Organisational Factors Involved in Catastrophic Heavy Mobile Machine Failures

F. Gatto and R.C. Morgan[1]

[1] Aspec Engineering Pty Ltd, Brisbane, Australia; fgatto@aspec.com.au, rmorgan@aspec.com.au

Summary

This paper summarizes a process for analyzing failures of heavy mobile machines to identify organizational factors contributing to the failures. A case study on a ship access walkway highlights the importance of risk awareness within a business enterprise and the special need to identify critical items which, without suitable defences, may lead to a catastrophic failure. Finally the paper has included some suggestions on how risk management could be applied to organizational factors with the objective of reducing the residual risks of structural failures.

1. Introduction

Structural failures occur comparatively infrequently but often involve catastrophic consequences such as injury or death and significant interruption to the function which the structure performs while repair or replacement occurs. Structures for mining, metallurgical and associated business enterprises have much higher failure rates than residential, commercial or structures associated with public infrastructure. Mobile structures such as stackers, reclaimers, shiploaders and heavily loaded structures such as bins feature most prominently in the failure statistics.

Major structural failures may have multiple contributing causes in addition to the technical issues normally considered in structural design codes. In this paper the authors have applied methods proposed by Reason (1997) to investigate organizational factors involved in structural failures for which detailed information was available. Implications for risk management of structures are then identified.

2. Accident Causation

Reason (1997) proposes that there are two types of accidents: individual and organizational. Individual accidents are larger in number than organizational accidents and generally a specific person is both the agent and the victim of the accident. Organizational accidents can be catastrophic often affecting uninvolved people, assets and the environment. As well, organizational accidents can have multiple causes with input from different people operating at different levels within the organization.

The principal stages involved in the development of an organizational accident are shown in Figure 1.

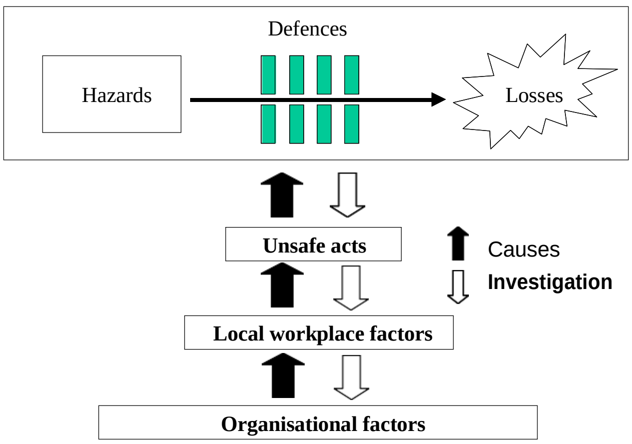

Figure 1 Stages in the development and investigation of an organizational accident

The accident sequence starts with the organizational factors: strategic decisions such as planning, scheduling, allocating resources and communication. These decisions and activities are then communicated to the individual workplaces. Local workplace factors can include time pressures, insufficient training, under-manning, poor communication, etc. These workplace factors combine with natural human behaviour to produce errors and violations – unsafe acts. A large number of unsafe acts will be committed but only a very small number will create a breakdown in the defences and lead to an accident.

Failures by operating personnel caused by human error can create gaps in defences. As well, weaknesses or latent conditions may be present from the beginning of the structure's life creating more gaps in the defences. An accident will occur when all the defences are ineffective in protecting against a hazard. Figure 2 shows a representation of Reason's "swiss cheese" model indicating that alignment of holes in defences is required to allow an accident to happen.

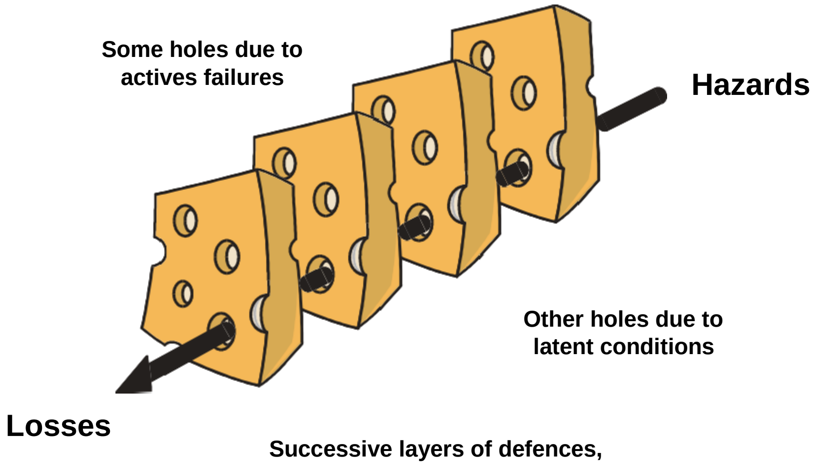

Figure 2 Reason's "swiss cheese" model

The methodology is described in detail in Reason (1997).

3. Case Study 1 – Ship Access Walkway Collapse

In order to present the methodology in detail the authors have developed a case study for a ship access walkway collapse utilising information available in the public domain. This relatively simple structure in a port environment, allows demonstration of the principles without undue involvement in the detail inherent in more complex structures.

Chapman (1998) has described details of the collapse of a pedestrian access walkway for roll-on/roll-off ferries at Ramsgate harbour in the United Kingdom. The failure of the walkway, which had only been in service for four months, caused the deaths of six passengers and serious injury to seven others resulting in charges brought against the designers, constructors, checkers and owners of the walkway.

The walkway and second level vehicle ramp installation occurred as additions to the existing pontoon and single level ramp system, for the purpose of servicing a new style of ferry for the port. Figure 3 illustrates the layout of the walkway, vehicle ramps and pontoon.

Procurement occurred by means of a design and construct contract between the port owner/operator and the suppliers of the original pontoon and lower ramp. An independent engineering firm had responsibility for checking of the design. A feature of the procurement was that documentation and design criteria for the design and supply were subject to considerable change and somewhat ill defined. A further factor in the contractual arrangement was that a local contractor who had responsibility for construction of the passenger terminal building into which the walkway connected became involved as a subcontractor in the erection of the walkway and vehicle access ramp. The section of walkway which collapsed spanned between the passenger terminal building and a major support frame on the pontoon.

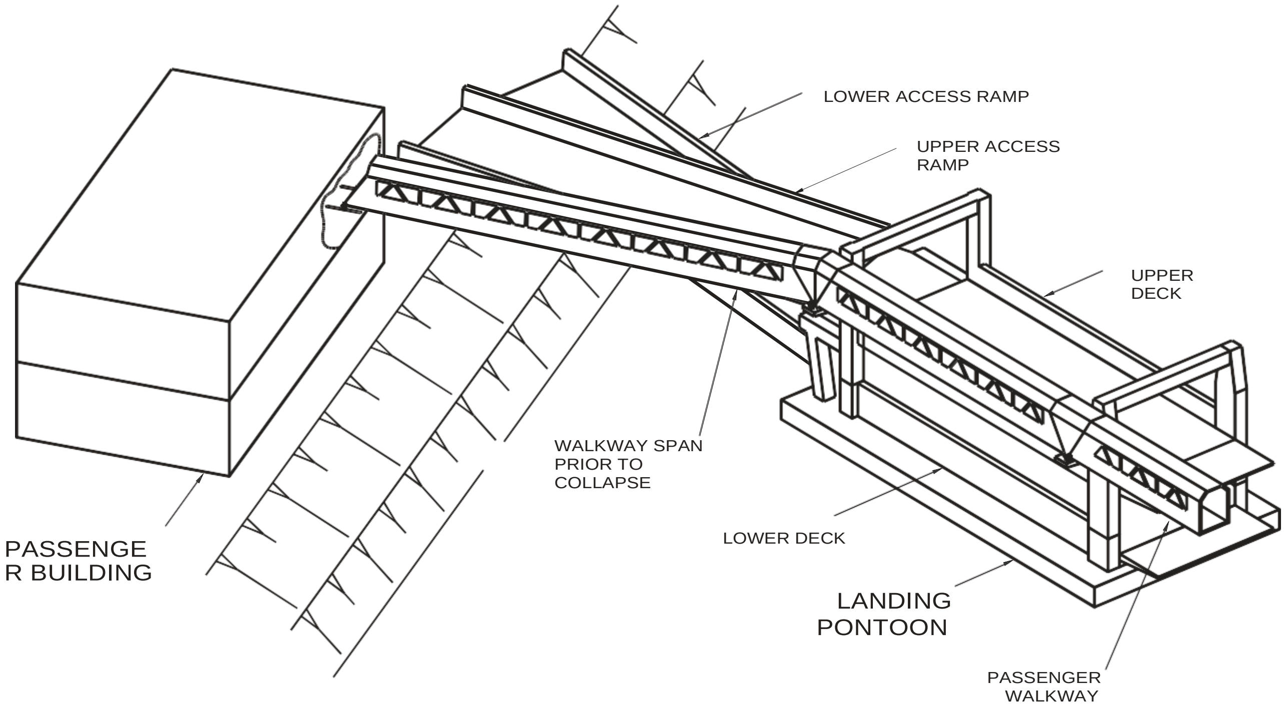

Figure 3 Layout of walkway vehicle ramps and pontoon

3.1. The Design

The walkway consisted of a fully welded “through truss” with external cladding which made it stiff in both flexure and torsion. The bearings, refer Figure 4, comprised a cantilever axle on each of the four corners of the truss, attached by welding into steel discs, in turn welded to the outer web of the bottom chords of the walkway truss. The axle rotated inside a sleeve attached by gusset plates to a base plate. A Teflon pad, attached to the baseplate with countersunk bolts, allowed horizontal translation. At the shore end, guides allowed for translation whilst restraining the walkway laterally with sufficient clearance to allow for some horizontal rotation. At the pontoon end, one corner was pinned to the support through the baseplate, with the other corner free to translate longitudinally and transversely. The bearing system relied on the flexibility of the truss to allow rotation about the axis of the walkway in the event of pitching motion of the pontoon. However since the truss was relatively rigid in torsion this assumption could not be relied on.

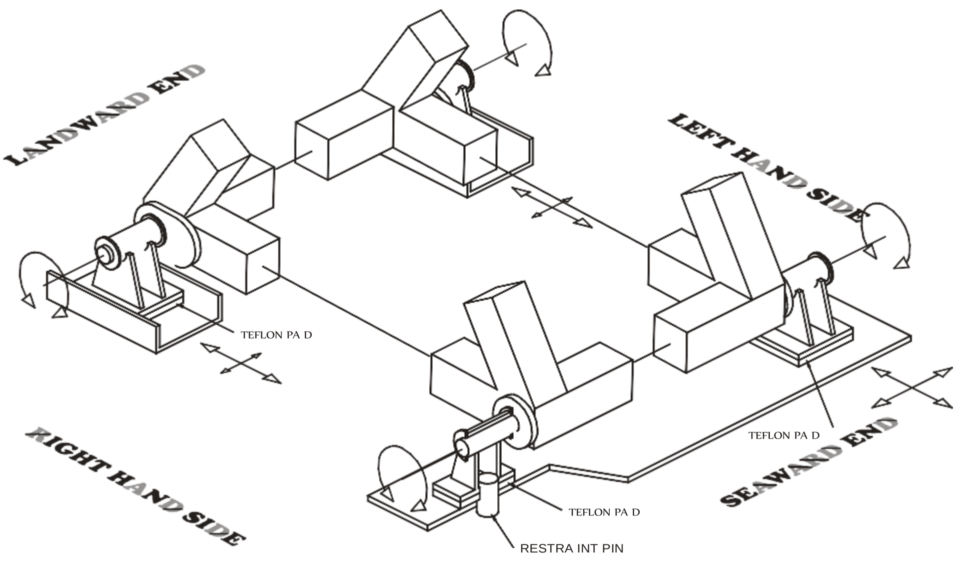

Figure 4 Bearing details

The axle sleeves had tappings to allow for grease injection by a lubrication system. However fitting of the lubrication system had not taken place. The contractor had also neglected to provide the client with a maintenance schedule.

3.2. The Collapse

The section of walkway between the passenger terminal and support onto the pontoon, became detached at the pontoon end, collapsed onto the deck of the pontoon and penetrated the deck. The collapse occurred as a result of failure of welds connecting the axle to the disc attached to the truss of the right hand seaward bearing as shown on Figure 5. The axle on the left hand side did not fail and this bearing, which was not physically attached to the support, stayed with the collapsed end of the truss.

The walkway had been inspected by the insurer's inspector, who had been trained to inspect ship-to-shore structures, one month before the accident; he had found nothing amiss. No unusual external effects occurred at the time of the failure other than vehicles traversing the linkspan ramp.

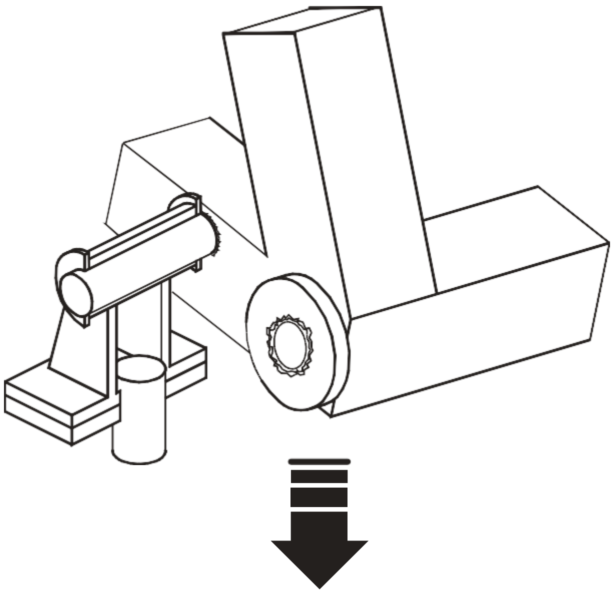

Figure 5 Failed bearing

3.3. The Investigation

Physical inspection showed that the left hand bearing still had grease in place between the axle and sleeve despite non- installation of the automatic greasing system. However, the right hand side bearing axle had seized onto the sleeve as the clearance was too small for grease to be effective. Design checking showed that the assumption for calculating the bending moment in the axles and connecting weld to the discs on the truss chords was incorrect and actual stresses in the axle would have magnitudes well in excess of yield. The connection to the disc had been designed as a pin which violated the laws of compatibility of strain. In practice the axles were found to have bent to some extent which would have relieved stresses sufficiently to account for the structure surviving for four months.

Both the design and independent checker had made similar errors in the calculations for the supporting bearings.

3.4. The Trial

There was no dispute concerning the cause of the failure - the designer and the independent checker both pleaded guilty. The port owner pleaded not guilty to two charges: that they failed to provide and operate a walkway so as to ensure that pedestrians were not exposed to risks to their health and safety; and, that they provided a walkway which was not of adequate strength and properly maintained.

Some of the relevant issues which emerged from the trial are summarized as follows:

- The court determined that the port owner/operator had an absolute requirement to provide a safe means of access.
- The lack of a formal specification and contract was identified.
- Expert witnesses identified lack of lubrication as something which may have affected the time of failure to some extent but not as the primary cause.

The judge asked the jury to consider the following questions:

“Were the provision and operation of the walkway conducted in such a way as to fail to ensure that members of the public were not exposed to risks to their safety from collapse of the walkway?”

”Has [the port owner] shown that it is more probable than not that it was not reasonably practicable for them to have done more than was in fact done to ensure that the provision and operation of the walkway were conducted in such a way that members of the public were not exposed to risk?”

The jury found the port owner guilty on all counts. It appears from the verdict that the jury concluded that design and construction was part of the owner/operator’s undertaking and that they therefore should have seen the need for safety chains in the event of failure of the bearings.

The jury found by its verdict that an owner and operator of a port cannot sit back and do nothing and rely on others, however expert – they should put in place effective risk management procedures.

3.5. Analysis to Determine Organizational Factors

Figure 6 shows the analysis of the incident to determine the organizational factors involved. This figure should be read from right to left commencing with the incident and working back to the organizational factors.

<u>Absent/failed defences:</u>

The investigation and trial identified a lack of awareness of the criticality of the support system and highlighted the need for consideration of a secondary support system in the form of chains. The primary protective defence of adequate structural capacity did not exist and the design configuration did not allow for detection of problems with the bearing.

<u>Individual/team actions:</u>

Mistakes in the design and design check formed the individual/team actions which produced active faults. Non-installation of the lubrication system or non-issuance of maintenance procedures, although not the immediate causes, could comprise contributory errors.

<u>Task/environmental conditions:</u>

The owner/operator was detached from the design/procurement process and were not aware of requirements for inspecting and maintaining the bearings.

<u>Organizational factors:</u>

Design - inadequacies were identified in the design model.
Organization – there was poor planning and no process for risk identification / assessment.
Management of maintenance – there were absent documents, poor planning and recording of information. Communication – no processes available for communication of critical information.

4. Case Study 2 – Failures of 5 Bulk Materials Handling Machines

The authors have analyzed the failures of the five rail mounted machines used for handling of bulk materials. Data for the failures could be found in company records or in the public domain, however for reasons of sensitivity, no specific details are included in this paper.

From the analysis, the relative occurrence of organizational factor types is summarized in Table 1 below.

Table 1 Identification of organization factor types

Identification of Organization Factor Types	
Organization Factor Type	**No. of Occurrences**
Organisation (namely poor planning and risk identification assessment)	5
Maintenance Management	4
Incompatible Goals	3
Communication	2
Design	1
Procedures	1
Housekeeping	1

Analysis identified the predominant feature of the 5 machine failures as the lack of awareness of the criticality of a component, local failure of which initiated a catastrophic failure. Thus the awareness defence becomes the critical issue which highlights Organization as the predominant organisation factor type identified.

5. Implications for Risk Management

In the case investigated, failure of a critical component initiated a catastrophic global failure of the structure. Prior to the incident occurring, the owners and operators of the facility had not developed an appreciation of the criticality of components on the structure which could ultimately lead to global failure.

Thus in terms of risk management it appears that owners and operating companies need to exhaustively investigate the criticality of components on structures of this type and ensure that this criticality is widely understood in their organization. Established risk assessment methods can assist in facilitating the process of identification of critical components and in allowing clear recording and reporting of such.

In particular the technique termed FMECA (Failure Mode Effect and Criticality Analysis) supports identification of modes of failure of individual components and the flow-on effect to other components which may lead to a global failure. The process includes consideration of possible methods of detection of problems in the component prior to failure occurring. This appears relatively straight-forward for new structures where calculations are available. However the design process is prone to human error hence proof checking is desirable to verify the design assumptions and accuracy of calculation.

In addition to design considerations in determining criticality, operational and maintenance considerations also contribute. Thus it is also necessary to capture the knowledge of operators, maintenance and plant management personnel as part of the risk management process. Such personnel are usually very busy on day to day matters running the facility and are difficult to release. Morgan and Gatto (1998) have developed a vulnerability assessment process which has proven to be very useful for conducting facilitated risk assessment workshops with operational, maintenance and plant management staff to capture their knowledge in a time effective manner.

Involving operations, maintenance and plant management personnel in regular facilitated risk workshops has the added benefit of improving awareness of critical items on the structures, which has been identified as one of the key organizational factors involved in the failures studies. Such workshops are a good forum to identify other organizational factors such as procedures, training, housekeeping, incompatible goals, etc.

In summary, the following areas were identified as a focus for risk management in order to reduce the risk of structural failures of the type investigated.

- Improved organizational awareness of risk by involvement of management, operators and maintenance staff in vulnerability assessment workshops.
- Identification of component criticality and redundancy with both proof engineering and Failure Modes Effects and Criticality Analysis (FMECA). This also allows identification of detection and other defences to reduce residual risk.
- Development of long term maintenance strategies which take into account the criticality of components in the structure.
- Development of measures to allow for a suitable balance between goals e.g. production versus maintenance.

6. References

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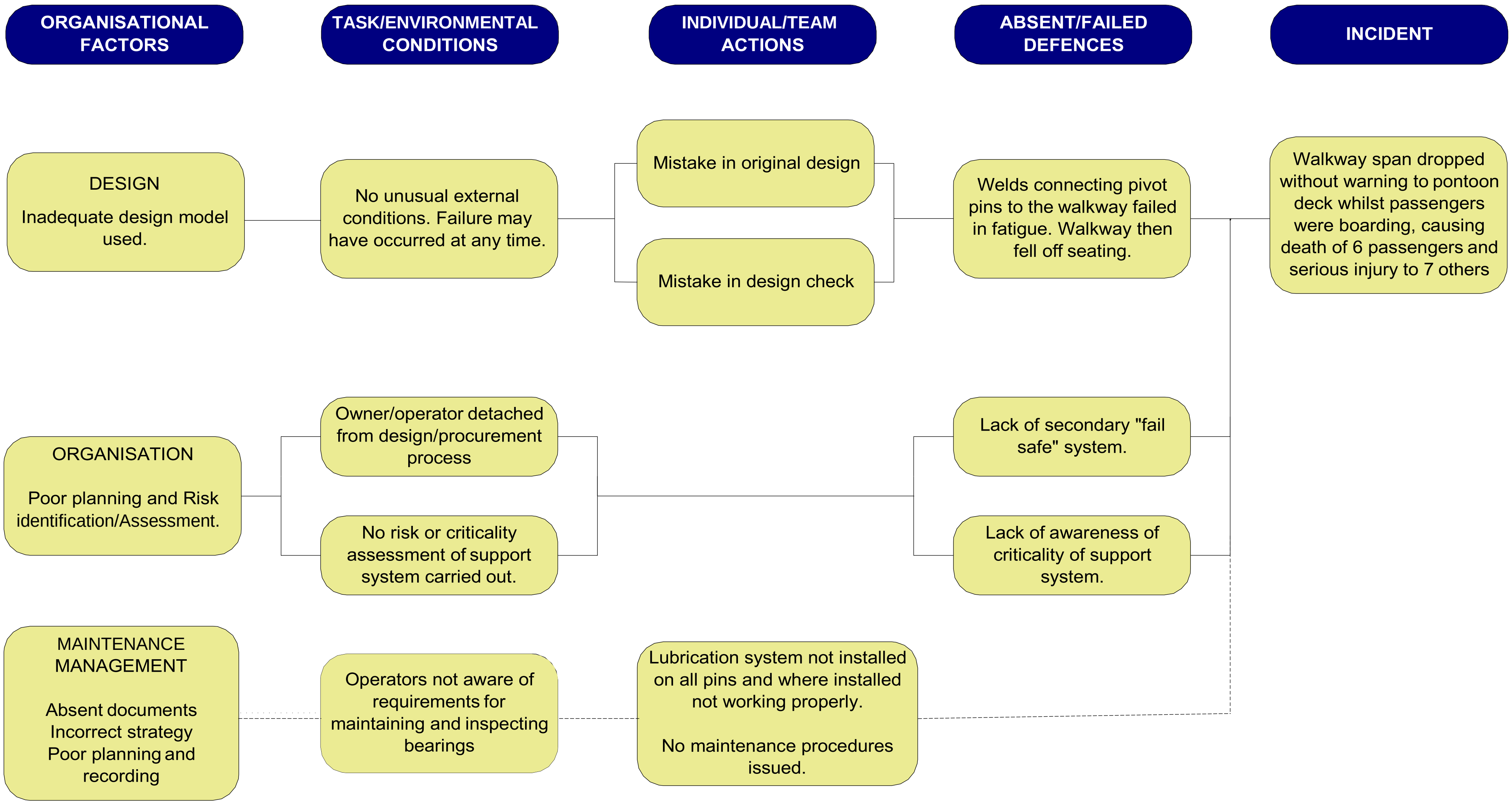

Figure 6 Organisational factors involved with collapse of ship's access