Damage to a CDG boat during locking

18/02/2020

Sablons (ISÈRE)

France

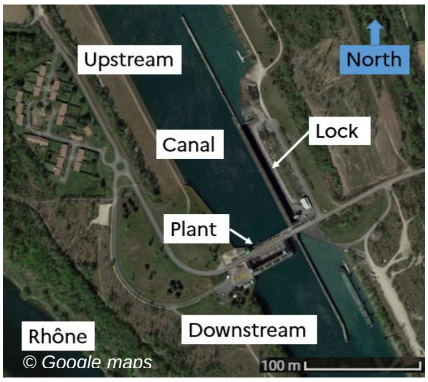
Automated systems
Settings
Maintenance
Safety reports
Liquefied gas

This detailed report was drawn up by BARPI after exchanges with the competent authorities as well as BEA-TT (Bureau d'Enquêtes sur les Accidents de Transport Terrestre, i.e. French Land Carriage Accident Investigation Bureau), whose technical investigation report drawn up after the accident is available here.

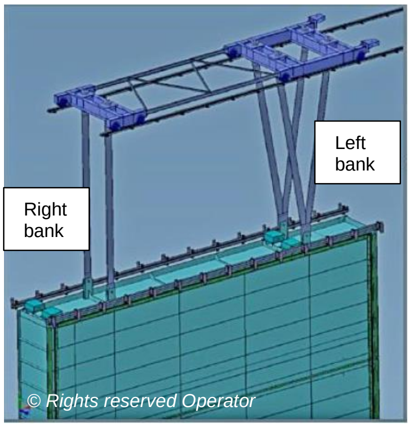
AFFECTED FACILITIES

The hydraulic structure:

The facility is part of the RHÔNE concession to operate hydroelectric structures. In addition to a dam 10km upstream and 12km-long side dams, the facility features a dam power plant including a hydroelectric power plant and a 195m-long, 12.10m-wide lock. This guarantees the left bank of the RHÔNE remains continuously navigable.



The plant, like the dam, is a class-A facility according to the French hydraulic structure safety regulation[1], which specifically requires that a safety report be drawn up, the facility be re-examined every 10 years, and maintenance and monitoring measures be taken.



This structure features 2 rolling gates (upstream, downstream). All the operations are automated and remote-controlled from a Navigation Management Centre (NMC), located approximately 100km away. In 2019, approximately 3,000 goods boat lockings were completed in Sablons.

The downstream gate features 4 sections stacked on top of each other (total mass: 90t, height: 15m, width: 13.10m, thickness: 1.50m). To enable it to roll, it is suspended from 2 carriages, and the carriage travel rails bear the weight of the gate. One, which is powered, is connected to a winch. The other, which is smaller, specifically serves to trigger the gate closure limit sensors. Various systems required to properly operate the gate are detailed below:

- for the large carriage gate operating winch:
  - presence of 2 overload protection systems, one mechanical, the other electrical via a variable speed drive (depending on whether the gate is at the start or end of operation or outside the start-up and slowdown time);
- for the gate position:
  - redundant limit sensors;

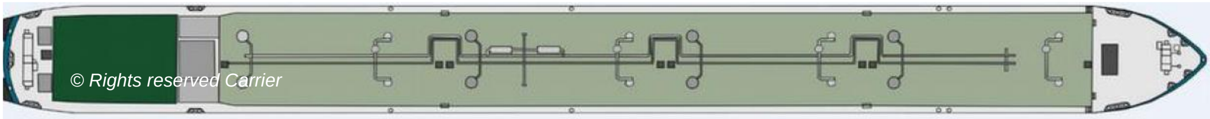
[1]Article R 214-112 of the French Environmental Code

- for the instrumentation and control system:
    - an “Excess Run Time” (ERT) generating a fault if the gate operating time is not fast enough.

The CDG boat:

The boat was a self-propelled tanker featuring 8 cylindrical tanks each with a volume of between 300 and 344m³. Its dimensions were as follows: 120m long, 11.4m wide. On average, this boat made 1.5 return trips per week between 2 Seveso upper tier sites carrying vinyl chloride monomer (VCM). This gas is mainly used to produce plastics (polyvinyl chloride and copolymers) and is also used as a raw material in organic synthesis. It is an extremely flammable gas (closed cup flash point: 78°C), which can form explosive mixtures with air within the limits of 3.6 to 33% volume. It is classified as carcinogenic to humans.

The boat was loaded with 2,200t of VCM in pressurised liquid form. It also contained 35,000l of fuel oil.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Vinyl chloride monomer

THE ACCIDENT AND ITS CONSEQUENCES

The accident:

On 18 February 2020, at around 00.20, the boat was locking upstream. It entered the lock without colliding and was moored by its crew. The locking cycle was launched step-by-step and remotely by the NMC. Though the crew reported a large quantity of wood in the lock on arriving, no gate closure anomaly was reported. As the lock chamber was filling, a few leaks appeared on either side of the downstream gate. These leaks were considered partially “normal”, given that the gate is not designed to be fully sealed and taking into account the discontinuous sealing where the 4 sections of the gate join.

However, as the chamber was 2/3 filled with water (height of water: approx. 8m), the 2nd and probably 3rd sections down from the top of the gate gave way. Despite the captain starting the boat’s motors at high speed, the boat’s mooring lines did not withstand the draft and the boat was ejected from the chamber, ripping off the top section of the gate (23t), which remained embedded in the stern of the boat. The wheelhouse collided with the lock structure and was ripped off. It fell on the pipes located on the boat’s bridge, which were connected to the VCM tanks. The boat’s hull was cracked and leaking. As the motors remained switched on after the barge’s ejection and in spite of the crew reacting quickly to turn them off, the barge collided at low speed with the guide wall downstream from the lock. The NMC, which watched events unfold by video link, called the emergency services. The crew members smelt gas vapours. Equipped with gas masks, they moored the boat downstream from the lock, then, using rafts and a rope, headed to the pleasure pontoon then the bank via a gangway.

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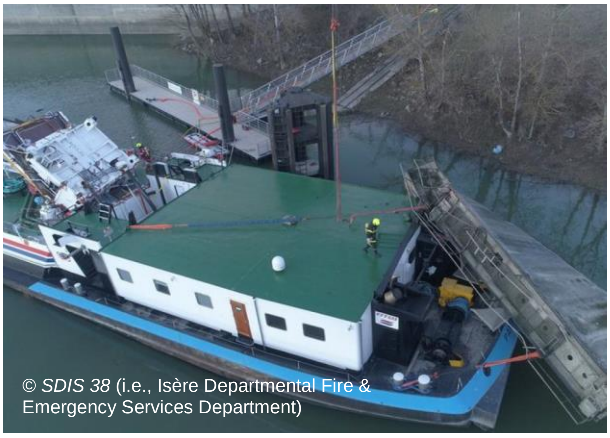

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The ORSEC[2] procedure was triggered by the Isère prefecture. Faced with the toxic, flammable, and explosive risk of the VCM, a 400m safety perimeter was put in place. Approximately twenty homes were evacuated. Their inhabitants were able to return home at night. Navigation was stopped along a 10km stretch. Floating booms were put in place to prevent potential dumping of the boat's fuel oil.

At around 07.30, measurements revealed concentrations at 30% of the Lower Explosive Limit (LEL). They were negative again a few hours later. The prefect of Isère contacted the regional certified air quality monitoring organisation[3] to arrange for a series of VCM air concentration measurements to be taken at several points. Measurements were taken by the boat and in local residential areas. DREAL[4] contacted INERIS CASU[5] to assess the risks in the event of breach of part of the tanks.

Pipe freezing equipment was used to plug the leaks without totally getting them under control, though other sources of leaks were inaccessible or unknown. Five days after the accident, a specialist firm finalised the plugging.

Given the risks of air and water pollution, as well as explosion, and the risk of instability (flotation / structure) of the boat, the prefect of Isère signed a prefectural order to take emergency measures on 21 February. The wheelhouse was lifted on 26 February, and the fuel oil drained on 28 February. In a new prefectural order dated 2 March, the prefect of Isère informed the carrier of the conditions to be met to safely unload the VCM. This process took from 4 to 11 March. During this period, an explosimeter measurement by the hold of 2 tanks was above the LEL. The unloading process was then stopped, and the open head systems of the boat into which the VCM was being unloaded were turned on. The hold was aired. On 8 March, for the purposes of unloading the 2 tanks at the stern of the boat, a 550m security perimeter around the lock was put in place, and the population evacuated.

The lock gate was removed between 16 and 20 March.

The boat remained in the downstream lock basin, awaiting transfer to the carrier, until November 2020.

[2] "ORSEC" stands for Organisation de la Réponse de Sécurité Civile, i.e. Civil Security Response Organisation
[3] ATMO Auvergne-Rhône-Alpes
[4] Direction Régionale de l'Environnement, de l'Aménagement et du Logement Auvergne-Rhône-Alpes, i.e. Auvergne-Rhône-Alpes Regional Environment & Housing Directorate
[5] Cellule d'Appui aux Situations d'Urgence de l'Institut National de l'Environnement Industriel et des Risques, i.e. French National Institute for Industrial Environment and Risks' Emergency Situation Response Unit

Consequences:

Though no members of the boat's crew were injured, they, like the staff on duty at the NMC, were shocked by the accident.169 canisters[6] were used on 9 sites[7] to take air quality measurements continuously until the end of the safety operations (from 18 February to 23 March).

Though the VCM measurement results were variable over the entire period, they were all below the reference value taken into account for population exposure[8]. The highest VCM concentrations were recorded over the first 10 days following the accident, with a peak on 20 February of 882µg/m^3 on average over 24hr on site 3, which was also the site most affected with an average concentration of 89µg/m^3 over the 37 days of measurements. These measurements enabled assessment of the risk incurred and adjustment of the security measures for the surrounding population (prohibited access perimeter, temporary evacuation, or evacuation during unloading).

Regarding the consequences for river navigation, navigation was stopped for nearly a month and a half, until a new lock gate (availability of a backup gate) could be put in place. The large-scale RHÔNE-SAÔNE basin, connecting the south of Dijon to the ports of Fos-sur-Mer and Sète on the Mediterranean, accounts for 20% of French national river traffic expressed in tonnes/kilometre.

Major property damage was observed, both to the lock and boat: the downstream lock gate was destroyed, and the boat was deemed difficult to repair from a technical/economic point of view. It was towed 9 months after the accident.

[6] Vacuum canister used to collect an ambient air sample.
[7] Samples taken at different intervals: 30 minutes, 8 hours, or 24 hours, then analysed via gas chromatography.
[8] VCM acute inhalation toxicity value taken into account by ATSDR and INERIS for 14-day exposure: 1,300µg/m^3.

European industrial accident scale:

By applying the rating rules applicable to the 18 parameters of the scale officially adopted in February 1994 by the Member States' Competent Authority Committee for implementing the “SEVESO” Directive and taking account of available information, the accident can be characterised by the following 4 indices:

Hazardous substances discharged	■ □ □ □ □ □
Human and social consequences	■ ■ □ □ □ □
Environmental consequences	□ □ □ □ □ □
Economic consequences	□ □ □ □ □ □

The parameters associated with these indices and their rating scale are available at the address: https://www.aria.developpement-durable.gouv.fr/in-case-of-accident/european-scale-of-industrial-accidents/?lang=en

Hazardous substances discharged (Q1): the exact quantity of VCM discharged could not be determined. As a consequence, and due to the involvement of a hazardous substance in accordance with the SEVESO directive, the accident has been classified as a level-1 incident.

Human and social consequences (H7): though no injuries were recorded, this parameter takes account of the social impact of the accident. Due to the emergency and precautionary measures taken (evacuation of local population), the accident has been classified as a level-2 incident.

Environmental consequences: the scale does not take air pollution into account. As no pollution was detected on the RHÔNE, the accident has been classified as a level-0 incident.

Economic consequences: BARPI does not have sufficient information to be able to classify the accident based on this parameter. By default, the accident has been classified as a level-0 incident.

THE ORIGIN AND CAUSES OF THIS ACCIDENT

The table below summarises the different phases of the accident up to the breach of the downstream lock gate. It compares and contrasts how the situations were seen by the boat’s crew locally and by the remote-controlled systems at the NMC.

Phases of the accident	Situation seen by the boat’s crew	Situation seen by the NMC	
		Actions taken	Available information
Boat entering the chamber	No collision despite the presence of dead driftwood, which was reported to the NMC	There was no sluicing (dredging/emulsion process) prior to the boat’s arrival (sluicing prohibited when a boat has entered or is approaching, and lock not equipped to enable downstream sluicing)	Monitoring on video screens helpful for the NMC to follow locking process but not necessarily to detect driftwood
Mooring of the boat	No anomalies	Proper mooring of the boat observed	Instructions from pilot and viewing on video screen
Gate closing and chamber starting to fill up	No anomalies	No operating anomalies detected on the instrumentation and control screens.	Slight water leaks visible on video screens, similar to other lockings.
Filling to 2/3 of the chamber and breach of the gate	Breach of mooring lines and ejection of boat from chamber despite motors full speed ahead.	View on control screen of lock failure and automatic securing	Security system: no action possible by operator

Based on the operator's investigations (examination of recovered parts, kinematic and mechanical studies, video-based photogrammetric analysis), it was concluded that the gate (N.B. "suspended" gate) was considered closed by the automated systems even though there was up to 40cm play from the nominal situation (top section potentially correctly engaged but bottom section either only very slightly or not at all engaged). This blockage may have been caused by the presence of a floating object. The lock gate breach scenario, due to incorrect engagement of the gate and a closure failure, was not taken into account in the site's Safety Report (SR).

The operator tasked with operating the lock performs the different stages by remote control from the NMC. They operate it via data retransmission using an instrumentation and control system and, for assistance, a system to view the situation by video surveillance. Though the presence of driftwood at the entrance to the chamber was not detected via the video surveillance cameras (remarked by the boat), no closure anomalies were reported to the NMC operator via the instrumentation and control system.

All the automated systems detected the gate was closed. The gate's closed position is indirectly detected based on the position of the small carriage on which mechanical tilt sensors are positioned. Therefore, if the carriage reaches its "closed" position, it does not actually reflect the gate's position in the event of mechanical stress. Three systems could have contributed to preventing such a situation, but they proved ineffective:

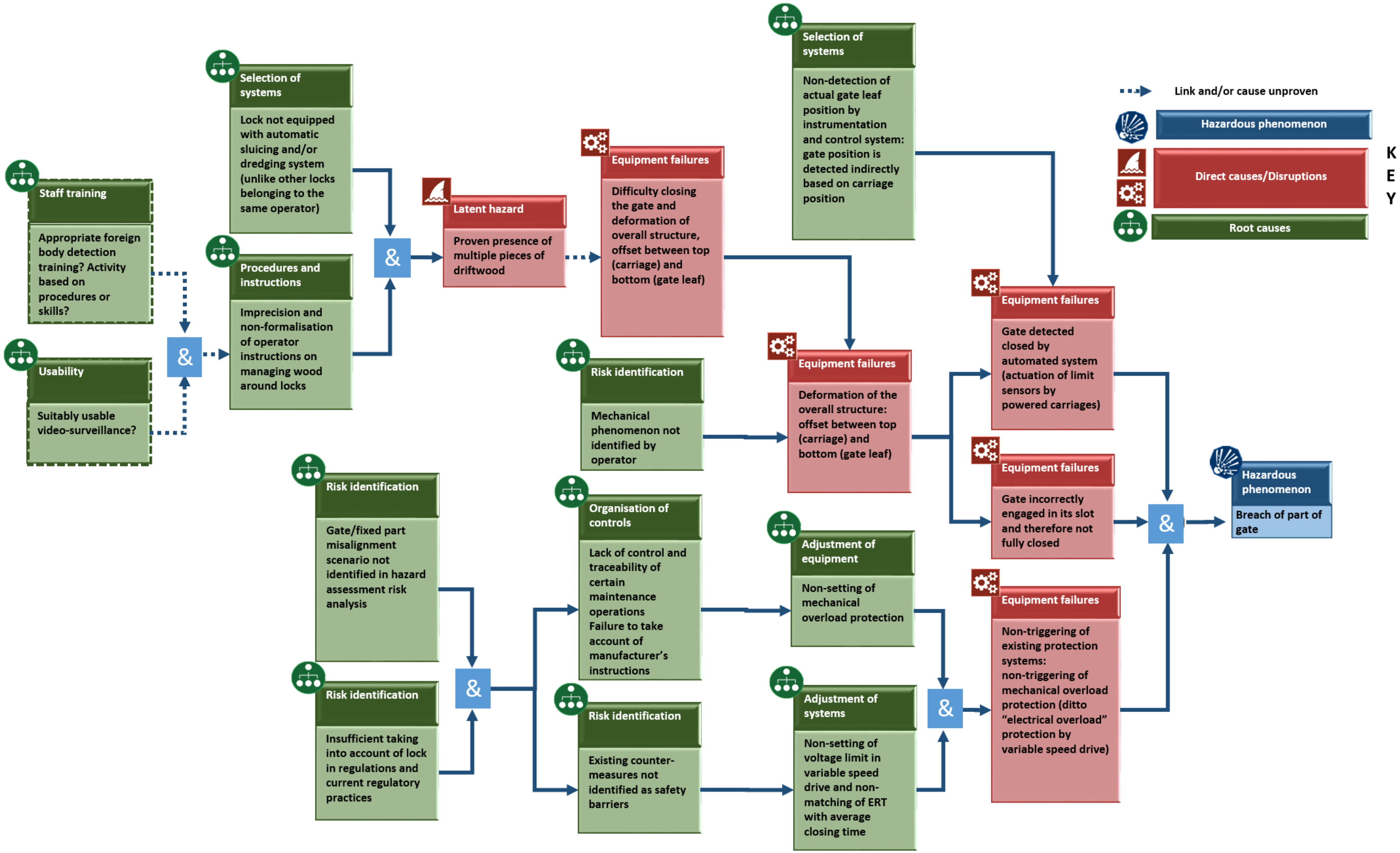
- mechanical overload designed to limit tensile strain for the gate operating hoist: its setting was unknown to the operator and no monitoring or maintenance traceability was available;
- gate operating time via monitoring of "Excess Run Time" (ERT): its setting was inappropriate. It was set to 3min 35s, but the average operating time is 1min 42s. For the accident, it was 12.5s higher than the average time;
- voltage limitation for the motor's variable speed drive: investigations revealed that a major strain exerted by the hoist does not necessary trigger this limitation.

Firstly, these systems were not set up for safety purposes, and secondly, were not considered as safety barriers in the SR drawn up by the operator in 2013.

Regarding detection of floating objects, according to the operator it is not easy for remote operators to view them and assess their hazardousness for locking. The Sablons lock downstream gate is the group's only gate not equipped with an automatic sluicing system.

BARPI has developed an analytical methodology to identity the root causes of events. So, the investigation can reveal disruptions (or primary causes) and root causes. Disruptions refer to direct failures that contributed to the event. They are accessible for observation. The root causes, located upstream from the apparent causes, are malfunctions of the socio-technical system where the accident occurred. They generally refer to dimensions involving human factors and organisational and managerial dimensions for which long-term actions must be taken to prevent the occurrence of a similar event. Designed as a simple toolbox, BARPI's methodology was developed to provide an overview of the chain of causation:

The full modelling of the accident is available on the following page. Another illustration is available in the BEA-TT technical investigation report available here.


Link and/or cause unproven
Hazardous phenomenon
Direct causes/Disruptions
Root causes
KEY
Staff training
Appropriate foreign body detection training? Activity based on procedures or skills?
Usability
Suitably usable video-surveillance?
Selection of systems
Lock not equipped with automatic sluicing and/or dredging system (unlike other locks belonging to the same operator)
Procedures and instructions
Imprecision and non-formalisation of operator instructions on managing wood around locks
&
Latent hazard
Proven presence of multiple pieces of driftwood
Equipment failures
Difficulty closing the gate and deformation of overall structure, offset between top (carriage) and bottom (gate leaf)
Selection of systems
Non-detection of actual gate leaf position by instrumentation and control system: gate position is detected indirectly based on carriage position
Risk identification
Mechanical phenomenon not identified by operator
Equipment failures
Deformation of the overall structure: offset between top (carriage) and bottom (gate leaf)
Equipment failures
Gate detected closed by automated system (actuation of limit sensors by powered carriages)
Equipment failures
Gate incorrectly engaged in its slot and therefore not fully closed
Hazardous phenomenon
Breach of part of gate
Risk identification
Gate/fixed part misalignment scenario not identified in hazard assessment risk analysis
Risk identification
Insufficient taking into account of lock in regulations and current regulatory practices
Organisation of controls
Lack of control and traceability of certain maintenance operations
Failure to take account of manufacturer's instructions
Risk identification
Existing counter-measures not identified as safety barriers
Adjustment of equipment
Non-setting of mechanical overload protection
Adjustment of systems
Non-setting of voltage limit in variable speed drive and non-matching of ERT with average closing time
Equipment failures
Non-triggering of existing protection systems:
non-triggering of mechanical overload protection (ditto "electrical overload" protection by variable speed drive)

ACTIONS TAKEN

Following the event, the operator, via its causal analysis:

- identified two of the “counter-measures” as safety barriers (mechanical overload and Excess Run Time). It updated its SR taking account of the gate breach scenario, i.e., gate did not correctly reach its closed position, even though it was detected as closed by the instrumentation and control system;
- studied how to best characterise the presence of floating objects and the measures to be taken, both locally and remotely;
- studied how to directly identify gate position, separately from carriage position;
- reset the mechanical overload protection, Excess Run Time (ERT), and variable speed drives’ internal voltage limitation thresholds;
- studied putting in place an automatic emulsion system in the groove into which the lock downstream gate slots when closing, as well as a new filling valve for downstream sluicing;
- analysed whether similar faults are found on (“suspended”) rolling side gates on other locks it operates.

From an organisational point of view, it carried out a study highlighting the improvements necessary to:

- take the findings of works reports (traceability, corrective actions, etc.) into account;
- identify then correct the recurrence of weak signals or malfunctions, particularly in detected gate blockage faults;
- promote exchanges between the NMC and on-site operators, regarding both the state of the lock and either maintenance done, or feedback received.

LESSONS LEARNT

A lot can be learnt from the analysis of the root causes of this accident. Though the last serious accident involving a locking boat was back in 1998 (Bollène), the one studied here stands out in that it combined carriage of dangerous goods, operation of hydraulic structures, and navigation. Therefore, the feedback is even more cross-disciplinary as it applies to multiple technological activities, other than hydraulic structures:

- taking all the systems on a site into account in the risk assessment, as well as the hazards they represent for the population and the environment, for workers or users;
- exhaustiveness of risk scenarios;
- putting in place and defining appropriate, effective, monitored, and maintained safety barriers to manage risk scenarios. In the event of automated systems, making sure that these 4 criteria are checked for 3 functions: detection (sensors), processing (all technical and human components of an automated system necessary to transmit information from the sensor to the actuator), and action (actuators and terminal elements);
- quality and traceability of maintenance and of the level of monitoring of systems contributing to the safety of a site to analyse weak signals and deviations;
- communication between services and clear definition of tasks and responsibilities;
- usability of video surveillance systems and training of operators regarding their uses and utilities, whether locally or remotely for the purposes of remote operations carried out.