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Applying CAST
to investigation of the FPSO's incident with an iceberg

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ABSTRACT

On 29 March 2017, the floating production storage and offloading unit (FPSO) did not disconnect and sail away when a medium iceberg came close to the FPSO. The tow of the iceberg was unsuccessful, and the crew was instructed to brace for impact. Because of favorable weather conditions, the iceberg passed 50 m from the FPSO. This incident was formally investigated, and the main conclusions were: (1) the company operating/owning the oil and gas field did not follow its ice management plan; (2) the company's senior management did not ensure that the ice management plan was followed; and (3) the offshore installation manager did not disconnect according to the procedures.

Learning from incidents, including near-misses, is crucial for accident prevention and for ensuring an acceptable risk level in offshore oil and gas operations. A prerequisite for learning is that a thorough investigation of the causes to why accidents and incidents occur is performed. Hence, it is reasonable to ask why plans and procedures were not followed in the above mentioned close encounter between the FPSO and the iceberg. The objective of this study is to analyze the incident by using the Causal Analysis based on Systems Theory (CAST). The purpose is to find out whether CAST, which is based on the Systems Theoretic Accident Model and Processes (STAMP), could reveal more causes to the incident, which could shed light on why the plans and procedures were not followed. Such results provide information about the changes that are needed in order to prevent similar incidents in the future, particularly with respect to safety climate, management, and crew training in offshore Arctic operations.

KEY WORDS: CAST; Ice Management; Incident Investigation; Iceberg

INTRODUCTION

Icebergs are of major importance to detect, monitor and avoid for ships and offshore structures operating in the Grand Banks and some parts of the Barents Sea. To maintain operations in iceberg infested waters and to prevent collisions with potentially dangerous icebergs, operators deploy an ice management system. This system consists of three main components: (1) an ice and weather forecasting, detection and monitoring system, (2) threat evaluation and an ice alert system, and (3) support vessels that perform physical ice management by towing, pushing, washing, breaking or providing ice reconnaissance (Connelly et al., 2014).

Despite a number of successful ice management operations conducted in the past, incidents can still happen. On 29 March 2017, the floating production storage and offloading unit (FPSO) did not disconnect and sail away when a medium iceberg came close to the FPSO. The tow of the iceberg was unsuccessful, and the crew was instructed to brace for impact. Because of favorable weather conditions, the iceberg passed 50 m from the FPSO. The investigation launched by the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) noted: (1) the company operating/owning the oil and gas field did not follow its ice management plan; (2) the company's senior management did not ensure that the ice management plan was followed; and (3) the offshore installation manager did not disconnect according to the procedures (C-NLOPB, 2018).

Learning from incidents, including near-misses, is crucial for accident prevention and for ensuring an acceptable risk level in offshore oil and gas operations (PSA, 2019). As in most of accident/incident investigations, this incident with the FPSO was described as a chain of events and human errors. Such an approach is limited in its ability to handle incidents arising from dysfunctional interactions among the components and complex human decision-making; thus reducing our ability for learning. A prerequisite for learning is that a thorough investigation of the causes to why accidents and incidents occur is performed. Hence, it is reasonable to ask why the plans and procedures were not followed in the above-mentioned close encounter between the FPSO and the iceberg. The C-NLOPB does not provide insights into such issues.

A lot of effort has been put into research on understanding why major accidents occur and finding the means for how we can prevent them from happening again. Many theories and perspectives on accidents and/or incidents exist. An overview can be found, e.g., in Kim et al. (2016). Each theory represents different perspectives on major accidents and understands the accident mechanisms in its own particular way, sometimes focusing on different causes to the same accident. In general, there are three types of accident models: sequential, epistemological, and systemic. The *sequential accident models*, for example, the Sequentially Timed Events Plotting (STEP), considers accidents as a chain of events which occur in a specific order. *Epidemiologic accident models* consider accidents similar to the spreading of a disease. This means that an accident is the result of a combination of manifest and latent factors. The Swiss cheese model is an example of such an approach. *Systemic accident models* are based on the systems theory, which assumes that systems cannot be decomposed into subsystems without losing important and relevant information about interactions and relationship between the constituent parts of the system. Examples are the Systems- Theoretic Accident Model and Processes (STAMP) and Functional Resonance Accident Model (FRAM) (Leveson, 2011; Rausand, 2011; Hollnagel, 2004). Both STAMP and FRAM have been applied for accidents and incidents analysis in aviation, shipping and offshore accidents, fire and explosion accidents and incidents (Leveson, 2016; Elliott, 2017). By re-analyzing the ferry capsizing accident using FRAM, Praetorius et al. (2011) report that they were able to gain a deeper understanding of the accident causes and to identify constructive countermeasures to help preventing such accidents from reoccurring. The different models have advantages and disadvantages and have evolved as a response to criticism of previous works. As Kim et al. (2016) and Holen et al. (2014) show, different models and approaches reveal different causes to the accidents, and could also be complementary in an investigation process.

The objective of this paper is to analyze the FPSO incident by using the Causal Analysis based on Systems Theory (CAST), which is an accident analysis technique based on the STAMP model. The purpose is to find out whether CAST could reveal more causes to the incident than found in the official investigation report (C-NLOPB, 2018). Such results could provide information about the changes that are needed in order to prevent similar incidents from happening in the future in offshore Arctic operations.

The next Section briefly describes CAST applied to the FPSO's incident with an iceberg.

THE CAST APPROACH TO INCIDENT ANALYSIS

The official investigation report follows the sequential approach, with some main conclusions regarding the overall causes as to why the incident occurred. In a CAST analysis (Leveson, 2011), accidents are viewed as a result of flawed processes involving interactions among system components, including people, societal and organizational structures, engineering activities, and physical system components. Hence, such an approach may reveal additional causes and information regarding as to why the incident occurred.

A step-by-step procedure of the CAST approach has been adopted from Leveson (2016) with some modifications, and includes the following elements:

1. Identification of the system hazard(s)
2. Development of the safety control structure in place at the time of the incident
3. Investigation of the control hierarchy and identification of components, feedback mechanisms, processes, control mechanisms and violations of safety constraints that were designed to prevent the specific event that occurred. Why were they not effective?
4. Assessing results, drawing conclusions, and proposing improvement actions to prevent similar events to occur again.

The detailed description of the CAST method is provided in Leveson (2011), and is thus omitted here. The rest of the paper presents an application of CAST to the FPSO's incident with an iceberg at the White Rose oil field.

CASE STUDY

The incident occurred on 29 March 2017 with the medium size tabular iceberg. Table 3 reports the main dimensions of the iceberg and the prevailing weather conditions in the area. Under these weather conditions (low visibility and high sea-states), the anchor handling tug supply vessel was not able to take the iceberg under the tow leading to the iceberg passing 50 m away from the SeaRose FPSO (Figure 1). For details, refer to the report of C-NLOPB (2018).

Sources of information and analysis

The CAST analysis of the incident has been conducted using the information provided in the C-NLOPB investigation report (C-NLOPB, 2018), the White Rose oil field development application documents (Husky Oil Operations Limited, 2001a,b,c), including the public reviews, and communication with people who have been involved in ice management planning in different offshore oil and gas projects. From these sources, a rational basis for the incident analysis has been formed.

The system-level hazard to be investigated in this paper is a threatening iceberg that exceeds a certain kinetic energy level and drifts into the iceberg exclusion area, and the FPSO does not disconnect for evasion. Such an event, depending on the ice and environmental conditions, could potentially lead to a collision and severe damage/downtime of the FPSO structure, mooring equipment and/or subsea installations on the sea bottom, not to mention loss of life or injury to people and environmental pollution. The overall system constraint is the ice management plan that is described in C-NLOPB (2018), and only a brief summary is presented herein.

Figure 1. A photograph of the SeaRose FPSO (Source: C-NLOPB).

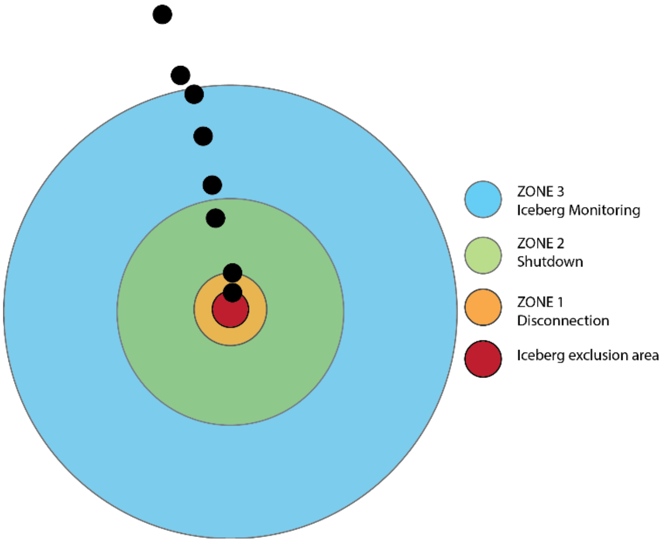

Figure 2. Schematics of the ice management zones and approximate positions of the iceberg (shown as black circles).

There are three ice zones around the SeaRose FPSO (Figure 2). Safe control actions should either prevent a threatening iceberg from drifting into the Zone 1 and the iceberg exclusion zone or ensure disconnection and evasion, in case the former should occur. Figure 3 shows the safety control structure (or hierarchy) developed for the analysis, and it is based on the information presented in the C-NLOPB investigation report (C-NLOPB, 2018). The main purpose of the safety control structure is to enable identification of unsafe control actions that may cause the system hazard. This forms a basis for understanding what happened and why. The blue arrows indicate information flow during the event, and black lines indicate the control actions and the feedbacks loops. The control actions and the corresponding feedbacks may be of three different types, i.e., (1) a physical action such as a vessel applying a towing force to an iceberg, (2) a regulatory action such as operational limitations prescribed in the rules and other regulatory documents, or (3) a direct command from one entity to another.

There are two major interconnected systems: the onshore system and the offshore system. The main stakeholders offshore are the FPSO itself and two ice management vessels (IMVs). The onshore organization consists of the onshore ice coordination center (OICC), the regional response management team (RRMT) and the governmental and regulatory agencies. There are several control loops in this structure: loops between the FPSO and the FPSO systems (engine-, propulsion-, mooring- and subsea systems), a loop between the FPSO and the offshore ice management assets (IMVs), a loop between the onshore and the offshore organizations, and a loop between the regulatory body (C-NLOPB) and the oil field operator.

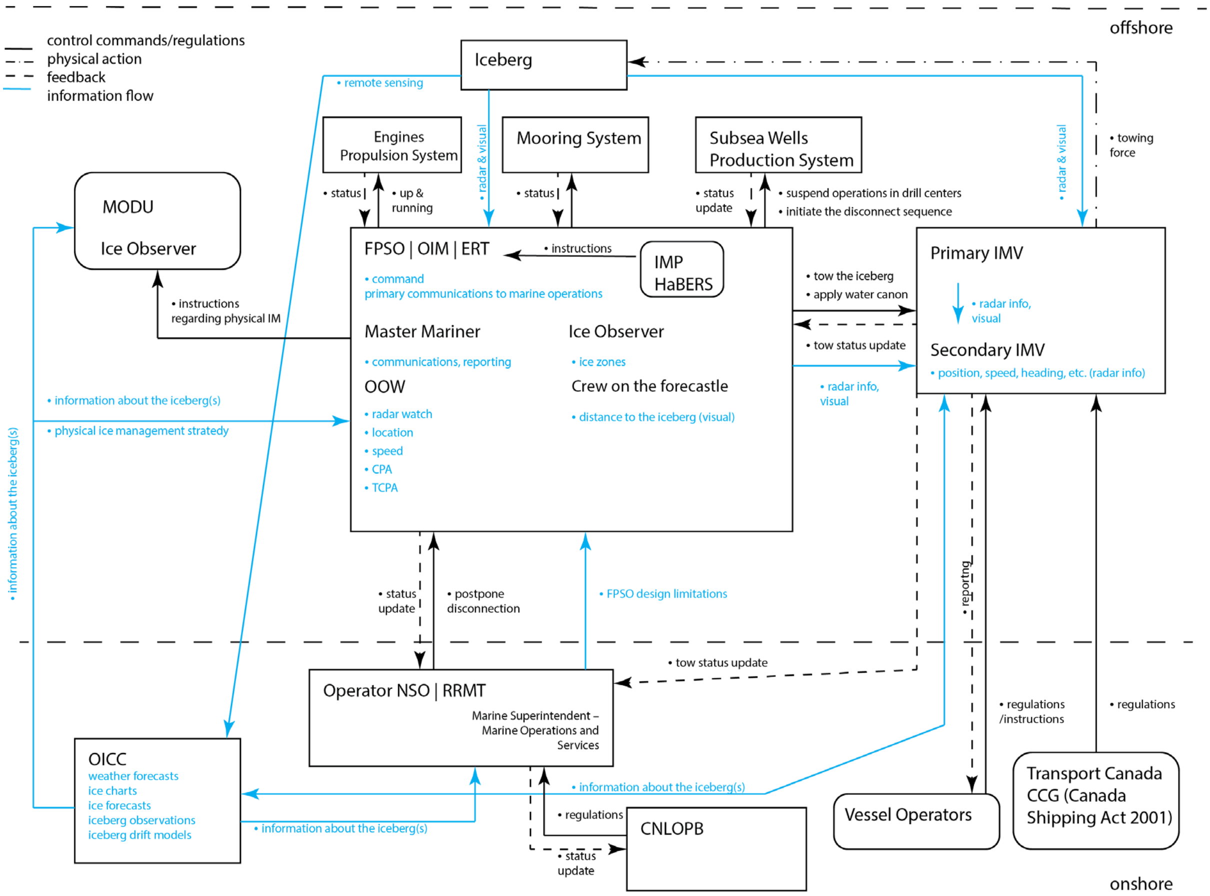

Figure 3. Safety control structure at the incident instance. NSO=Non Standard Operation Team, RRMT=Regional Response Management Team, OICC=Onshore Ice Coordination Center, CCG= Canadian Coast Guard, C-NLOPB= Canada-Newfoundland and Labrador Petroleum Offshore Board, IMP=Ice Management Plan, IMV=Ice Management Vessel, OOW=Officer of the Watch, OIM=Offshore Installation Manager, ERT=Emergency Response Team, MODU=Mobile Offshore Drilling Unit, HaBERS = vessel collision avoidance procedures.

Table 3 presents safety requirements and constraints identified from Figure 3, and lists relevant unsafe control actions and process model flaws as well as presents the context in which the decisions were made. There are four ways the unsafe control actions can occur:

A. A control action required for safety is not provided or is not followed
B. An unsafe control action is provided that leads to a hazard
C. A potentially safe control action is provided too late, too early, or out of sequence
D. A safe control action is stopped too soon or applied for too long (for a continuous or non-discrete control action)

The aforementioned differences between the unsafe control actions are highlighted in Table 1 (see column “Unsafe Control Actions”). There are more unsafe control actions that can be identified, but due to limited space, only the most relevant actions are listed in the table.

Table 1. Safety requirements and constraints, unsafe control actions, process model flaws, and context in which the decisions were made

No	Controller	Safety Requirements and Constraints	Unsafe Control Actions	Process Model Flaws	Context in Which Decisions were Made
1	FPSO/OIM/ERT	• Provide primary commands of the ice management • Prepare production system for disconnection • Transfer of responsibility for the installation to the Master Mariner when disconnection is required • Provide primary communications to the operation manager onshore	• (A) No decision that there is a potential requirement for disconnection • (A) No transfer of the responsibility for the installation to the Master Mariner • (D) Stopped following the ice management plan	• This controller received towing status from two different sources: (1) from the primary ice management vessel and (2) from the secondary ice management vessel (via NSO/RRMT)	• There were two conflicting reports about the towing status • This controller believed that the iceberg was being towed or was not threatening
2	NSO/RRMT	• Increase the state of readiness and establish clear communication lines between operation and senior management • Provide necessary support and coordination required by the offshore ERT • In reactive phase**: act in support capacity (do not take command of the response)	• (B/C) Request from NSO to postpone disconnection to FPSO/OIM/ERT	• NSO was supposed to receive information about towing from FPSO/OIM/ERT, but NSO directly contacted secondary IMV to get information	• NSO/RRMT received misleading information from the secondary IMV
3	Primary IMV / Secondary IMV	• Tow an iceberg • Apply water cannon against an iceberg • Provide towing status and iceberg information to FPSO/OIM/ERT/RRMT	• (A/C) Successful towing not timely provided • (B) Misleading information about the tow status • (A) Water cannon not provided	• No discussion about probability of a successful tow nor about the towing possibilities between the primary and secondary IMVs. For instance, the towing might be possible for the secondary IMV, but (as far as we found) there was no recorded discussion with the secondary IMV about it	• The captain of the primary IMV judged that it was too dangerous to initiate towing process due to the heavy weather conditions. However, the other vessel was able to tow an iceberg at another location
4	C-NLOPB*	• Approval of development plans and all activities respecting the exploration, drilling, production, conservation, processing of transportation of petroleum – particular regard to environment and safety	• (B) Uncertainty about who did approve the Ice Management Plan	• This controller have received large data files containing important information about the development plans, etc. including changes. In some of the plans, the information about the iceberg is in the section for vessel collisions	• Uncertain
No	Controller	Safety Requirements and Constraints	Unsafe Control Actions	Process Model Flaws	Context in Which Decisions were Made
6	Ice Observer	• Review of the OIM's T_time calculations, calculate, communicate and record ice Zones, advise when ice enters the Zones, and give	• (A) Did not record ice Zones or advise when ice enters the Zones, nor gave one hour notice prior to entering Zone 2.	• It seems there have been only one ice observer on the FPSO who was not on the bridge until March 29 0420 hrs, and hence	• Seemingly came to the bridge at 0420 hrs, meaning he was not present when ice entered Zone 2

		one hour notice prior to entering Zone 2.		was not able to perform duties	
7	Tactical IMT	• Designating threatening ice	• (A/ C) Uncertainty about whether or not the iceberg was defined as threatening	• No documented discussion regarding if the iceberg was threatening nor on the probability of a successful tow under the given weather conditions and iceberg size, and considering a single vessel tow	• Members of this team are onshore and offshore • Information format provided about the iceberg (size, shape, speed, trajectory, forecast) (see Table 2) differs from the information provided about the FPSO structural limitations (i.e. impact kinetic energy of the iceberg)

*before the incident; **emergency response uses a two-phase approach, (1) reactive phase and (2) proactive phase, each having different control structure

Table 2. Iceberg information supplied by OICC on March 29

Name	Size	Time	Range	Bearing	CMG	SMG	Ref Facility	CPA	TCPA	Source	Tow
2017-011	Medium	0230	6.1	340.2	141.9	1.8	SeaRose	1.9	3.2	Maersk Dispatcher	N

CMG=Course Made Good, SMG=Speed Made Good, CPA =Closest Point of Approach, TCPA= Time to CPA

Based on the conducted analysis, the following recommendations can be made:

- For FPSO/OIM/ERT: It is required to ensure that this controller receives information about the ice management status from a reliable source only. It should be clearly indicated (in the ice management plan) that indirect information from other sources must be ignored.
- For NSO/RRMT: It is required to clearly define that the towing status must be informed by FPSO/OIM/ERT. It should be clearly indicated (in the ice management plan) that NSO/RRMT should not contact IMVs directly (only allowed when it is impossible to get reliable information from FPSO/OIM/ERT)
- Two ice observers are necessary on the installation that is responsible for coordination of ice management activities.
- The probability of a successful tow, as a function of the crew experience and weather conditions, should be explicitly included in the ice management plan formulations.
- The information provided about the iceberg must be sufficient to judge whether or not the iceberg is threatening without additional hand calculations. For instance, the kinetic energy of the iceberg can be computed/updated automatically and provided by the OICC on a timely basis. The latter value can be directly compared to the design kinetic energy values in the documentation. Alternatively, the design limitations could be presented in a suitable format. e.g., similar to that for the serviceability criteria of the FPSO in the ice management plan.

Other considerations

- Since there is a blind spot of the FPSO due to the radar shadow, crew on the forecastle that were tasked to measure the distance to the iceberg must be equipped with appropriate equipment.
- Requirements to the application documents. The section dealing with ice and icebergs should always be in a separate section. It should not be allowed to present iceberg-related information in the section for ship impacts. The collisions with icebergs should not be treated in the same manner as collisions with supply vessels because the iceberg draught could be larger than that of a supply vessel, and thus, the iceberg can

strike outside of the region strengthened against the vessel impact. The FPSO design limitations against iceberg impacts are presented in the Ship Impact Section (refer to page 84 in Husky Oil Operations Limited, 2001b).

DISCUSSION

In this paper, we have re-analyzed the FPSO incident using CAST approach. The analysis highlights the additional issues, which were not identified in the original investigation report. It should be mentioned that since we are partly basing our analysis on the information provided in the investigation report, our analysis may be subjected to errors and bias made in the incident information sources. In addition, it was not possible to investigate control actions higher up in the organization (i.e., beyond the operator of the oil field) because the required information was not available.

Challenges, limitations and possible improvements of the CAST approach

One challenge we have experienced during this case study was that there could be multiple (and/or dynamic) safety control structures, while the CAST approach focuses on the safety control structure in place at the time of the incident. The safety control structure of normal operation is different from that of an emergency operation. The safety control structure of an emergency operation can even vary depending on the situation. For instance, the information about the iceberg is provided by OICC to FPSO when the iceberg is located outside the radar coverage of FPSO, while the information is provided by IMVs and FPSO to OICC when the iceberg drifts into the radar coverage of FPSO and IMVs. In a same situation, we may have multiple safety control structures: a planned safety control structure and a safety control structure that was actually followed. For instance, was it according to the plan that the onshore teams (NSO/RRMT) received information about the tow from the secondary IMV, whereas the primary vessel executed the tow operation and communicated directly to OIM? This organizational structure resulted in a confusion of the OIM, because the information relayed to OIM from the primary vessel and from the NSO/RRMT (via secondary IMV) was not the same. If we focus on only one safety control structure in place at the time of the incident, it may narrow and/or limit our view of the incident, as it is impossible to include all these variations into a single safety control diagram. Therefore, we recommend studying how to utilize and analyze multiple safety control structures in CAST analysis.

Challenges related to coordination and communication between different stakeholders involved have been revealed, but it may also be questioned if some of these problems were due to lack of training and insufficient quality of procedures for how to handle such situation. Further, it may be questioned if the reluctance to disconnect could be due to the safety climate and pressure to maintain production and avoid downtime. The CAST analysis does not provide insights into such issues.

Discrepancies in the available information about the incident

Some discrepancies in the available information were discovered during the analysis.

Discrepancies in the report and other documents at the C-NLOPB website: There is a discrepancy between the investigation report and the development plan of Husky Oil Operations Limited (2001a). According to the C-NLOPB report "The ice management plan indicates that during ice season when a MODU is present, coordination of ice management activities is conducted from the MODU for the field assets". In contrast, the development plan states: "All drilling will be carried out by semi-submersible drilling units, each of which will be the responsibility of a dedicated installation manager onboard. The FPSO OIM will, however, have responsibility for coordination of all offshore activities. These include drilling workover, diving and ice management, in addition to the FPSO-related activities of production, storage, offloading and shipping". Both the development plan and the actions made show that ice management activities were coordinated by the FPSO OIM, however, the ice management plan "indicates" otherwise.

Discrepancies in information about the iceberg and some calculations: Another discrepancy found is in the information about the size of the iceberg and the met ocean conditions (see Table 3). In order to make a decision whether or not the iceberg can be considered as threatening, the information about the iceberg mass is required. The Onshore Ice Coordination Center did not provide the mass value, and the recorded iceberg dimensions were found to be inconsistent. The iceberg dimensions (Length – Width – Height) recorded by the Maersk Captain are different from that reported by the SeaRose Ice Observer (Table 3). There are also variations in the reported met ocean parameters such as wave height, wind speed, etc.

Table 3. Iceberg dimensions and met ocean conditions

	C-NLOPB Report 29 March 0300-hrs	SeaRose Ice Observer Timeline, 29 March 0420 hrs	Maersk Captain Timeline 29 March 0200 hrs
L-W-H (m)	No information	60-40-8	90-30-8
Wind Speed (m/s)	18	12[1]	22 to 27
Seas: (m)	4.7	4.0/6.5[1]	5
Visibility (NM)	1	No information	Dense fog
Air Temperature (°C)	-0.6	No information	No information

[1]Source: RRMT, 29 March 0313 hrs

Based on the above data, we have calculated the iceberg mass, draught, and the corresponding kinetic energy based on the reported drift speed. Table 4 presents result of the calculations. For comparison purposes, Tables 5 and 6 present the FPSO design limits and the iceberg towing considerations, respectively.

Table 4. Estimated iceberg parameters

Parameters/Source	Maersk Captain Data	SeaRose Ice Observer Data
Iceberg mass (M)		
$M = 7.12 \cdot LWH \cdot 0.5$ (tonnes)	76900	68400
$M = 3 \cdot LWH$ (tonnes)	64800	57600
Draft (D)		
$D = 3.781 \cdot L^{0.63}$ (m)	64	50
Kinetic energy (KE)		
Drift Speed =0.75 knot (MJ) 0448 hrs	5-6	5-6
Drift Speed =1.2 knot (MJ) [1]	14-16	12-14
Drift Speed =1.8 knot (MJ) 0036 hrs	31-36	27-32

[1]Calculated by C-NLOPB

Ice management zones, disconnection sequence, probability of a successful tow, threatening ice and consequences of a collision with the iceberg

Zones (Figure 2) have not been calculated during the incident but have been calculated after the incident by the C-NLOPB investigation team. The center of the zone 0.0 seems to be aligned with the FPSO; however, considering the wells, the zones could be more complex due to the limited depth at the location of about 120 m.

According to the investigation report, it is the responsibility of the Ice Observer to calculate, communicate and record the ice Zones, advice when the ice enters the Zones and give one hour notice prior to entering the Zone 2. It seems that only one Ice Observer was on the SeaRose FPSO who worked dayshifts and was not on the bridge until March 29 0420 hrs. (C-NLOPB, 2018, pp. 21-22). It is also uncertain how many ice observers were planned to be on-board of the FPSO (Husky Oil Operations Limited, 2001c, refer to Table 5.1-2 on page 39).

Table 5. FPSO design limits

FPSO design limit (hull)	Description; Source
Kinetic energy	"The FPSO hull will be designed to withstand an impact of a 100,000-t iceberg impacting at 0.5 m/s (1 knot). This equates to a kinetic energy of approximately 15 MJ. In reality, however, the energy required to cause damage will be significantly greater than 15 MJ…" (Husky Oil Operations Limited, 2001b, Chapter 7.2 Ship Impact, pp. 84-85)
Serviceability criteria to avoid significant damage to the bow and only a small deformation to the vessel side	With significant wave height of 5 m, only icebergs with waterline lengths less than 5 m will satisfy serviceability condition (Ice Management Plan via C-NLOPB, 2018)
	FPSO Hull is ice strengthened to comply with DNV Baltic Ice Class 1A+ (the SeaRose FPSO Operations manual via C-NLOPB, 2018)

Table 6. Limitations of Active Ice Management (McClintock et al., 2007; Stepanov et al., 2009 and C-NLOPB, 2018)[1]

Single Vessel Tow, conventional single line	Time required to deploy the towing system 0.5-2 h. Towing process itself takes longer. Single vessel towing technique is practical in seas to a significant wave height of about 4 m Considered unsafe at present vessel crew (C-NLOPB, 2018)
Water cannons	Effective in managing small ice masses up to 60,000 tones, up to 7 m seas and 15 m/s wind speeds.

[1] There may be additional weather limitations (poor visibility, winds, waves) that restrict towing operation for a vessel.

In the Husky Oil Operations Limited (2001a,c) plans, it is stated: "the OIM will retain control and responsibility for the FPSO as long as the production system remains connected and the vessel is on station. When it becomes necessary to disconnect, the OIM will prepare the production system at the time of disconnection and then hand over control to the senior marine officer for control of the disconnection. The senior marine officer will remain in control until the vessel has been reconnected. Control will then revert to the OIM." According to this plan, it is natural that the disconnection sequence was paused by the OIM, because he needs to hand over the control of the FPSO to the senor marine officer (Master Mariner) to continue with the disconnection.

According to the ice management plan (EC-O-99-X-PR-00002-001, Rev. E7 via C-NLOPB, 2018) any ice that poses hazard(s) to offshore operations can be designated "threatening ice" by the tactical ice management team which is the OIM and Master Mariner/Marine Supervisor, the Senior Husky representative and the Ice Observer. From the available to us information, it is not clear whether the Senior Husky Representative acted from onshore, nor whether the iceberg was still considered threatening when its drift speed dropped down to 0.75 knots (kinetic energy of approximately 6 MJ). The evidence for the former is the email sent to OIM and to unknown actors about the FPSO design limits. This email was sent from Marine Superintendent − Marine Operations and Services with onshore affiliation and contained description of FPSO design limitations and critical ice parameters from serviceability and structural integrity point of view.

According to the information in Table 6, the single vessel tow or the water cannons would be impractical, given the sea states with waves above 4.0 m and the iceberg size above 60000 tons. It is strange why there has been no record of communication about this. The investigation report does not comment on this either.

Considering the reduced drift speed of the iceberg and thus the available kinetic energy (Table 5), the primary collision most likely would not result in a structural failure. However, there is a safety concern if the iceberg were to stay at the FPSO structure after the collision. Coupled motion of two bodies in waves, draught of the iceberg and its underwater shape might lead to a situation when un-strengthened parts of the FPSO hit by the ice, including repeated impacts and global forces on moorings etc.

CONCLUSIONS

In this study, we have re-analyzed the FPSO's incident with an iceberg from a systemic point of view using CAST approach. The objective was to find out whether the CAST approach would reveal more causes to the incident, which could shed light on why the plans and procedures were not followed. The results of analysis indicate that human errors may not be one of the major reasons for why the undesired events have happed, considering in the context in which the decisions were made. Rather the overall system weaknesses related to the ice management plan have been revealed and discussed, and several recommendations, for example, related to communication and responsibilities, have been proposed to avoid similar incidents from reoccurring in the future.

In this paper, only a small part of the CAST framework, pertaining specifically to the lower levels of the sociotechnical system, has been explored. Future analysis should include also the higher levels, take into account the dynamic nature of the safely control structure, and investigate organizational factors more in detail.

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