the loaded barge Seaspan 566 was being towed by the tug Sheena M. However, the barge did not respond to the direction change, and as a result the tug started to be girded by the barge and capsized [2].

The literature review for this study can be divided into two categories: tugboat accidents and risk assessment in the maritime sector.

Data from the European Maritime Safety Association (EMSA) show that towing operations are responsible for 23% of accidents involving ships in the technical fleet [3]. There were 236 accidents in total between 2011 and

2015, 43 of which resulted in crew deaths, as well as major damage to or total loss of ships.

Eleven tugboats that capsized and sunk in European waters are included in this total. The Transportation Safety Board of Canada (TSB) received reports of 26 girting events between 2005 and 2018, 21 of which resulted in capsizing. The TSB received reports of 12 girting occurrences in the 14 years prior (1991-2004), which led to 9 capsizes and 5 fatalities. Six of these incidents have investigative reports released by the TSB.

Towing force, short towlines, the position of the towing point, and lack of awareness training of the girt were recurring factors in these reports, according to [4].

According to previous research Darbra et al. (2007) [5], tugboat failure is one of the factors contributing to accidents in ports. The quantity of tugboats, their power, and the tugmaster's operating competence are other elements influencing the effectiveness of tugboat operations (Hsu, 2012) [6].

According to the Australian Transport Safety Board's safety report, collisions, contact damage, and capsizing were the results of accidents involving tugboats (ATSB, 2011) [7]. According to an incident reported by the International Tugowners Association, the tug capsized after colliding fatally with the ship, mostly to hydrodynamics' sphere on a tug sailing near to the ship's bow. Due to the contact force surrounding the bulbous bow, the tug was unable to maintain a safe distance (ITA, 2012) [8].

The British Tug Association published a notice about the risk of girting after a barge capsized and foundered while berthing as a result of the tug's wrong operational procedure. (BTA, 2010) [9].

Merkelbach and Van Wijnen (2013) [10] recognized the value of competency for tug masters, pilots, ship's masters, and crew participating in towage operations. Competency is attributable to skills, exceptional teamwork, and experiential complete training. The significance of keeping to standard operating procedure was highlighted in Stockman (2010) [11], which detailed an event of near-girting that potentially may have caused a tugboat to capsize.

Using historical data on tugboat accidents, Çakır E et al. (2021) examines the variables influencing accident severity. Several statistical techniques and algorithms were used to analyse the contributing elements in tugboat accidents (i.e., ARM, logistic regression) [12].

Researchers with a wide range of goals frequently conduct risk assessments for maritime sector. For example, J. Zhang et al. (2016) [13] built a Bayesian network model for risk assessment and prediction of the effects of various types in the Tiajian port, and Li et al. (2012) [14] reviewed quantitative risk assessment models for vessels operating in maritime waterways.

Using the decision tree method, Erol and Başar [15] conducted study on marine incidents that happened in Turkey's SAR region. The study found that human error in navigation and carelessness were the main causes of accidents.

The most frequent type of accident on tugboats, according to Çakır E et al. (2017) [16], is a collision, and human error is the main cause of tug accidents in 75% of accidents.

The risk associated with various systems in a maritime vessel is quantified using the bow-tie methodology by A. Aziz et al. [17] utilizing the operational database that is currently in use. The suggested methodology is anticipated to be a helpful tool for risk management and vessel safety. Many techniques had been used in past studies for risk assessment such as bayesian networks formal safety assessment, event tree technique, fault tree technique, and quantitative risk assessment [18].

Formal Safety Assessment (FSA) techniques were decided by the International Maritime Organization (IMO) as a framework work for risk assessment and management.

Using the FSA guidelines, numerous maritime risk assessments had been carried out [19, 20]. A well-worked strategy to improve marine safety, the FSA methodology uses the risk and cost-benefit analysis to aid decision making [20].

According to the preceding literature, there is a scarcity of research on the events and hazards that lead to tug capsize due to girting. Therefore, the goal of this study is to evaluate potential risks that can arise during towing operations and cause tug girting and to identify preventative measures.

2 BACKGROUND

Towage can be performed using a variety of techniques and configurations, such as pushing, pulling, pushing over the stern or bow, utilising short or long towlines, and using one or more tugs. The size, type and capabilities of the tug, as well as the size, type, and capability of the assisted vessel, will influence the techniques that are used. The various tugboat designs and assistance methods are covered in the following sections.

2.1. Harbour Tug Types

It is essential to realise that tugs with various design features have various handling qualities. A combination of the hull profile, engine and/or rudder type, propeller configuration, towing winch design, and power are only a few examples of these. According to where the propulsion system is located and the assisting technique, there are three primary types of tugs employed in harbours; each has benefits and drawbacks. Figure (1) shows the three tugs utilized in harbour operations.

1- **Conventional Tug**: A tug equipped with single or twin propellers, and one or two rudders,
2- **Azimuth Stern Drive (ASD) Tug**: A tug equipped with two azimuth propellers in nozzles at the stern.

3- **Tractor tug** which may be:
   - **Voith Water Tractor (VSP) Tug**: A tug with two Voith-Schritter propellers typically situated front off the midship and a skeg placed aft.
   - **Azimuthing Tractor Tug (ATT):** A tug with two azimuth propellers located generally forward off the midship and a skeg placed aft.
   - **ROTOR tugs**: A tug with two azimuth propellers generally located forward off the midship and one azimuth propeller located at aft.

Table (1) includes data on some of the above types of tug boats for the purpose of providing comparative information on their maneuverability characteristics.

2.2. Assistance Techniques

As seen in figure (2), there are two main assistance techniques used in ship handling operations today:

1. **Direct assistance technique**, such as push-pull or on-the-line.
2. **Indirect assistance technique.**

The applicability of the three different tug types in respect to the fundamental shiphandling techniques that were previously described is summarized in table (2).

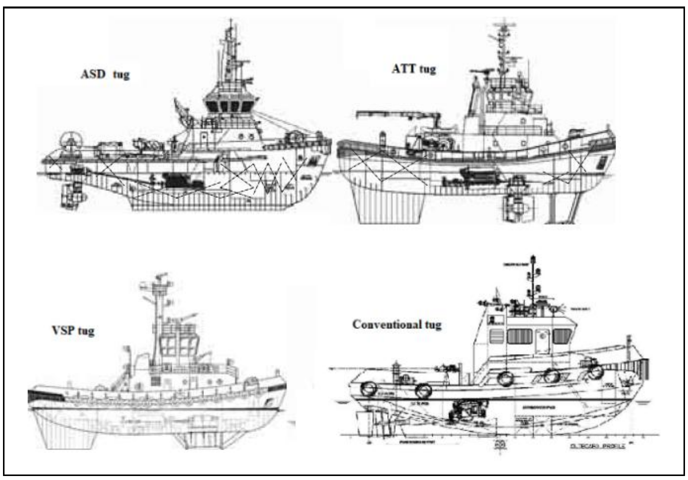

Figure 1: Harbour tug types
Source: based on [21]

Table 1: Tug boats characteristics [21]

Type	*Thrust (100%)*			*Safe during towing (Maneuverability during towing)*
	Ahead	*Astern*	*Sideways*	
Conventional Tug	100	60	0	Not safe (Bad)
Tractor Tug	100	95	80	Very safe, (Very good)
ROTOR Tug	100	100	100	Very safe (Excellent)
(ASD) ***Tug***	100	98	60	Safe (Very good)

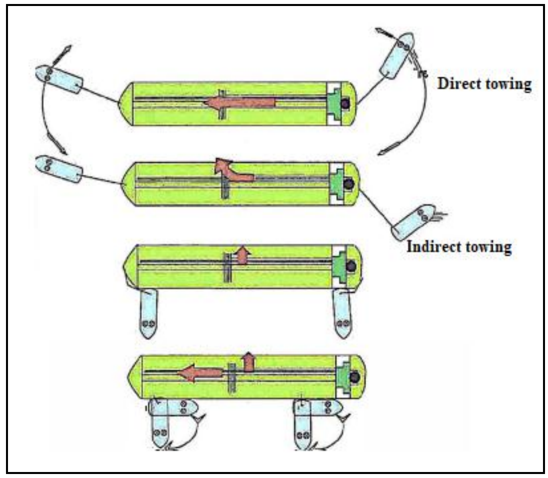

Figure 2: Assistance Techniques
Source: based on [22]

Table 2. Tug types and technique of operation [22]

Assisting Technique		**Conventional Tug**	**(ASD) Tug**	**Tractor Tug**
Direct	**Push-Pull**	Only pulling or pushing.	Very good performance	Good performance.
	On the line	Bad maneuverability at sharp, large angles.	Good performance	Good performance
Indirect		Very difficult due to lack of directional control of the tug.	Good performance	Good performance

3 GIRTING

By their very nature, towing operations can be hazardous if not handled and performed safely. One particular hazard is "girting," which can quickly result in the tug or pulling vessel capsizing and the loss of lives, as seen in figure (3). Girting is also known as tripping or girding (3).

Girting poses a special risk to conventional single screw tugs. The tug master of tractor and azimuth stern drive (ASD) tugs can generate significant thrust in all directions to maintain the tow alignment, which makes them less prone to girt. A conventional tug is inherently unstable when towing from a point close to amidships and may suffer situations in which the weight of the load on the towline causes the tug to heel over at a significant and hazardous angle.

Figures (4-A) and (4-B) illustrates this. Table (3) displays the probability of girting between various types of tugs. Table (4) lists some tug accidents caused by girting.

Table 3: Probability occurrence of girting [23]

Assisting Technique		Conventional Tug	(ASD) Tug	Tractor Tug
Direct	Push-Pull	None	None	None
	On the line	Higher risk of girting	Risk of girting when towing over the stern. Working over the bow reduces girting risk.	Lower risk to girting
Indirect		Higher risk of girting	Working over the bow reduces girting risk	Lower risk to girting

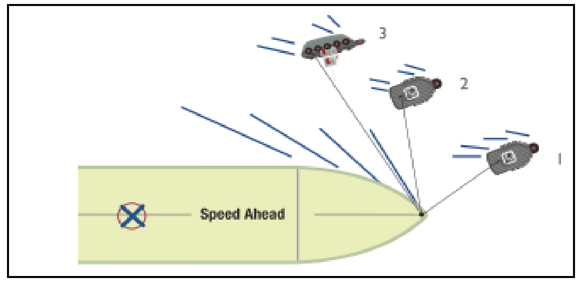

Figure 3: Girting a tug

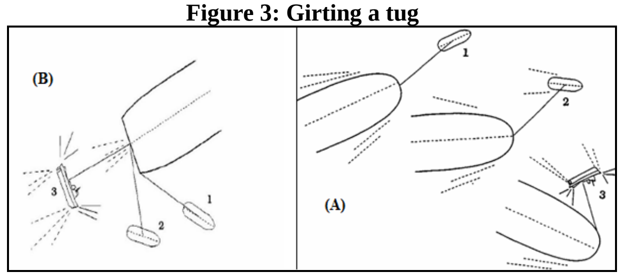

Figure 4: Types of tug girting

Table 4: Summary of towing accidents

Tug Name (Tug Type) (Year)	*Accident Occurrence*	*Consequence of The Casualty*	*Cause*
Koi3 (Conventional) (2019) [24]	A collision occurred between the tanker "Shun Sheng" and the barge "Koi 5" that was being towed by the tug "Koi 3."	The tug capsized after girdling. Four of the tug's six crew members were saved from the water, but two were reported missing.	The absence of a gob rope, which would have prevented girting, on the tug in addition to the tug's doors, and other openings were all fully open, which caused the tug to flood quickly.
George H Ledcor* (Conventional) *(2018) [4]	When the tug turned to the port while towing a laden barge, the barge continued in a straight line.	The tug capsized after girdling.	When George H Ledcor changed its route, the barge did not react and eventually overtook the tug.
Domingue* (Conventional) *(2016) [25]	As the container ship was assisted by the tug as it left the berth.	The tug capsized after girdling.	Domingue was a less manoeuvrable tug, and its crew was inexperienced in assisting ships.
Asterix (Conventional) (2015) [26]	When the tug towed the chemical tanker to leave Fawley Marine Terminal's berth 6 for a manoeuvre,	The tug capsized after girdling.	Because operators lacked appropriate knowledge of how to handle gob ropes, the lead of the towline was pushing across the tug as the tanker started to move forward.
Diver Master (Conventional) (2014) [27]	The sail training ship 'KRUZENSHTERN' was receiving assistance from the tug as it departed the harbour.	The tug capsized after girdling. After then, the tug was salvaged but not put back into action	The tug was placed in a dangerous scenario when it manoeuvred into a position where it was overtaken by its own tow. The tug's control was lost, and the girting occurrence happened.
North Tug* (Conventional) *(2013) [28]	As the cruise liner was being assisted by the tug as its departure the quay.	Tug capsized and sank	As a result of heeling moments from the towline and water on deck.
Chiefton* (Conventional) *(2011) [29]	When the tug was pulling the barge	Tug capsized and sank	No one had been identified to be in overall charge of the towing operation due to the lack of tug master experience.
Adonis* (Conventional) *(2011) [7]	When the tug pulls a barge at the port with the assist of a second tug	The tug capsized	Due to poor manoeuvring, the tug's crew was unable to release the towline.
Ijsselstroom* (Conventional) *(2009) [30]	When the tug works as the barge's stern tug.	Tug capsized	Due to the inexperience of the tug master and the very high tow speed.

Girting can happen for a variety of reasons, such as [21]:

1- The ship or barge that is being towed makes a sharp turn or shears away from the tug.

2- The speed of the barge or vessel being towed is too high, either on purpose or as a result of external conditions like stronger currents or windage on a towed unit.
3- If the tow is moving forward, the tug is too far ahead of its desired location in relation to the vessel's speed; conversely, if the tow is travelling astern, the tug is too far behind.

4 STABILITY DURING TOWING

As seen in figure (5), If the line is fastened around amidships and is leading off toward the beam, the tug will suffer a heeling moment as a result. The center of buoyancy moves toward the center of the underwater volume of the tug, counteracting the heeling moment, and pushes the tug back upright. This is the same process that occurs with any vessel that heels over as a result of an external force. But if the towline's force is strong enough, it might overcome the tug's righting lever and cause it to capsize or "girt." Girting can happen very quickly, and there have been occasions where crew members were unable to flee in time. The two categories of girting scenarios that the IMO rules consider are [22]:

1- Self-tripping is the tendency for a tugboat to flip over while under the influence of the heeling couple produced by the propeller and towline forces.
2- Tow-tripping is the tendency for a tug to veer off course and drag itself along, maybe as a result of a lack of steering or propulsion.

The heeling moment may result from [31]:

1- The tow occurs when the tug is pulled across the water at a specific speed and course by the tow via the towline.
2- The combined action of the propellers, rudders, and towline force, or hydrodynamic lateral force on the hull, results in the pull (self-tripping), which causes the heeling moment. The thrust forces or the bollard pull of the tug are crucial.
3- A tow and tug manoeuvre.
4- Water Ingress

The following are the IMO stability requirements for harbour tug towing operations [22]:

1- For self-tripping, it is necessary that the energy available to right the tug be equal to or greater than the energy available to heel the tug. This requirement is stated in the criteria for the stability curve with respect to reserve stability.
2- For tow-tripping: A transverse heeling moment produced as the tug is pushed sideways through the water at a speed of 5 knots is used to compute the tow-tripping heeling lever.

The main contributing factors that may have caused a tug to capsize when girting include [21]:

1- A little freeboard.
2- Insufficient righting lever (GZ).
3- Inadequately fastened holes that are weather and water-tight.

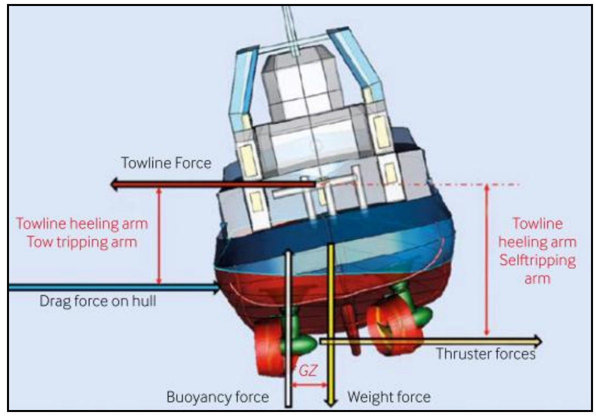

Figure 5: Forces during towing in a vertical plane

The turning pivot of the tug is moved to the point of the propeller using the gob rope axis, as shown in figure (6), which eliminates the turning lever and significantly reduces the tug's ability to manoeuvre, but also protects the conventional tug from capsizing due to the towed ship's rapid turning due to its higher speed of movement [32].

Introduced the gob rope on the tow axis, the turning-pivot is on the propeller causing the turning around at this point and with this the repositioning of the tug's stern into the tow which prevents side-positioning of the tug on tow, thus avoiding danger of coming in the position of girting and ultimately of disaster.

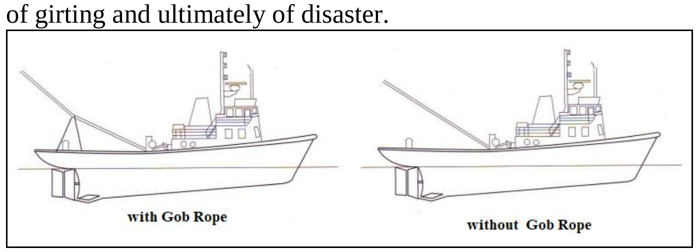

Figure 6: Tug with and without gob rope
Source: based on [33]

5 RISK ASSESSMENT METHODOLOGY

The modelling and quantification of risks in a given situation for a system is done through the technical process of risk assessment. Decision-makers may request and/or receive qualitative and quantitative data from risk assessment for use in risk management. Risk assessment or risk analysis provides the process for identifying hazards, event-probability assessment, and consequence assessment as shown in figure (7). The first step of the risk assessment is to define the structural system. A system is an assembly or combination of components with different levels of detail or action working together to achieve a specified goal.

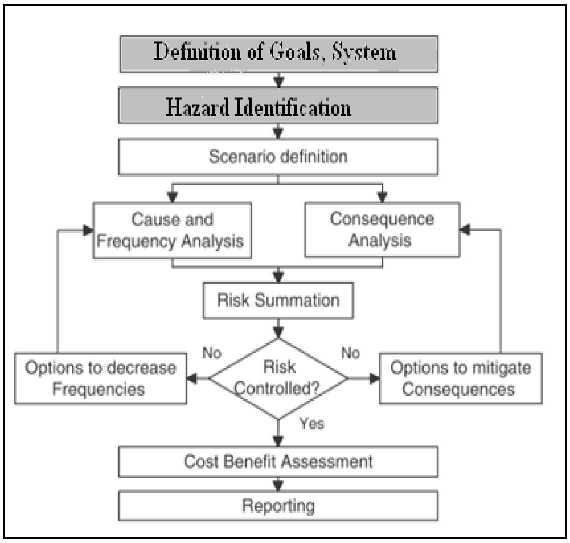

Figure 7:Risk assessment process

Defining the system provides the risk-based methodology with the information it needs to achieve the analysis objectives. The system definition phase has the following activities [33]: define the goal and objectives of the analysis, define the system boundaries, define the success criteria in terms of measurable performances and collect information for assessing failure likelihood.

Hazard is defined as a 'physical situation with a potential for human injury, property damage, environmental damage, or some combination of these'. A structured and systemic approach to hazard identification is essential if important hazards are not to be missed. Three general approaches are used as summarized in Table (5).

Table 5: Hazard identification methods [35]

Method	***Examples***
Intuitive	Brainstorming
Inductive	Checklists
	Failure modes and effects analysis
	Job safety analysis
	Hazard and operability study
	Event tree analysis
Deductive	Accident and incident databases
	Fault tree analysis

6 RISK ASSESSMENT PROCESS

This section describes the methodology used to identify the hazard that resulted in loss of tug stability.

6.1. The Goal, Objectives and System of the Analysis

In this paper, the risk during towing operation that may lead to the tug girting and then capsizing will be evaluated for good towing operation and safety for the tug's crew, the tug, and the ship. The following points describe the system that is analyzed, including:

- The harbour tug types and their specifications are mentioned in title No. (2.1).
- Assistance techniques are mentioned in title No. (2.2).

As the system and physical boundary, the conventional tug and direct assistance technique would be chosen.

6.2. Hazard Identification in Towing Operations

A situation that can result in a loss of stability accident is called a hazard. The majority of accidents that do happen during towing operations can be attributed to improper planning, improper setup, or insufficient crew and equipment control. However, tug stability is vulnerable to a variety of hazards that cause girting and raise the possibility of capsize, which is regarded as a catastrophic occurrence.

There are many different ways to recognize hazards, including the intuitive method (Hazard Review) utilized in this research to evaluate the hazards associated with a towing operation.

The girting is regulated by a number of factors, and it was recognised after several accidents in the girting and subsequent tugboat capsizing. The following subsets of these factors can be generally divided:

1.Forces of the environment.
2.Watertight integrity of the hull.
3.Transverse stability.
4. Towing operation.
5. Tugboat operation.

The factors and possible hazards that could affect the tug's stability were classified and illustrated in figures (8).

7 PRECAUTIONS TO PREVENT GIRTING

Operators can lower the risk of girting by learning about girting and the various factors that contribute to it. They can also take into account the towing procedures in table (6).

8 CONCLUSION

Harbour tugs play a significant role in harbour business and issues related to navigational safety. Harbour tugs are crucial for many different port operations, including the entry, manoeuvring, mooring, and unmooring of large ships. This research is an important step toward developing a reliable and practical risk assessment framework for tug capsizes caused by girting.

By using the intuitive method to identify the factors or events that lead to tug girting, this study investigated the enormous number of accidents involving tugboats caused by girting, which may be due to insufficient training, an inexperienced crew, poor tow planning...etc.

Girting is particularly hazardous to conventional tugs because towing from a point near amidships is inherently unstable and can result in situations where the load on the towline can heel the tug over to a large and dangerous angle. Tractor and (ASD) tugs are less likely to girt because the tug master can produce significant thrust in all directions to maintain the tow alignment.

It should be noted that this study contributes the following efforts: it is crucial to develop a training programme for the tug crew, ensure the qualifications of the tug crew, and take all necessary precautions to prevent girting when preparing the towing plan in order to reduce the likelihood of girting occurring and to mitigate its effects.

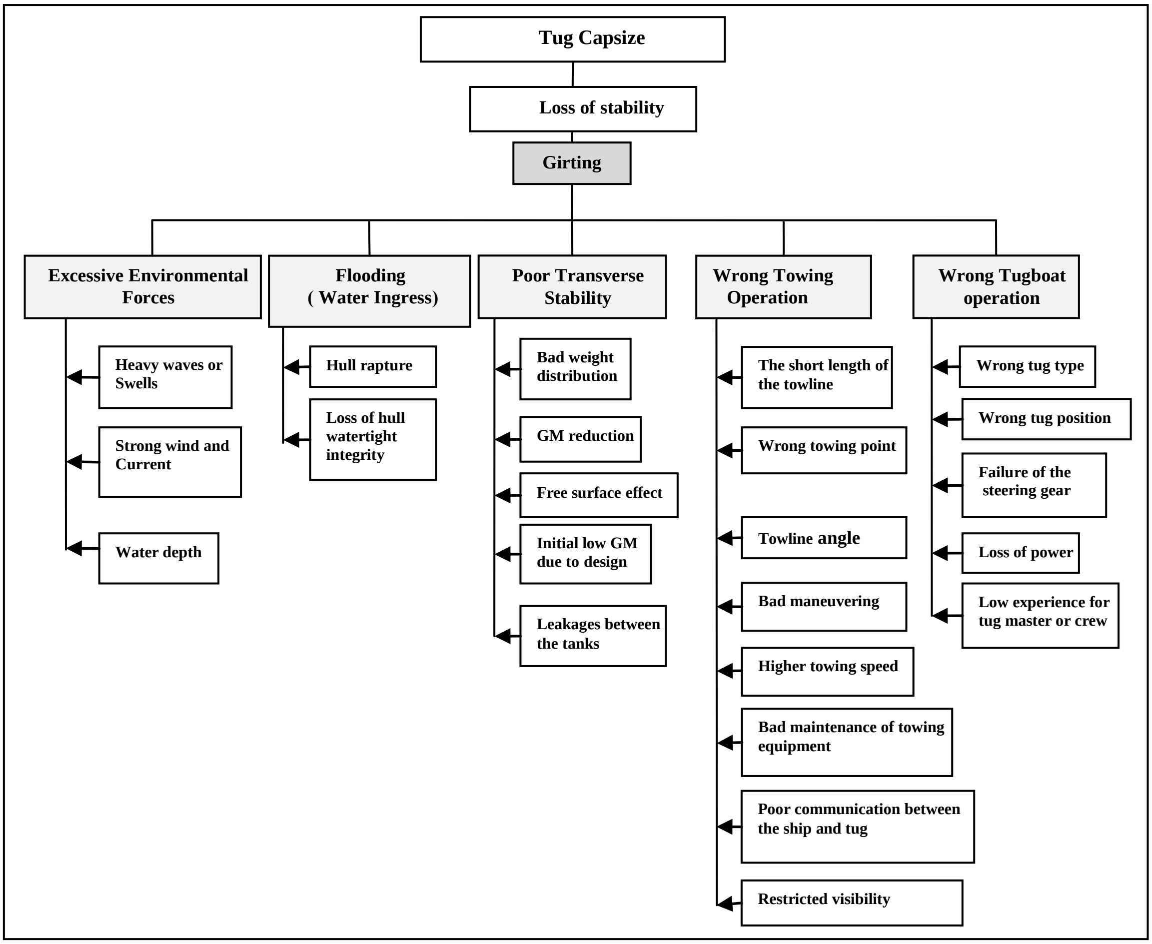

Figure 8:Schematic presentation of hazards affecting tug stability during towing operation

Table 6: Ship towing procedures

Before towing operation	During towing operation
1- The tug's capability (considering its horsepower and bollard pull). 2- The towline length, and the tug's location. 3- The position of the towing point. 4- Towing equipment that is suitable for the job. 5- Stability of the tug and tow, when used together. 6- The limits of the working area such as reduced depth, tidal limits, etc. 7- Navigation information and weather forecasts. 8- Using fixed gob line. 9- Training of tug crews. 10- All staff involved in towing operations should receive specific guidance on operating procedures. 11- Risk assessments and toolbox talks involving all related parties should be carried out prior to all towing operations. 12- The tug crew should be aware of and test the emergency brake release systems on tugs. 13- Qualified persons shall be responsible for the maintenance of the towing gear.	1- Know the towline length and the position of the tug. 2- Know the position of the towing point. 3- Verify the towing wire is also paid out for extended periods to "freshen the nip" while towing. 4- Watch for signals that the tow is overtaking the tug. 5- Frequently check with the crew on the deck and any other tugs involved in the operation. 6- Check the environmental conditions. 7- During towing activities, openings such as watertight doors and ports must be held locked.

9 GLOSSARY OF ABBREVIATIONS

ATT : Azimuthing Tractor Tug
FSA : Formal Safety Assessment
EMSA: European Maritime Safety Association
TSB : Transportation Safety Board of Canada
ATSB: Australian Transport Safety Board
BTA : British Tug Association
ITA : International Tug masters Association
MAIB: Marine Accident Investigation Branch
AIBN: Accident Investigation Board Norway
ASD: Azimuth Stern Drive tug
VSP : Voith Water Tractor

Credit Authorship Contribution Statement

Osama M. EL-Desouky: Conceptualization, Methodology, Writing Review & Editing, Supervision.

Declaration of Competing Interest

The author declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

Declaration of Funding

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